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**CENTRIFUGE MODELING OF AXIAL CYCLIC
BEHAVIOR OF HELICAL PILES IN SAND –
DATA REPORT FOR NI02**

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Centrifuge Modeling of Axial Cyclic Behavior of Helical Piles in Sand –

Data Report for NI02

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Conditions and Limitations

Permission is granted for the use of these data for publication in the open literature. It is essential that the authors and sponsors be consulted prior to publication to discuss errors or limitations in the data not known at the time of the release of this report. There may be later releases of this report. Questions any regarding the report may be directed by email to ldeng@ualberta.ca.

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1 Introduction

The test program NI02, is the second part of the test series to study the axial cyclic behavior of helix piles in sand using the centrifuge modeling technique. NI02 is aimed to 1) Implement pseudo-static cyclic loads along the axial direction of the pile. 2) Investigate the effect of helices and inter-helix spacing on the axial responses within the piles. 3) Investigate the effect of pseudo-static cyclic load on the axial load distribution and internal load transfer mechanism within the piles.

Five types of aluminum model helical piles prepared for axial static load testing in NI01 was reused for this test. The piles include one smooth pile without helix, one single-helix pile and three double-helix piles with spacing ratio of 1.5, 2.5 and 3.5. The shaft diameter, d , was kept 12.7 mm (0.5 in), the helix diameter, D , was 38.1 mm (1.5 in), and the embedment of the piles was 150 mm. The pitch of a helix defined as the opening size of the helix of 12.7 mm was set to be scaled from the pitch size of a prototype pile at 254 mm. Table 1 lists the dimensions of all the model piles. Fig. 1 shows the schematics of the model piles and Fig. 2 presents the fabricated photos of the piles. The dimensions were considered from standard practice. The model soil box was prepared with silica sand (Sil-3) supplied by Sil Industrial Minerals in Edmonton, Alberta. The model sand box was prepared with air pluviation of sand with a portable travelling pluviator (PTP). The relative density of the deposited sand was estimated from the developed calibration chart relating to the height of fall of sand in the model box.

Axial strain gauges were installed at various sections of the pile to measure the axial load distributions. The piles were installed at 1 g level. Hence, after installation, a sequence of vertical up and down cyclic displacements was applied for an average normalized axial displacement of 1%, 2%, 5%, and 10% in four complete cycles at a 1 mm/min velocity (see Fig. 3). Afterward, a monotonic compressive displacement controlled loading test was conducted at a velocity of 0.33 mm/min upto a normalized axial displacement of 20%; to assess the ultimate capacity of the piles. All the stages will be completed inflight. The readings were measured using an HBM Data Logger MX1615 B and later read through the computer program CATMAN.

Table 1. Dimensions of the model piles

Pile Code	Number of helices	L (mm)	d (mm)	D (mm)	P (mm)	E (mm)	H _b (mm)	S (mm)	S/D
P0	0								
P1	1							N.A.	N.A.
P2	2	273.1	12.7	38.1	12.7	228.6	150	57.2	1.5
P3	2							95.2	2.5
P4	2							133.4	3.5

Note: d = shaft diameter; D = helix diameter; P = pitch of helix; E = length of pile from soil surface to tip; H_b = length of pile from soil surface to leading edge of bottom helix; S = spacing of two helices.

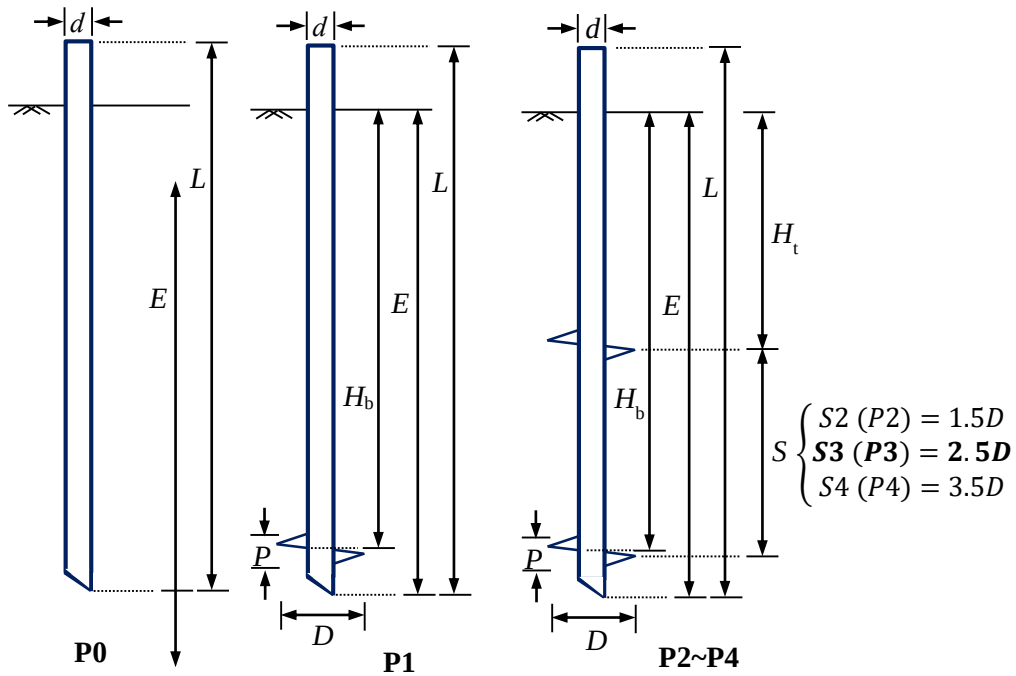


Figure 1. Schematic Diagram of the Model Helical Piles (P0 to P4)

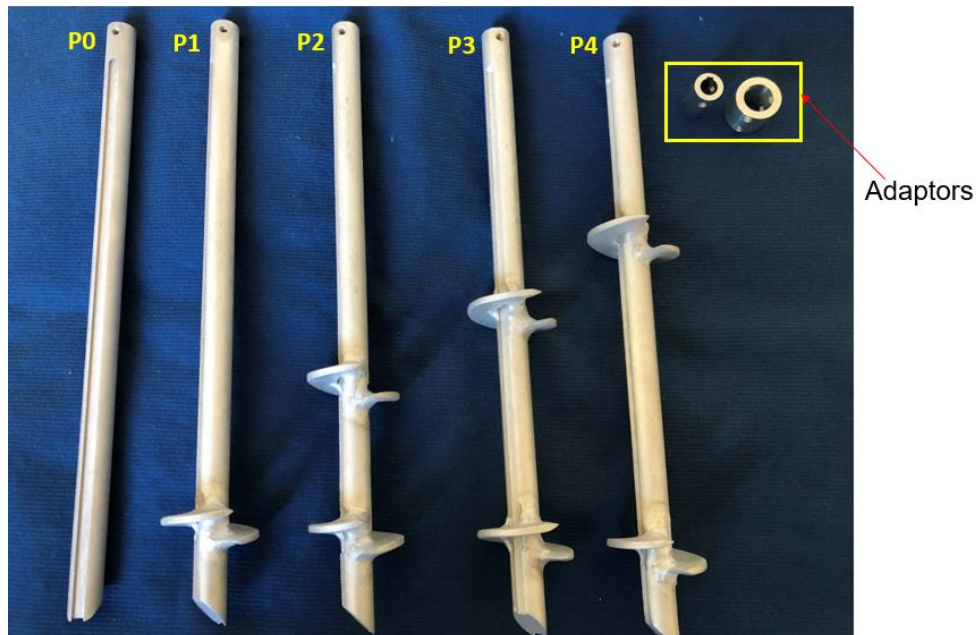


Figure 2. Fabricated Model Piles & Adaptors (P0 to P4)

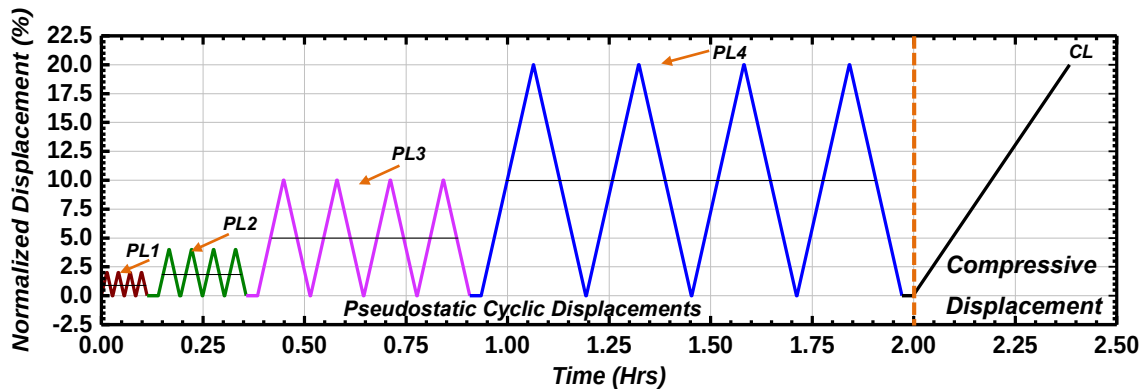


Figure 3. Stages of subsequent pseudo static cyclic and compressive loading against the normalized axial displacements (w/d for P0 and w/D for P1-P4) on the Pile.

Tests were conducted on the 2-m- radius Broadbent centrifuge at UAlberta. The centrifugal acceleration was set at a 20 g scale for the tests. Model scale factors of the analyzed parameter are listed in Table 2.

Table 2. Selected scale factors (prototype/model) of centrifuge modeling tests

Term	Force	Dimension	Stress
Scale Factor	400	20	1

2 Centrifuge Testing Program

2.1 Test matrix

Figure 4 shows the test layout plan and cross sections for NI02. Five model piles were tested in axial cyclic with four packets of pseudo static loads and one monotonic compression load test. The piles are designated as PXCyC, where P stands for pile, X stands for pile number, and CyC stands for pseudo-static cyclic loads. (The smooth pile without helix is denoted as P0CyC, and helix piles, as P1CyC to P4CyC). Table 3 shows the summary of the test matrix for NI02 with the model pile dimensions corresponding to each test type.

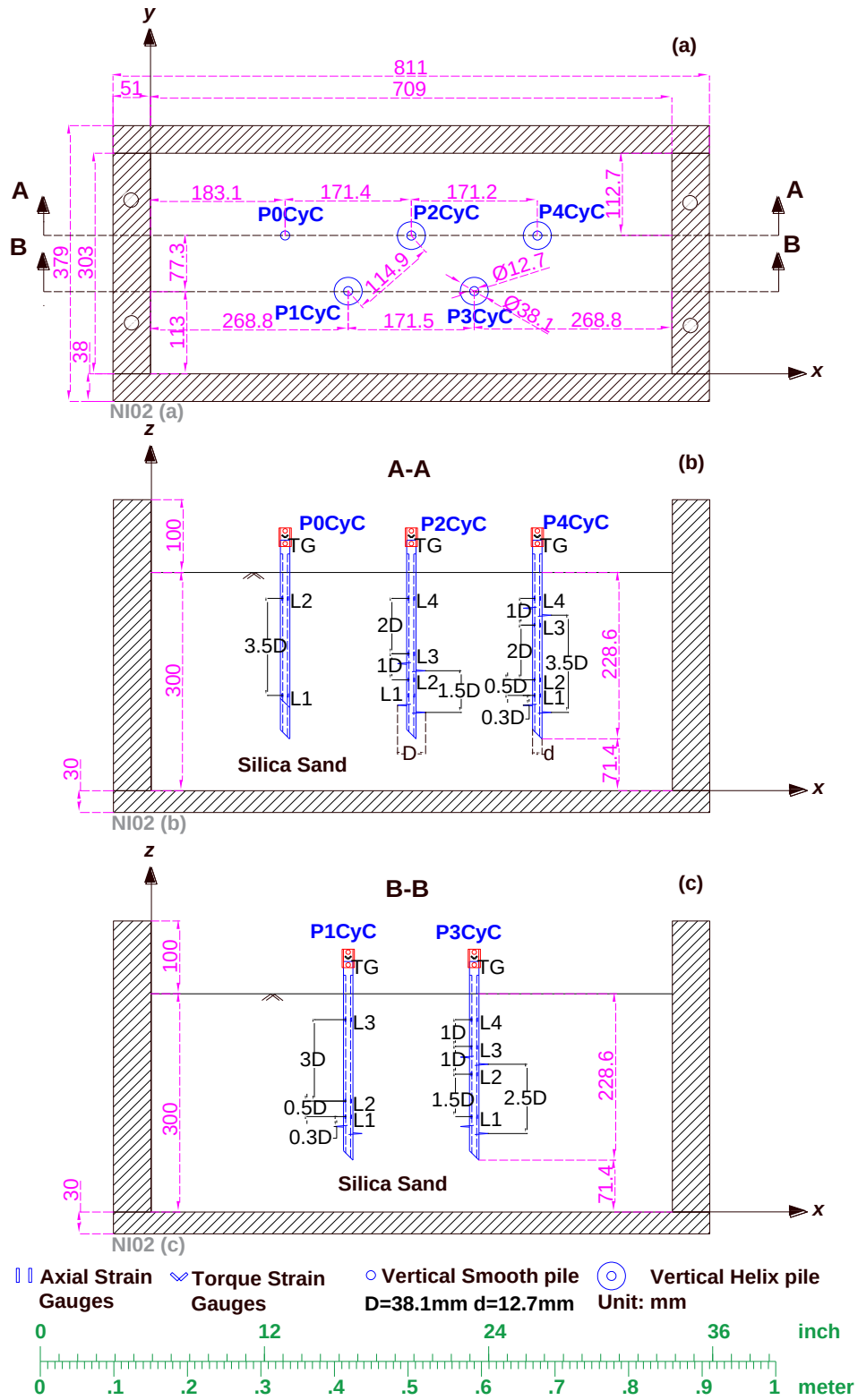


Figure 4. (a) Layout plan of test NI02; (b) Cross-sectional profile at A-A section; and (c) Cross-sectional profile at B-B section. All dimensions are in model scale.

Table 3. Summary of Test Matrix and Pile Dimensions in Model and Prototype Scale Unit

Tests Plan	Test Loading Type	Scale	Pile Test ID	No. of helices	Shaft dia. d (mm)	Helix Dia. D (mm)	Pile Length L (mm)	Helix Spacing S (mm)	Lower Helix Embedment E (mm)	$S_r = (S/D)$
NI02	Pseudo-static Cyclic Load followed by Axial Compression	Model Scale Unit	P0CyC	0	12.7	38.1	271.8	NA.	150	NA.
			P1CyC	1	12.7	38.1	271.8	NA.	150	NA.
			P2CyC	2	12.7	38.1	271.8	57.2	150	1.5
			P3CyC	2	12.7	38.1	271.8	95.2	150	2.5
			P4CyC	2	12.7	38.1	271.8	133.4	150	3.5
		Prototype Scale Unit	P0CyC	0	254	762	5436	N.A.	3000	N.A.
			P1CyC	1	254	762	5436	N.A.	3000	N.A.
			P2CyC	2	254	762	5436	1144	3000	1.5
			P3CyC	2	254	762	5436	1905	3000	2.5
			P4CyC	2	254	762	5436	2668	3000	3.5

2.2 Soil Properties

The model test was performed upon dry silica sand (Sil-3) supplied by Sil Industrial Minerals in Edmonton, Alberta. The geotechnical properties of Sil-3 sand are summarized in Table 4. The minimum and maximum density of the Sil 3 sand was measured following ASTM D4254-16 and ASTM D4253-16e1 respectively. The tested particle size distribution (PSD) of Sil-3 sand is shown in Fig. 5. From the PSD, the estimated, $d_{50} = 0.29$ mm, $C_u = 1.5$ mm and $C_c = 1.08$ mm, indicates uniform distribution of grain sizes. As per Schiavon et al. 2016, effective model sand for centrifuge test of helix piles should carry uniformly distributed grain sizes, should not contain a lot of fine sand dust and maintain the ratio of the effective helical radius of the model helix piles (r_h) to the average grain size (d_{50}) of the sand, r_h/d_{50} greater than 58. Hence, for Sil- 3 as model sand, the r_h of the model piles was kept greater than 16.82 mm (discussed in the following section). The direct shear test on the Sil-3 sand is shown in Fig. 6. Table 5 shows the estimated parameter for the direct shear test.

Table 4. Geotechnical properties of model silica sand

Term	Value
Specific Gravity (G_s) (Correlated)	2.65
Average Bulk density (ρ), Mg/m^3	1.61
Constant Volume Friction angle (ϕ_{cv}), deg.	31.7
Maximum Dry Density (ρ_{max}), Mg/m^3	1.73
Minimum Dry Density (ρ_{min}), Mg/m^3	1.52
Minimum void ratio (e_{min})	0.53
Maximum void ratio (e_{min})	0.74

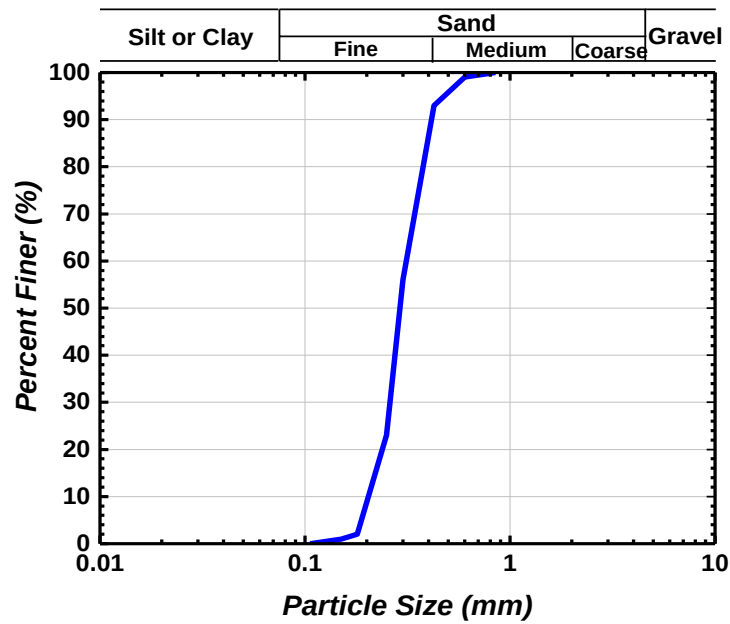


Figure 5. Particle size distribution of model silica sand

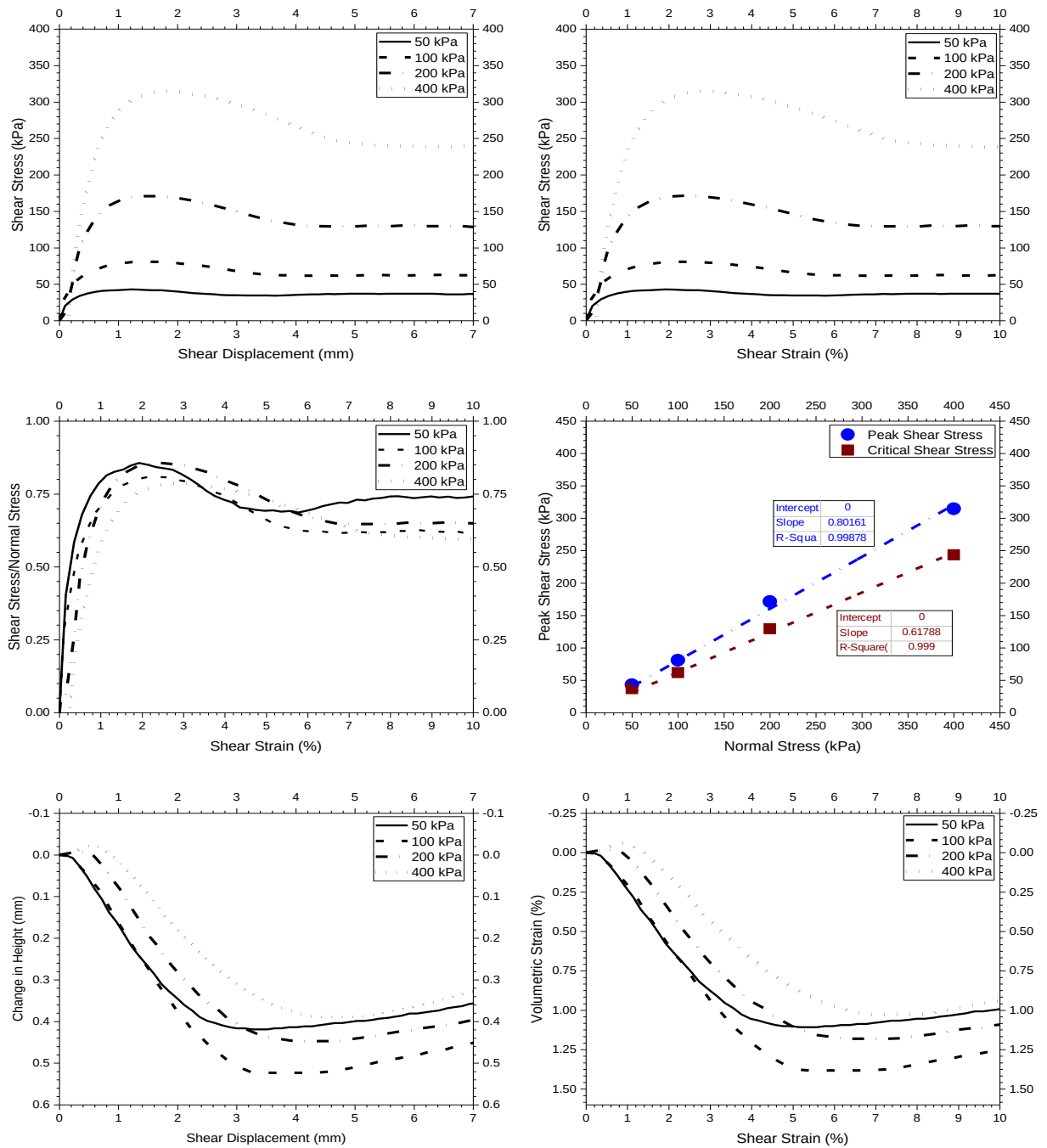


Figure 6. Direct Shear test results on Sil 3 Sand (strain rate: 0.76 mm/min)

Table 5. Estimated Shear Strength parameters of Sil 3 sand from the direct shear test

Cohesion intercept condition	Estimated c' and ϕ'
With zero intercept for cohesion	$c' = 0 \text{ kPa}$ and $\phi' = 38.7^\circ$
	$c'_{cv} = 0 \text{ kPa}$ and $\phi'_{cv} = 31.2^\circ$
Without zero intercept for cohesion	$c' = 6.2 \text{ kPa}$ and $\phi' = 37.9^\circ$
	$c'_{cv} = 5.9 \text{ kPa}$ and $\phi'_{cv} = 30.8^\circ$

2.3 Soil model construction

The soil model was constructed in an aluminum container. The container measures internally, 709.2 mm (length), $\times$ 300 mm (width) $\times$ 400 mm (height) with wall thickness $\geq$ 30 mm. The box was designed for a maximum centrifugal acceleration of 50 g scale unit. To reduce the gross weight in-flight, all the walls were made of aluminum. The model sand deposition was controlled with a portable traveling pluviator (PTP) setup to allow uniform density deposition of sand at each layer in the model box.

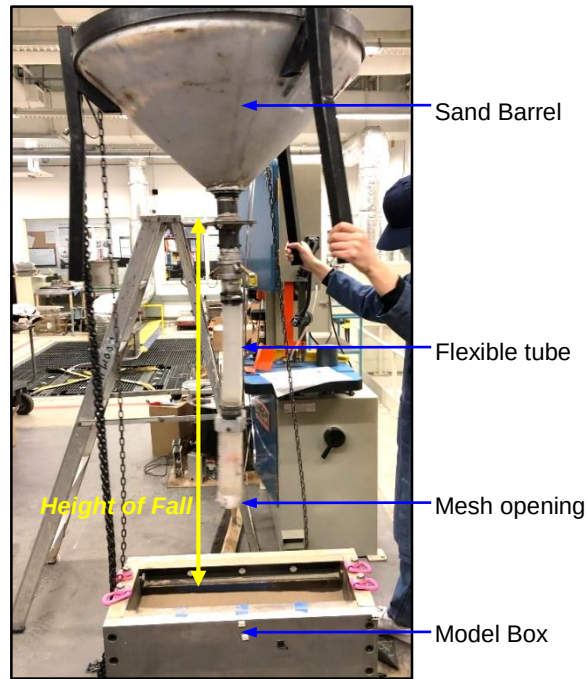


Figure 7. Portable traveling sand pluviator setup

Figure 7. shows the various components of the portable travelling pluviator (PTP) setup for the Sil-3 sand deposition in the model box. The configuration of PTP is similar to the stationary/portable travelling pluviator (PTP) as reported in literature (e.g. Dave and Dasaka 2012, Gade and Dasaka 2016, Hakhamaneshi et al. 2016 and Taeseri et al. 2018). The height of fall and the mesh size can be adjusted to control the density of the sand in the model box. The PTP was used to calibrate the Height of Fall against the relative density, varying the deposition height between 110 -150 mm and changing the mesh size opening

for 5 mm and 100 mm. Figure 8. shows the calibration assembly for the PTP using a density mould.

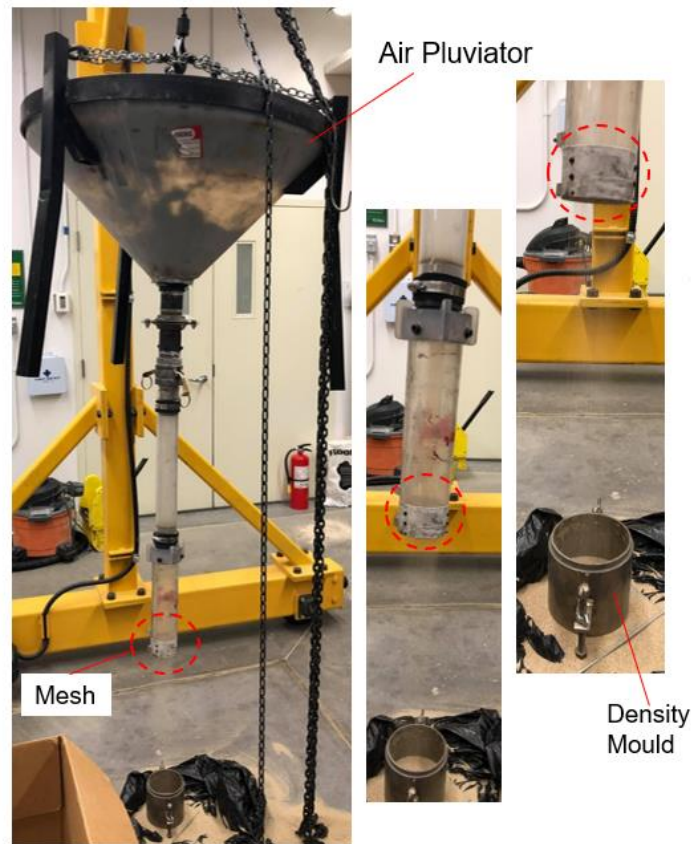


Figure 8. Calibration Assembly for the Portable Travelling Pluviator

Figure 9. presents the calibration chart developed to ascertain the relationship between the relative density of sand with the height of fall of sand from the PTP to the model box for mesh openings of 5 mm and 10 mm, respectively. The height of fall varied between 110 cm to 150 cm to deposit the sand in a density mold. Later, the relative density of sand for each calibration test was determined. As observed in Fig. 9, the relative density ranged between 72 to 100 % for 10 mm mesh opening and 46 to 86 % for 5 mm mesh opening. For test NI01, the relative density was fixed at 55%, which corresponds to a height of fall of 114 cm at the PTP. Figure 10 shows the schematic of the plan view of the model soil box showing the path of motion of the PTP during preparation of the sand bed.

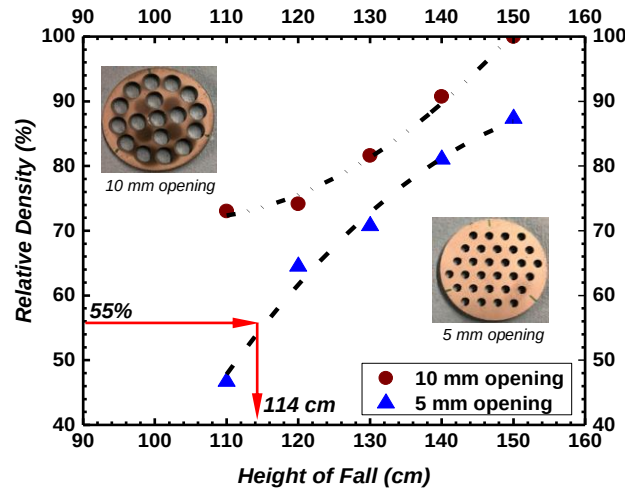


Figure 9. PTP calibration chart for the relationship between the relative density of sand with Height of fall for two mesh openings.

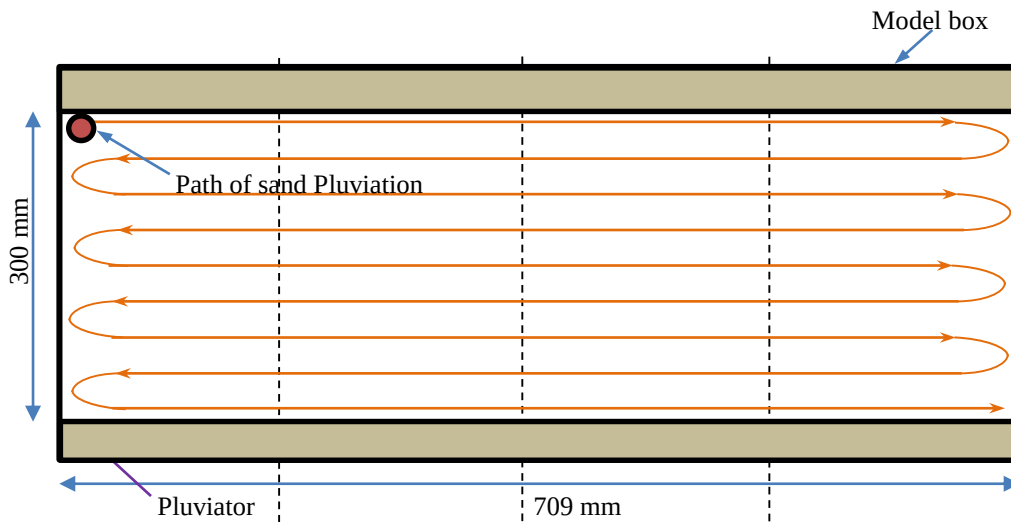


Figure 10. Plan view of plain strain model box showing path of sand Pluviation.

Figure 11 shows the photos of sand pluviation in the model box. The quality of deposition of sand in the model box was verified using the small container method (see Choi et al. 2010 and Tabaroei et al. 2017). A total of 12 small containers (four in each layer) were selected to estimate the density on it along the course of travel of the PTP maintaining a uniformity in the height. The configuration and the dimensions of the containers are shown in Fig. 12.

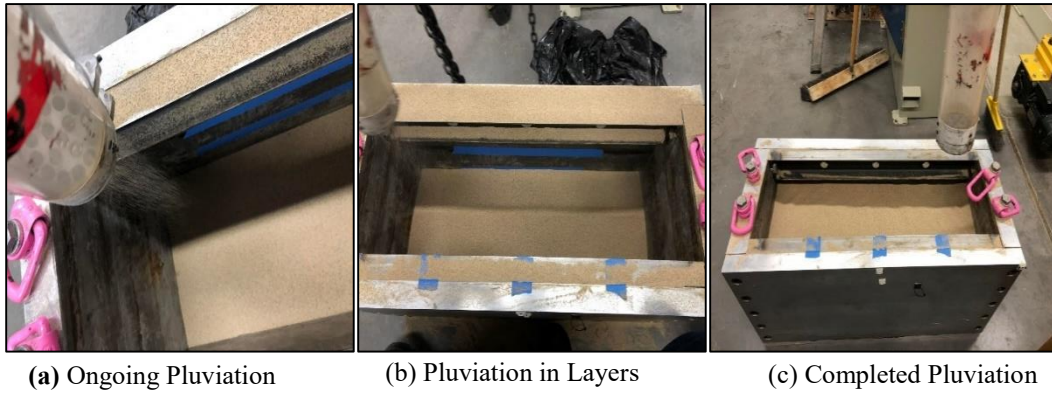


Figure 11. Pluviation of sand in the model box

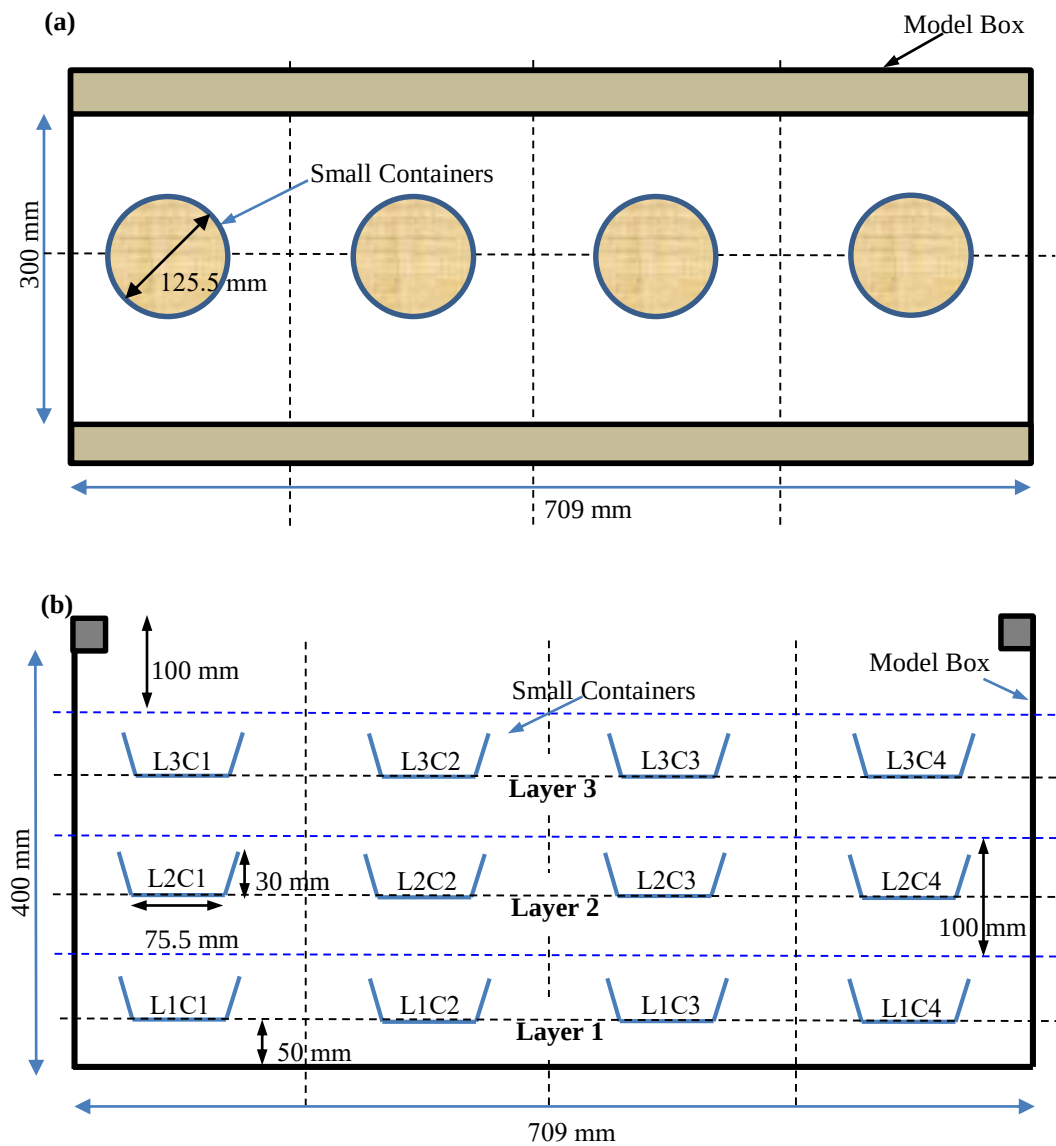


Figure 12. Schematic of calibration test (a) Plan View (b) Side view of the model box

Figure 13. shows the photos of the measurement and placement of the model box in the container. Figure 14 summarizes the estimated relative density (D_r) from the containers. The measured average $D_r = 54.3\%$ which is in closer approximation to the desired density 55%.

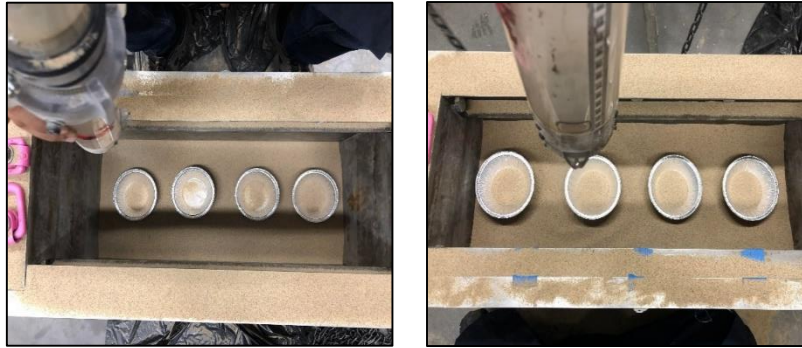


Figure 13. Photos of the measurement and placement of the container in the model box.

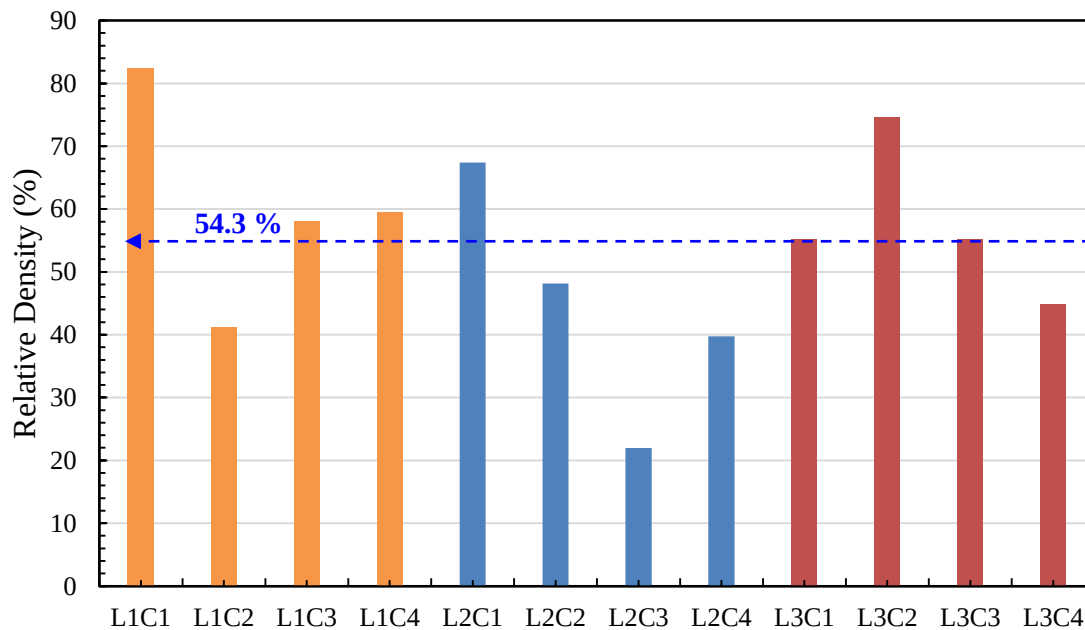


Figure 14. Comparative Sand Density of Small Containers in the Model Box

The average relative density was also measured from the weight of the strong box before and after the pluviation of sand. The measured average relative density was 49.7% for an average soil bulk density of 1.61 gm/cm^3 .

2.4 Model Pile Instrumentation

In the present research, model piles are instrumented with axial strain gauges and torsional strain gauges for measuring the internal axial forces during pile loading tests and the torque during pile installation. Table 6 shows the description of the strain gauges and Fig. 15 shows the configuration of the gauges. The gauges were ordered from the supplier Terracene International (made by Micro Measurements VPG) that are universal general-purpose type with strain ranges of $\pm 3\%$.

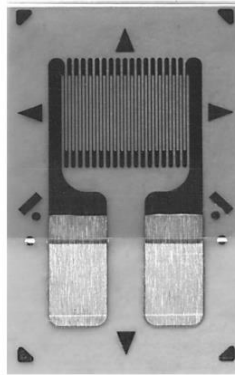
As per the precision Strain Gauges handbook from the supplier, the terminologies: **CEA** indicates Universal general purpose strain-gages. Constantan grid completely encapsulated in polyimide, with large, rugged copper-coated tabs. The following number **13** (Item a) or **06** (Item b) designates the approximate thermal expansion coefficient in ppm/ $^{\circ}$ F of the structural material on which the gage is to be used. The following number, **062** designates the active gage length in Mils [0.001 in (0.0254 mm)]. **UW** or **UV** stands for grid and tab geometry and the number at the end indicates the resistance in Ohms.

Two types of strain gauge circuits will be adopted. For torque measurement, a full Wheatstone bridge consisting of two pads of strain gauges was used; the gauge model is CEA-06-062UV-350. Two strain gauges, on a base pad, were placed at the 45 and 135 $^{\circ}$ rosette, with respect to the pile cross-sectional plane. The full-bridge configuration will compensate the effects of temperature, pile axial strain, and bending moment on the pile.

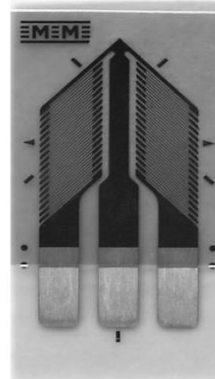
For axial strain measurement, a half Wheatstone bridge circuit consisting of two active single gauges will be adopted. The gauge model is CEA-13-062UW-350. The gauges are placed on two grooves cut into the pile shaft. The active gauges are wired to two dummy gauges on the data acquisition box. The locations of strain gauge stations are determined with the consideration of anticipated load distribution, so that the axial load transfer mechanism along the shaft and helical plates can be inferred.

Table 6. Description of the Strain Gauges

Items	Description of the Strain Gauges
a	CEA-13-062UW-350
b	CEA-06-062UV-350



a) Strain Gauge, CEA-13-062UW-350



b) Strain Gauge, CEA-06-062UV-350

Figure 15. Strain Gauge Configuration

The arrangement of the approximate locations of the strain gauges are presented in Figure 16. In order to protect the strain gauges from any potential damages from moist invasion or physical abrasion, especially for these axial gauges embedded in soil, the following techniques are adopted:

- Two grooves, 5 mm wide and 4.75 mm deep, were excavated along the shaft on the opposite sides.
- Axial strain gauges were then glued to the bottom of the grooves. To prevent moisture attack and electric leakage, the strain gauges were covered with VPG M-B coating and Teflon tapes, and then the grooves were carefully filled with epoxy (shown in Fig 16 a)
- The surfaces of the cured epoxy will eventually be smoothed with #240 sand papers and polished with soft cloth.

Calibration of the strain gauges were performed using the HBM data logger MX 1615B to convert the electronic signals into engineering units. The analyzed results and setup for calibration are presented in Appendix G.

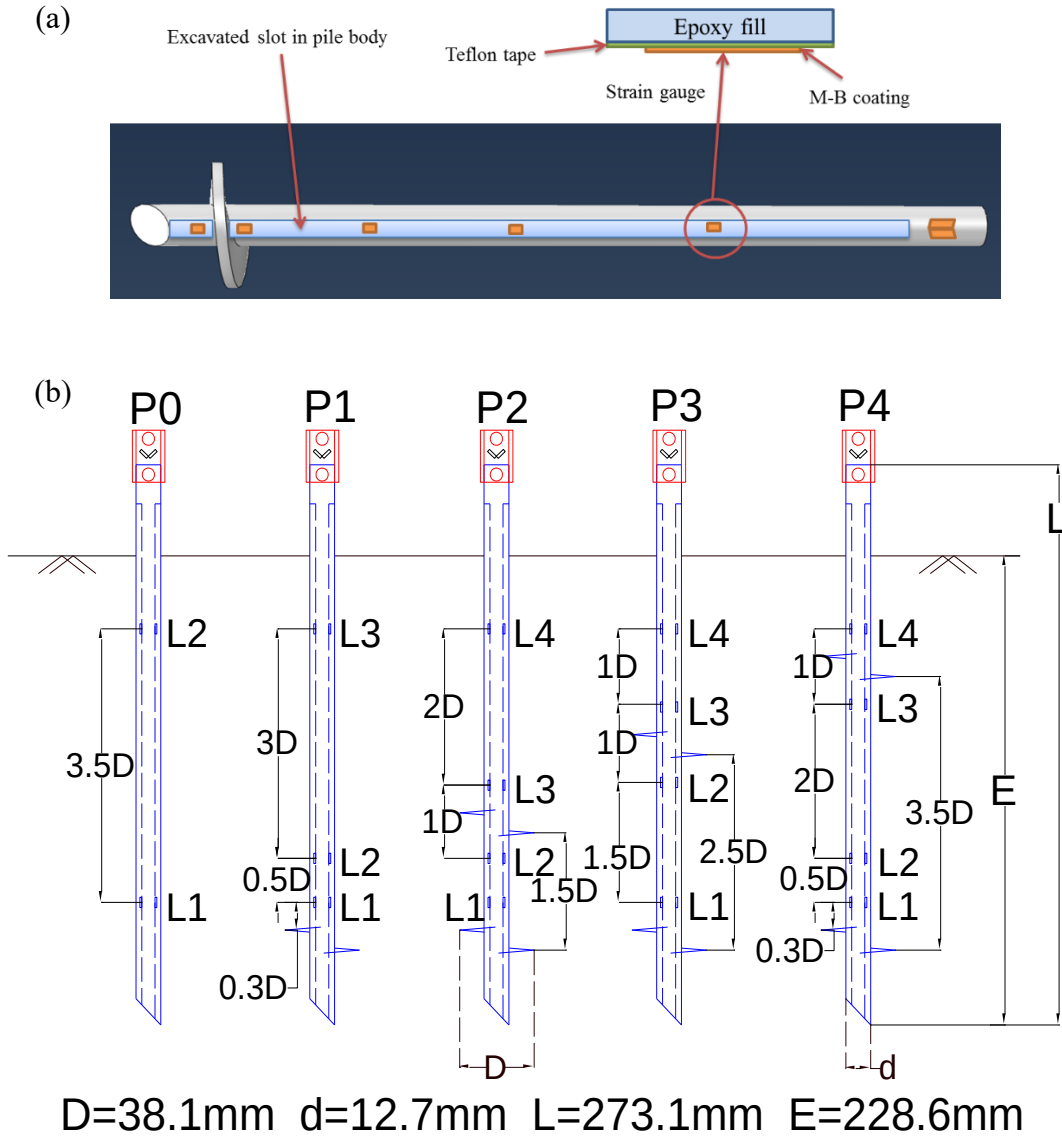


Figure 16. a) Approximate locations of strain gauge stations and protection technique and b) Position of strain gauges (L1-L4) and Torque Gage (TG) on the model piles.

Figure 17 presents the Wheatstone bridge connections for the axial and torque strain gauges as in the model connection assembly.

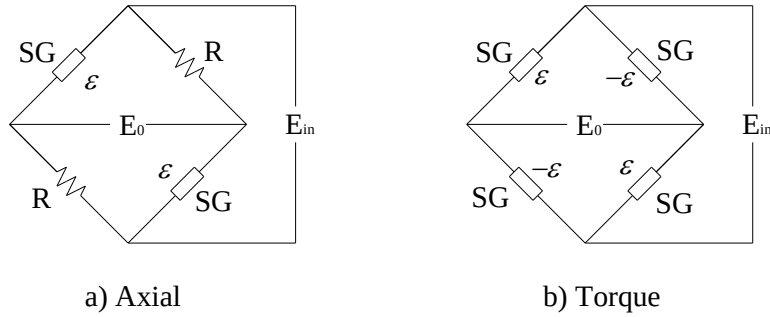


Figure 17. a) Half bridge circuit for axial strain measurement, where SG = axial strain gauge on pile shaft and R = complementary resistor embedded in the data logger and b) Full bridge circuit for torque measurement.

2.5 Calibration of Gear Motor

A slender gear motor is required that can simulate the pile installation during the motion of the centrifuge at high g level and that can fit the working space of the test setup. Hence, a slender gear motor, MMP S17-400A-12V manufactured by Midwest Motion Products, was selected for installing model piles in flight (see in Figure 18).



(a) Plan View



(b) Cross Sectional View

Figure 18. Slender gear motor, MMP S17-400A-12V (by Midwest Motion Products)

Prior to use, the motor needs to be calibrated such that it can fulfill the recommended output speed (in rpm) of installing the pile as practiced in field for the variation of soil resistances.

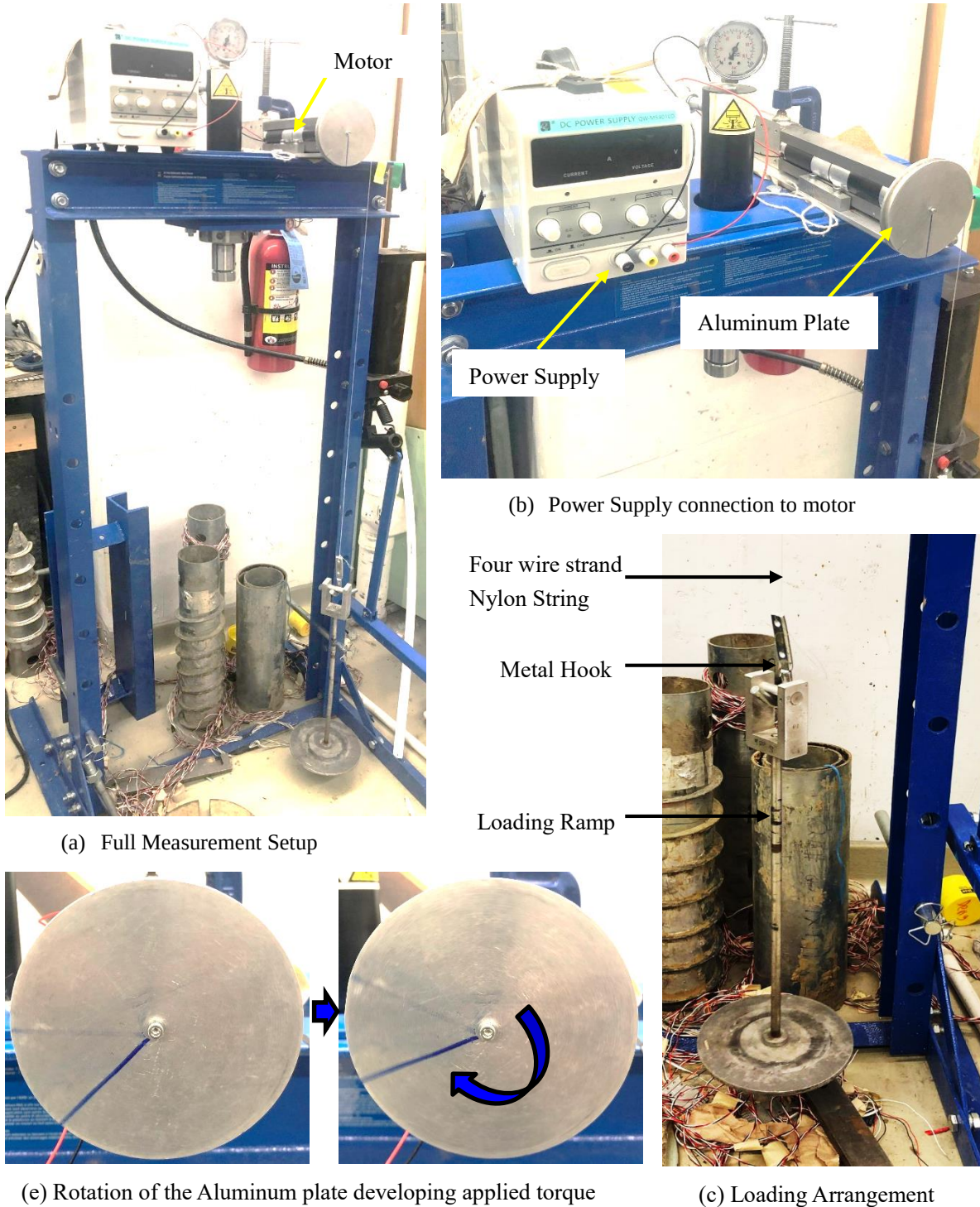


Figure 19. Photos showing measurement setup for output speed of the motor to applied torque.

Tsuha et al. (2007, 2012), Schiavon et al. (2016) adopted a motor speed of 5.3 rpm during the anchor installation and pullout in dense sand both at 1g and 22g. According to Perko

(2009), typical rotation rates range from 10 to 30 rpm. As per AB Chance's (2012) guide to model specification, the helical anchors are usually installed with a rotation rate ranging from 5 to 20 rpm to provide a continuous and smooth advance into the soil. Li and Deng (2021) adopted a rotation rate of 22.5 rpm overall during the helix pile installation at 20g. The motor is calibrated by adopting variable torque combinations mounted with an aluminum circular plate and connected with a DC power supply that can generate variable voltage outputs. The applied torques (in N-m) simulates the nature of soil resistances. Figure 19 shows the photos of the setup used for the measurements. A circular aluminum plate (of diameter = 92.58 mm) was fixed onto the shaft of the motor, and a four-strand nylon string was tied on the edge of the plate to add variable dead weights (ref to Fig 19 (a-c)). A total number of fourteen load combinations were adopted and hanged to the nylon string in the vertical direction for the motor to uplift each of them (see Fig 19 (e)). The rotations were measured using a camera and later counting the elapsed time over three complete revolutions of the aluminum plate for each of the torque combinations. Figure 20 shows a screenshot from the measurement of time (in milliseconds). Correlations of output motor speed (rpm) against applied torque (Nm) for variable power supply voltage is shown in Figure 21.

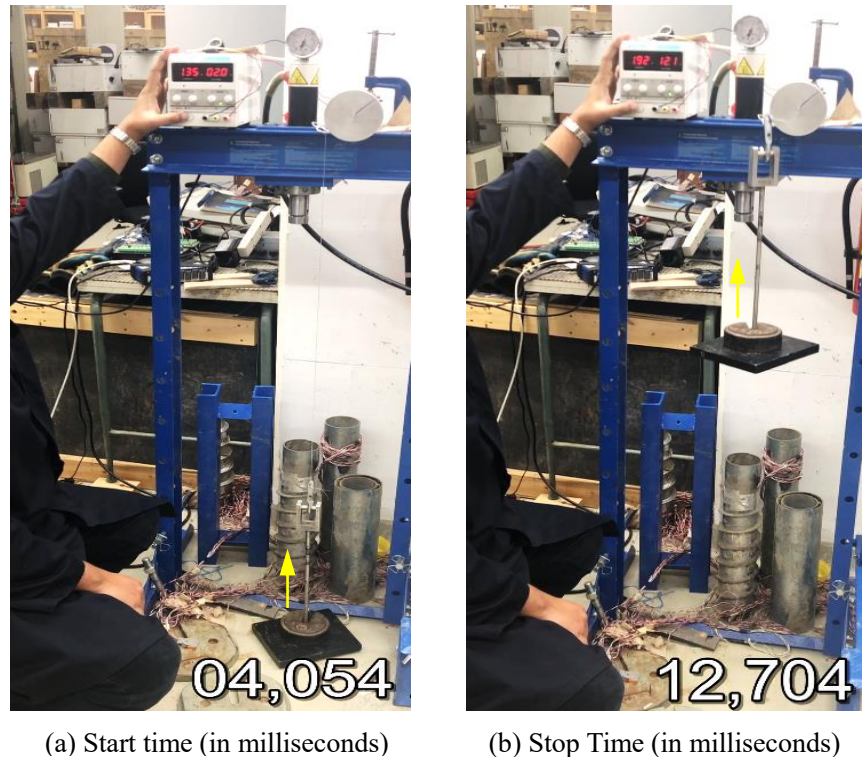


Figure 20. Measurements of output speeds against variable torque combinations for 3 complete revolutions of the aluminum plate.

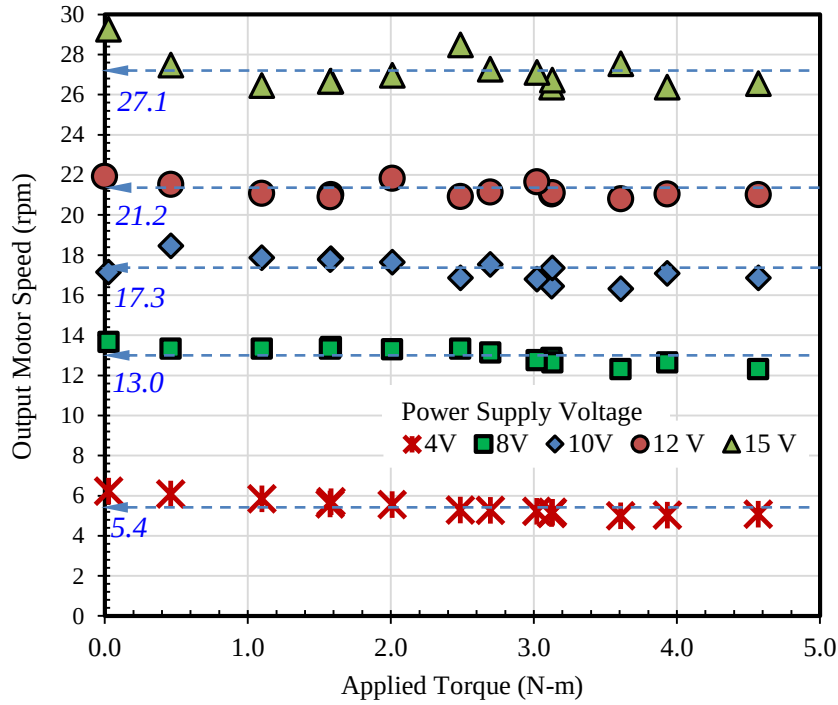


Figure 21. Motor output speeds against applied torques for changed power supply voltage.

As observed in Figure 21, the speed of the motor is maintained constant at 5.4, 13.0, 17.3, 21.2 and 27.1 rpm overall regardless the magnitude of torque (from 0 to 4.6 N-m) for power supply voltage of 4V, 8V, 10 V, 12 V and 15 V respectively.

2.6 Centrifuge Model Box Configuration

Figure 22 shows the model assembly on the centrifuge with its various components. Figure 23 shows the connection assembly to the centrifuge data logger placed alongside the model box in the loading arm.

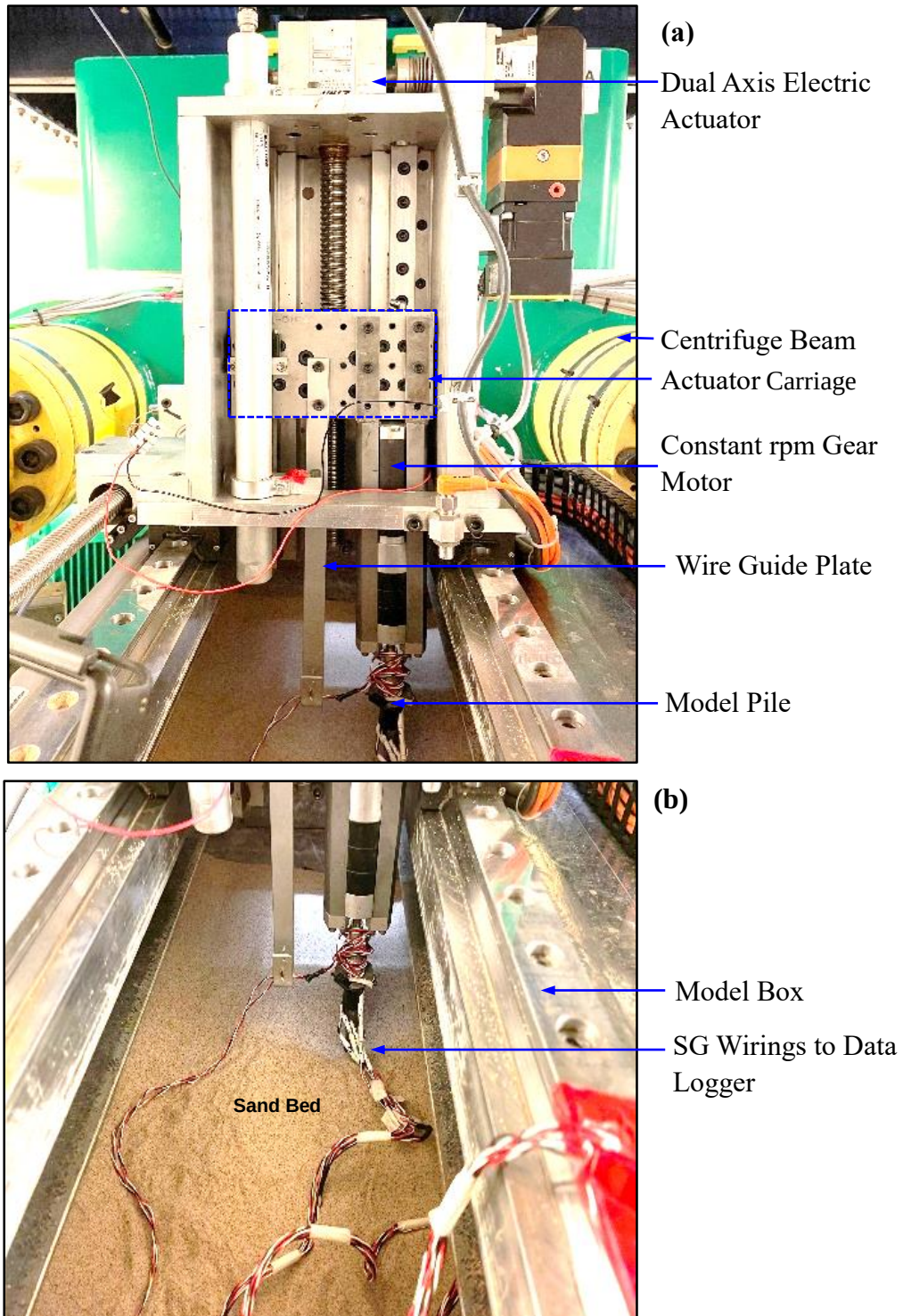


Figure 22. Centrifuge Model Assembly.

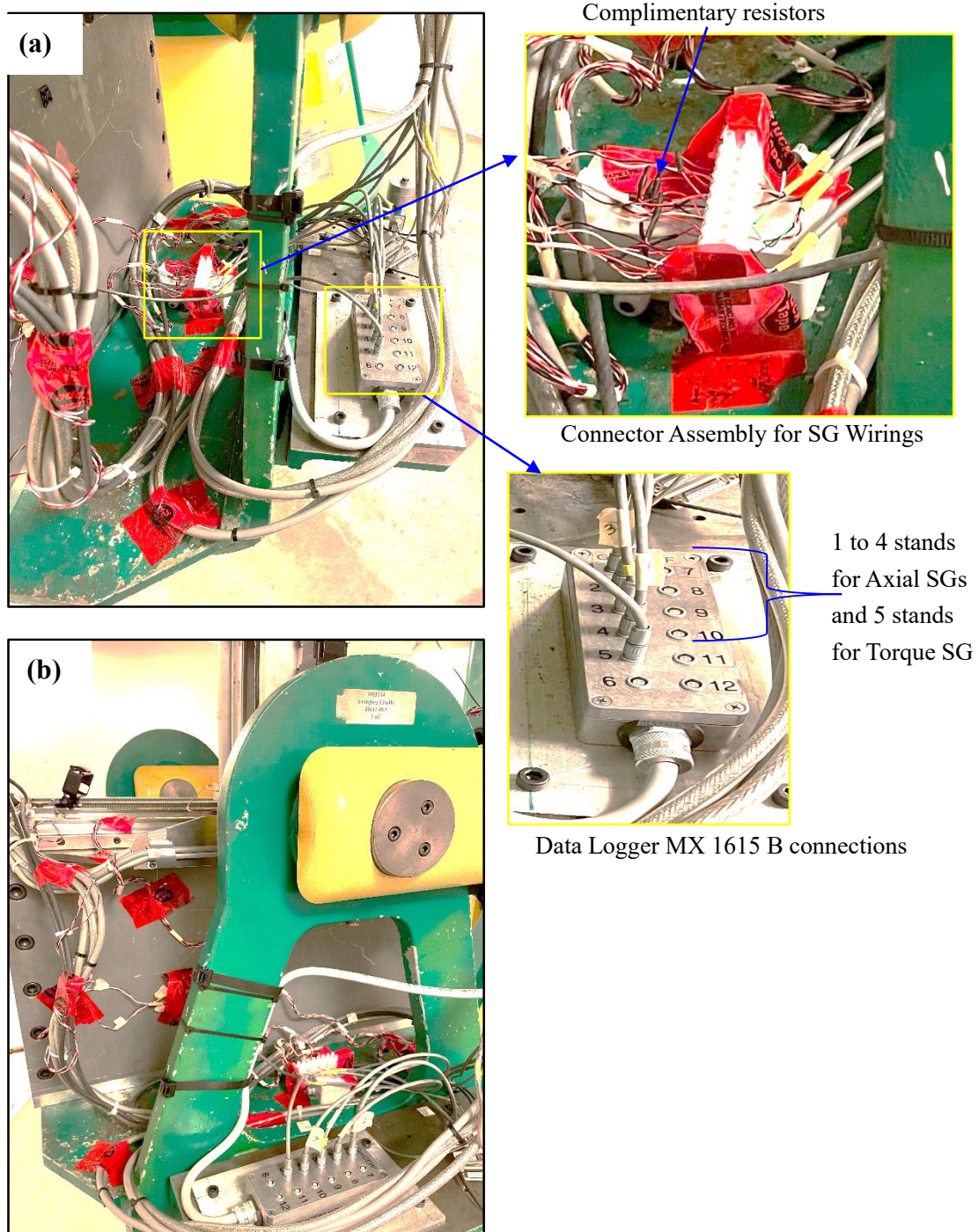


Figure 23. Wire Connections on the Centrifuge Assembly to the Centrifuge Datalogger;
(a) Front view and (b) Side view

3 Test and Loading Sequence

The test and loading sequence were arranged based on the test matrix. In the test sequence, the actions at each day with the time and date were recorded and presented in a tabular format. Table 7 shows the test sequence for NI02.

Table 7. Test sequence for NI02 centrifuge model test

Day Count	Date	Work/St	Action
1-3	5 – 7 Dec 22 Monday - Wednesday	1	Air pluviation of sand in model box
4	8 Dec 22 Thursday	2	Lowering of model box in the swinging table and loading setup arrangement
5	9 Dec 22 Friday	3	Wirings and connections check and safety check of centrifuge testing
6	13 Dec 22 Tuesday	4	Installation, Cyclic and Monotonic Compression on P1CyC
7	14 Dec 22 Wednesday	5	Installation, Cyclic and Monotonic Compression on P3CyC
8	15 Dec 22 Thursday	6	Installation, Cyclic and Monotonic Compression on P0CyC
9	16 Dec 22 Friday	7	Installation, Cyclic and Monotonic Compression on P2CyC
10	19 Dec 22 Monday	8	Installation, Cyclic and Monotonic Compression on P4CyC
11	20 Dec 22 Tuesday	9	Retrieval of data from the data logger and Go Pro Videos
12	21 Dec 22 Wednesday	10	Lowering of loading setup, uplifting of model box and safe storage

Table 8 shows the loading sequence for NI02 test series. In the loading sequence, the power supply voltage, pile installation rpm, actuator speed and the loading rate were recorded for each pile type.

Table 8. Loading sequence for NI02 centrifuge model test

Test ID	Pile type	Load type	Power supply voltage (V)	Pile Installation rpm (1g)	Actuator speed (mm/sec)	Pseudostatic Loading rate (mm/min)	Monotonic Loading rate (mm/min)	g level
P0CyC	P0	Pseudostatic Cyclic	12	21.2	4.487	1	0.33	20
P1CyC	P1		12	21.2	4.487	1	0.33	20
P2CyC	P2		12	21.2	4.487	1	0.33	20
P3CyC	P3		12	21.2	4.487	1	0.33	20
P4CyC	P4		12	21.2	4.487	1	0.33	20

4 Recorded Data

The data was recorded in HBM Data Logger and arranged on the folder titled Centrifuge Test NI02 in the format shown in Table 9.

Table 9. Organization of data files

Test ID	Pile ID	SG Station ID	Data file	Description
NI02 P1 PL1	P1	L1-L3	1_P1_PL1	Pseudo static Cyclic Load 1
NI02 P1 PL2	P1	L1-L3	2_P1_PL2	Pseudo static Cyclic Load 2
NI02 P1 PL3	P1	L1-L3	3_P1_PL3	Pseudo static Cyclic Load 3
NI02 P1 PL4	P1	L1-L3	4_P1_PL4	Pseudo static Cyclic Load 4
NI02 P1 CL	P1	L1-L3	5_P1_CL	Axial Compressive Load
NI02 P3 PL1	P3	L1-L4	6_P3_PL1	Pseudo static Cyclic Load 1
NI02 P3 PL2	P3	L1-L4	7_P3_PL2	Pseudo static Cyclic Load 2
NI02 P3 PL3	P3	L1-L4	8_P3_PL3	Pseudo static Cyclic Load 3
NI02 P3 PL4	P3	L1-L4	9_P3_PL4	Pseudo static Cyclic Load 4
NI02 P3 CL	P3	L1-L4	10_P3_CL	Axial Compressive Load
NI02 P0 PL1	P0	L1-L2	11_P0_PL1	Pseudo static Cyclic Load 1
NI02 P0 PL2	P0	L1-L2	12_P0_PL2	Pseudo static Cyclic Load 2
NI02 P0 PL3	P0	L1-L2	13_P0_PL3	Pseudo static Cyclic Load 3
NI02 P0 PL4	P0	L1-L2	14_P0_PL4	Pseudo static Cyclic Load 4
NI02 P0 CL	P0	L1-L2	15_P0_CL	Axial Compressive Load
NI02 P2 PL1	P2	L1-L4	16_P2_PL1	Pseudo static Cyclic Load 1
NI02 P2 PL2	P2	L1-L4	17_P2_PL2	Pseudo static Cyclic Load 2
NI02 P2 PL3	P2	L1-L4	18_P2_PL3	Pseudo static Cyclic Load 3
NI02 P2 PL4	P2	L1-L4	19_P2_PL4	Pseudo static Cyclic Load 4
NI02 P2 CL	P2	L1-L4	20_P2_CL	Axial Compressive Load
NI02 P4 PL1	P4	L1-L4	21_P4_PL1	Pseudo static Cyclic Load 1
NI02 P4 PL2	P4	L1-L4	22_P4_PL2	Pseudo static Cyclic Load 2
NI02 P4 PL3	P4	L1-L4	23_P4_PL3	Pseudo static Cyclic Load 3
NI02 P4 PL4	P4	L1-L4	24_P4_PL4	Pseudo static Cyclic Load 4
NI02 P4 CL	P4	L1-L4	25_P4_CL	Axial Compressive Load

Note: L1-L2, L3 or L4 identifies the axial strain gauge station from the tip of the pile and up.

5 Processed Results

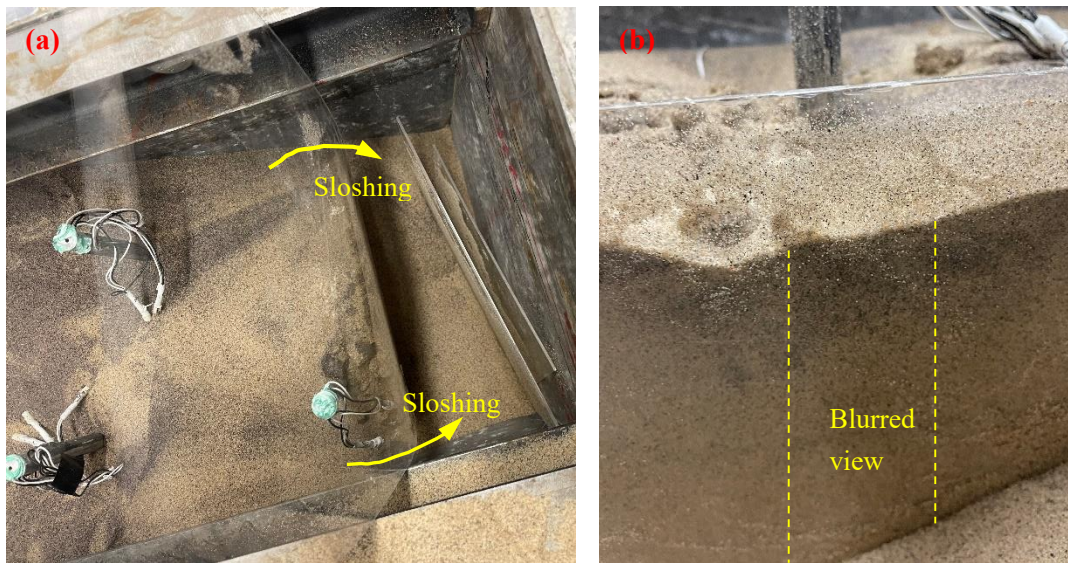
Appendix A shows the photos from the model box after installations of the pile and after the spin for loading. The results for individual pile types are processed in MATHCAD and are presented in details in Appendix B-F.

6 Limitations

The model piles were installed at 1g due to the limitation on the capacity of the installation gear motor in the development of adequate torque. The specified maximum gear motor continuous torque was 16 N-m with a gear head efficiency of 70% that leads to a torque value of 11.2 N-m. Even at 1g, all of the piles reached the maximum capacity at about halfway distance within the pile installation. The estimated torque at 1 g (in model scale) was about 15.5 N-m and at 20 g (in prototype scale) was about 122.8 kN-m. A larger gear motor than can provide the required torque was again beyond the present accommodation capacity of the centrifuge assembly.

The applied pseudostatic cyclic displacement was adjusted to be as one-way cyclic distribution due to the simplicity of the actuator movement.

Attempted were made to visualize the soil-structure interaction at the cross section of the pile by excavating sands at the end of the test and providing acrylic transparent sheet on one side. However, due to the adhesive nature of the sand and sloshing of sand, the pile-color sand layer interaction was not quite clear. Figure 24 shows the visualization attempt along the cross section of the piles.



(a) Cross Section 1
(b) Cross Section 2
Figure 24. Visualization of Pile-Soil Interaction along the cross section.

7 Summary

NI02 centrifuge test series consists of the axial pseudostatic cyclic load tests on five model piles in one model box. Both smooth and helix piles were tested in pseudostatic loading followed with axial compression at the GeoCERF Centrifuge facility at the University of Alberta. Among the helix piles, one single helix and three double helix piles were tested.

The piles were installed in dry Sil-3 sand. All the model piles were installed at a 1 g model scale and later tested at 20 g acceleration. A crater formed at the ground surface surrounding each pile after installations and later loading. The illustrations are listed in Appendix A for each pile. Appendix B-F presents the results from the centrifuge tests for all the model piles tested. The appendices summarize the test results for the various intensity of cyclic load effect on each piles. The axial shaft, end bearing resistances are also shown. Moreover, the internal load transfers along the pile shaft is plotted. Lastly, the dissipation of energy during the loadings are shown over the entire depth of pile.

The results presented here are from the second phase of centrifuge tests of helical pile research in the sand at the University of Alberta. The tests were conducted recently and are therefore considered preliminary for the current stage. Detailed interpretation will be presented in the following report or publications.

8 Future Tests and Modifications

In the last series of centrifuge test NI03 for group piles the following additions and modifications will be adopted:

- The model piles will be pre installed with the cap rather than installing it at 1 g.
- The model piles after each tests will be left in place rather than removal.
- Colored sand will be deposited in layers. The soil will be saturated at the end of tests. The transparent screen to visualize the soil structure interaction at the cross section after the test will be lubricated with silicon oil. Such lubrication might ensure the non adhesion of sand to the screen.

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Appendix A Photos from the centrifuge test series

Appendix B Data Conversion and Processing Sheet for smooth pile P0

Appendix C Data Conversion and Processing Sheet for smooth pile P1

Appendix D Data Conversion and Processing Sheet for smooth pile P2

Appendix E Data Conversion and Processing Sheet for smooth pile P3

Appendix F Data Conversion and Processing Sheet for smooth pile P4

Appendix G Calibration of Strain Gauges

Appendix A

Illustrations for Surface Crater Formation from NI02 Centrifuge Test Series

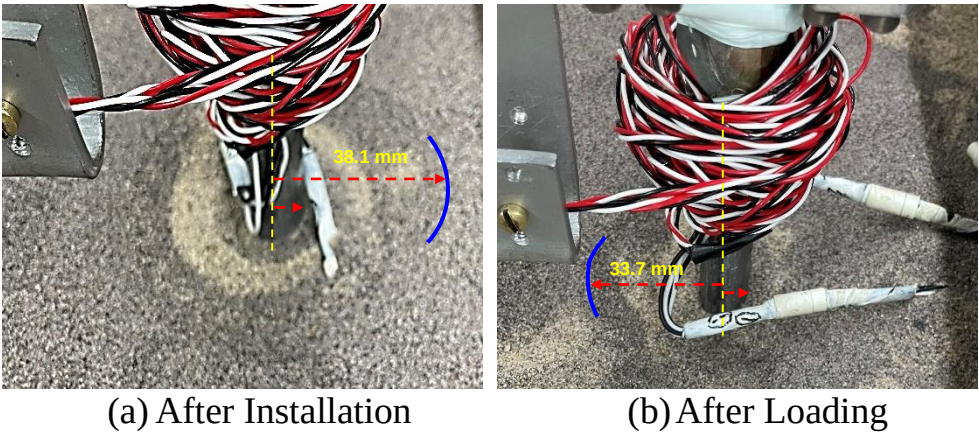


Figure A-1. Illustration of Surface Crater Formation for P0 Pile

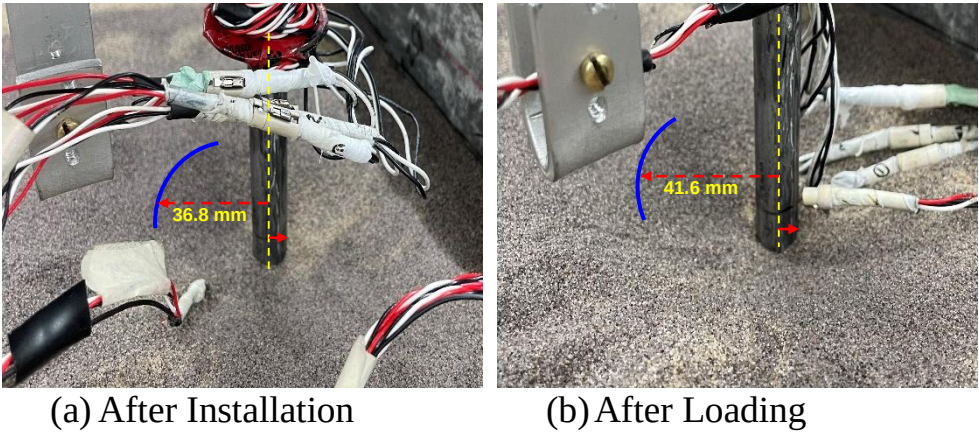


Figure A-2. Illustration of Surface Crater Formation for P1 Pile

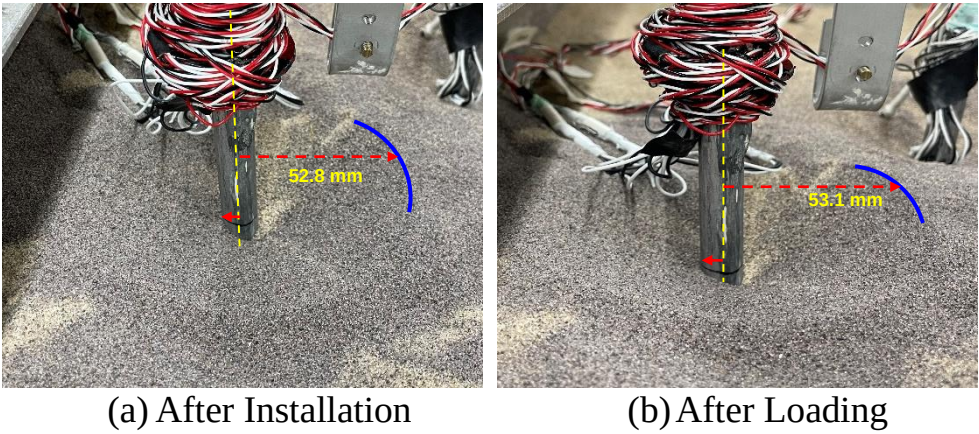


Figure A-3. Illustration of Surface Crater Formation for P2 Pile

Appendix A
Illustrations for Surface Crater Formation from NI02 Centrifuge Test Series

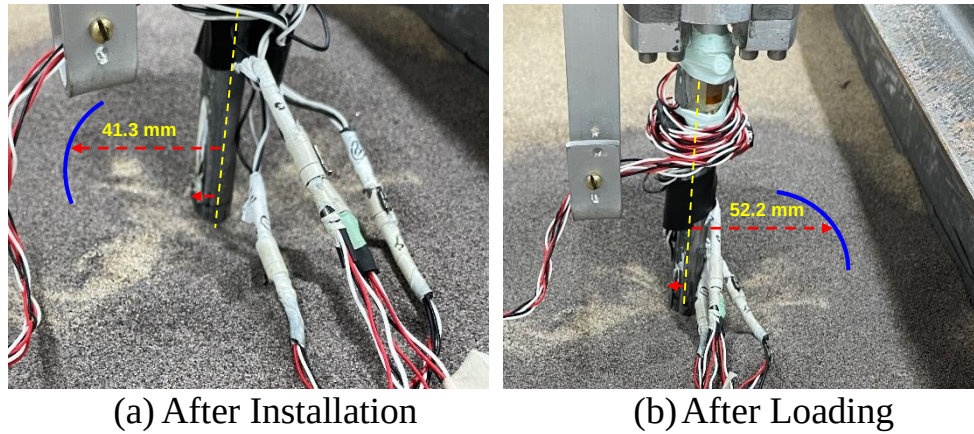


Figure A-4. Illustration of Surface Crater Formation for P3 Pile

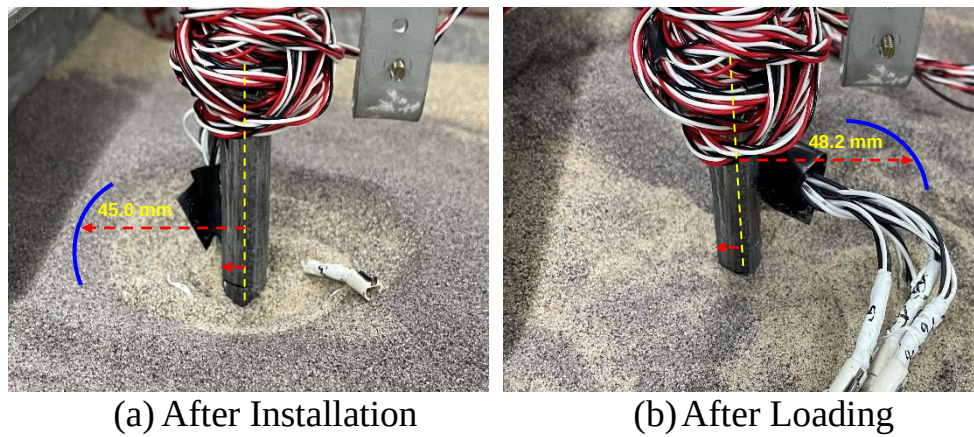


Figure A-5. Illustration of Surface Crater Formation for P4 Pile

1. Introduction

The series of sheets in Appendix B contains the data conversion and processing procedures specifically for the NI02 centrifuge test series on P0 smooth pile. For the data conversion procedures, the raw data files were first corrected by subtracting the initial value of pre spin data depending on file index. The data were then converted into engineering units through recalibrations of the strain gauges in the centrifuge data logger.

2. HBM Data Conversion

HBM data were recorded by the HBM Data Logger connected to the main computer unit of the GeoCerf centrifuge.

2.1 General Information

2.1.1 Model Pile Dimensions

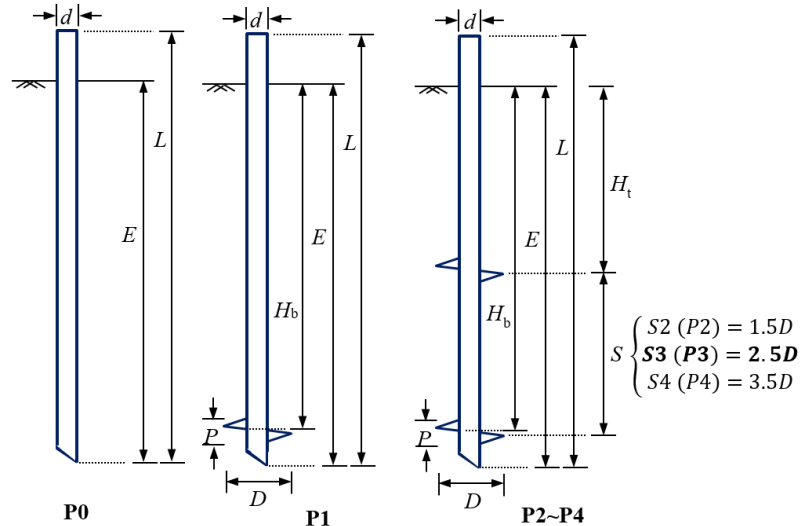
$L := 271.8 \text{ mm}$	Length of the Pile
$d := 12.7 \text{ mm}$	Diameter of the shaft
$D := 38.1 \text{ mm}$	Diameter of the helix
$E := 169.1 \text{ mm}$	Embedment depth of pile
$H_b := 150 \text{ mm}$	Depth to bottom helix
$H_t := [150] \text{ mm}$	Depth to top helix
$P_s := \pi \cdot D = 0.12 \text{ m}$	Perimeter of the Helical Pile Shaft
$H_{eff} := (H_b - D)$	Effective Shaft Length
$P := 12.7 \text{ mm}$	Pitch of the helix

2.1.2 Properties of Sand

$\gamma := 16.1 \frac{kN}{m^3}$	Unit Weight
$\varphi := 31.2 \text{ deg}$	CV Friction Angle
$\delta := \left(\frac{3}{4} \cdot \varphi \right) = 23.4 \text{ deg}$	CV Dilation Angle

2.1.3 Centrifuge Scale

$NoSGages := 4$	1 refers to the Strain Gage at the bottom and 4 the Strain Gage at the top of the pile; Total No of Strain Gages: P0=2, P1=3, P2 to P4= 4
$Nscale := 20$	Centrifuge g-level



Schematic of the model piles

$sclfac := [1 \ 2 \ 3]$ Centrifuge scale factor $N^{\wedge}scale$, 1 for displacement, 2 for force, 3 for Torque

2.1.4 Pseudostatic Loading Stages

2.1.5.1 Actuator Scale Factors

$$RateScale := \frac{8}{\frac{mm}{sec}} \quad <= 1V8 = 1mm/sec$$

$$DistanScale := \frac{64000}{mm} \quad <= 1D64000 = 1mm$$

2.1.4.2 Pseudostatic Loading Stages for Helix Piles (P1 to P4)

$$LDisp := \begin{bmatrix} 0.01 \\ 0.02 \\ 0.05 \\ 0.10 \\ 0.10 \end{bmatrix} \quad LNoLoop := \begin{bmatrix} 8 \\ 8 \\ 8 \\ 8 \\ 1 \end{bmatrix} \quad PsdoTLag := 5 \ s \quad LRate := \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 0.33 \end{bmatrix} \frac{mm}{min}$$

$$LTime(Dia) := \left\| \begin{array}{l} \text{for } i \in 0, 1 \dots \text{rows}(LDisp) - 1 \\ \quad \left\| \begin{array}{l} 2 \cdot LDisp_i \cdot Dia \cdot LNoLoop_i \\ k_i \leftarrow \frac{\quad}{LRate_i} + (PsdoTLag \cdot (LNoLoop_i - 1)) \end{array} \right\| \\ k \end{array} \right\|$$

$$LTime(D) = \begin{bmatrix} 400.76 \\ 766.52 \\ 1863.8 \\ 3692.6 \\ 1385.455 \end{bmatrix} s \quad LTime(d) = \begin{bmatrix} 156.92 \\ 278.84 \\ 644.6 \\ 1254.2 \\ 461.818 \end{bmatrix} s$$

2.2 Calibration of the Strain Gages in HBM Data Logger

2.2.1 Calibration of Axial Strain Gages

RawDataCalib := READEXCEL (“..\Finalized NI01\Calibration SGages HBM Centrifuge Corrected.xlsx”, “Sheet1!A1:G12”)

$$\text{RawDataCalib} = \begin{bmatrix} 4.427 & 1 & 0.076 & 0.104 & 0.149 & 0.098 & 0.132 \\ 7.97 & 1 & 0.152 & 0.171 & 0.23 & 0.195 & 0.244 \\ 13.606 & 1 & 0.391 & 0.295 & 0.343 & 0.287 & 0.336 \\ 4.427 & 2 & 0.048 & 0.06 & 0.078 & 0.091 & 0.1 \\ 7.97 & 2 & 0.053 & 0.114 & 0.114 & 0.136 & 0.194 \\ 13.606 & 2 & 0.088 & 0.214 & 0.161 & 0.225 & 0.231 \\ 4.427 & 3 & 0 & 0.043 & 0.028 & 0.052 & 0.037 \\ 7.97 & 3 & 0 & 0.063 & 0.151 & 0.087 & 0.078 \\ 13.606 & 3 & 0 & 0.127 & 0.199 & 0.149 & 0.112 \\ 4.427 & 4 & 0 & 0 & 0.089 & 0.035 & 0.028 \\ 7.97 & 4 & 0 & 0 & 0.109 & 0.067 & 0.055 \\ 13.606 & 4 & 0 & 0 & 0.145 & 0.127 & 0.141 \end{bmatrix}$$

Colm 0 represents calibration loads in kg, Colm 1 represents Strain Gage Number, Colm 2-6 represents Strain Gage HBM readings for piles P0,P1,P2,P3 and P4 respectively

CmbLdAx := RawDataCalib⁽⁰⁾ **kg • g** Load Combinations

CalibdataPile := submatrix (RawDataCalib, 0, rows (RawDataCalib) – 1, 2, 6) • 10⁻³ • $\frac{\text{mV}}{\text{V}}$ HBM Strain Gage Data

Function for Calibration factor for all strain gages in each pile

$$CF := \begin{bmatrix} \text{for } i \in 0, 1 \dots \text{rows}(\text{CalibdataPile}) - 1 \\ \text{for } j \in 0, 1 \dots \text{cols}(\text{CalibdataPile}) - 1 \\ k_{i,j} \leftarrow \text{CmbLdAx}_{i,0} \\ q_{i,j} \leftarrow \text{CalibdataPile}_{i,j} \\ m_{i,j} \leftarrow \text{if } q_{i,j} = 0 \\ \quad 0 \\ \text{else} \\ \quad \frac{k_{i,j}}{q_{i,j}} \end{bmatrix} = \begin{bmatrix} 571.237 & 417.443 & 291.369 & 443 & 328.894 \\ 514.204 & 457.07 & 339.822 & 400.815 & 320.324 \\ 341.251 & 452.303 & 389.007 & 464.91 & 397.111 \\ 904.459 & 723.567 & 556.59 & 477.077 & 434.14 \\ 1474.698 & 685.605 & 685.605 & 574.699 & 402.881 \\ 1516.242 & 623.501 & 828.753 & 593.019 & 577.616 \\ 0 & 1009.629 & 1550.501 & 834.885 & 1173.352 \\ 0 & 1240.619 & 517.609 & 898.379 & 1002.038 \\ 0 & 1050.624 & 670.499 & 895.499 & 1191.333 \\ 0 & 0 & 487.798 & 1240.401 & 1550.501 \\ 0 & 0 & 717.055 & 1166.552 & 1421.073 \\ 0 & 0 & 920.202 & 1050.624 & 946.307 \end{bmatrix} \frac{\text{kN}}{\frac{\text{mV}}{\text{V}}}$$

Calibration Factor. Here, the columns represents the Piles from P0 to P4 (left to right) and the rows represents the Strain Gage readings SG1 to SG4 (top to bottom) for three load combinations

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

2.2.1 Calibration of Torque Strain Gages

RawDataTorque := READEXCEL (“..\Finalized NI01\Calibration Torque S Gages HBM Centrifuge .xlsx”, “Sheet1!J34:K36”)

$$\text{RawDataTorque} = \begin{bmatrix} 0.144 & 0.022 \\ 0.206 & 0.03 \\ 0.35 & 0.052 \end{bmatrix} \quad \text{CmbLdTr} := \text{RawDataTorque}^{(0)} \text{ N} \cdot \text{m} \quad \text{CalibdataTr} := \text{RawDataTorque}^{(1)} \cdot 10^{-3} \cdot \frac{\text{mV}}{\text{V}}$$

$$\text{CFTr} := \begin{array}{|l|} \hline \text{for } i \in 0, 1 \dots \text{rows}(\text{CalibdataTr}) - 1 \\ \hline \quad \text{for } j \in 0, 1 \dots \text{cols}(\text{CalibdataTr}) - 1 \\ \hline \quad \quad k_{i,j} \leftarrow \text{CmbLdTr}_{i,0} \\ \hline \quad \quad q_{i,j} \leftarrow \text{CalibdataTr}_{i,j} \\ \hline \quad \quad m_{i,j} \leftarrow \text{if } q_{i,j} = 0 \\ \hline \quad \quad \quad 0 \\ \hline \quad \quad \quad \text{else} \\ \hline \quad \quad \quad \frac{k_{i,j}}{q_{i,j}} \\ \hline \end{array} \quad = \begin{bmatrix} 6.674 \\ 6.813 \\ 6.763 \end{bmatrix} \text{ m} \cdot \frac{\text{kN}}{\frac{\text{mV}}{\text{V}}}$$

2.3 Pseudostatic Cyclic Centrifuge Test on Piles

Five piles were tested in compression and four piles were tested in tension in two separate model boxes two ascertain the axial load transfer mechanism within the pile.

2.3.1 Pseudostatic Cyclic Displacement Time History

$$\text{Lag} := 5 \quad \text{LagCyc} := 100 \quad \text{LoadCycRate} := 1 \frac{\text{mm}}{\text{min}} = 0.017 \frac{\text{mm}}{\text{s}} \quad \text{LoadCompRate} := 0.33 \frac{\text{mm}}{\text{min}} = 0.006 \frac{\text{mm}}{\text{s}}$$

Actuator Loading rate in cyclic

Actuator Loading rate in compression

$$\text{NormDisp} := \begin{bmatrix} 0.01 \\ 0.02 \\ 0.05 \\ 0.1 \\ 0.2 \end{bmatrix} \quad \text{NormDispPeakCycles} := 2 \cdot \begin{bmatrix} \text{NormDisp}_0 \\ \text{NormDisp}_1 \\ \text{NormDisp}_2 \\ \text{NormDisp}_3 \end{bmatrix} = \begin{bmatrix} 0.02 \\ 0.04 \\ 0.1 \\ 0.2 \end{bmatrix}$$

Appendix B

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

Function for calculating time required for each pseudostatic load

$$\begin{aligned}
 &Time(Dia) := \text{for } j \in 0, 1 \dots 3 \\
 &\quad \text{for } i \in 0, 1 \dots 4 \\
 &\quad \quad k \leftarrow NormDisp \\
 &\quad \quad p \leftarrow \frac{Dia}{m} \\
 &\quad \quad z \leftarrow \frac{LoadCycRate}{s} \\
 &\quad \quad x \leftarrow \frac{LoadCompRate}{m} \\
 &\quad \quad q_{0,0} \leftarrow k_{0,0} \cdot \frac{p}{z} \\
 &\quad \quad q_{1,0} \leftarrow k_{1,0} \cdot \frac{p}{z} \\
 &\quad \quad q_{2,0} \leftarrow k_{2,0} \cdot \frac{p}{z} \\
 &\quad \quad q_{3,0} \leftarrow k_{3,0} \cdot \frac{p}{z} \\
 &\quad \quad q_{4,0} \leftarrow k_{4,0} \cdot \frac{p}{x} \\
 &\quad q
 \end{aligned}$$

$$TimeHelix := Time(D) = \begin{bmatrix} 22.86 \\ 45.72 \\ 114.3 \\ 228.6 \\ 1385.455 \end{bmatrix}$$

$$TimeShaft := Time(d) = \begin{bmatrix} 7.62 \\ 15.24 \\ 38.1 \\ 76.2 \\ 461.818 \end{bmatrix}$$

Function for calculating initial time required for each pseudostatic load

$$\begin{aligned}
 &DispIniTime(DispHelixShaft) := \text{for } j \in 0, 1 \dots 3 \\
 &\quad \text{for } i \in 0, 1 \dots 5 \\
 &\quad \quad q_{0,0} \leftarrow 0 \\
 &\quad \quad q_{1,0} \leftarrow \left((16 \cdot DispHelixShaft_{0,0}) + (7 \cdot Lag) + LagCyc \right) \\
 &\quad \quad q_{2,0} \leftarrow q_{1,0} + \left((16 \cdot DispHelixShaft_{1,0}) + (7 \cdot Lag) + (LagCyc) \right) \\
 &\quad \quad q_{3,0} \leftarrow q_{2,0} + \left((16 \cdot DispHelixShaft_{2,0}) + (7 \cdot Lag) + (LagCyc) \right) \\
 &\quad \quad q_{4,0} \leftarrow q_{3,0} + \left((16 \cdot DispHelixShaft_{3,0}) + (7 \cdot Lag) + (LagCyc) \right) \\
 &\quad q
 \end{aligned}$$

$$IniTimeHelix := DispIniTime(TimeHelix) = \begin{bmatrix} 0 \\ 500.76 \\ 1367.28 \\ 3331.08 \\ 7123.68 \end{bmatrix}$$

$$IniTimeShaft := DispIniTime(TimeShaft) = \begin{bmatrix} 0 \\ 256.92 \\ 635.76 \\ 1380.36 \\ 2734.56 \end{bmatrix}$$

Appendix B

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

$PseuPL1H := \begin{bmatrix} TimeHelix_{0,0} & NormDisp_{0,0} \end{bmatrix}$	$IniTimePL1H := DispIniTime(TimeHelix)_{0,0} = 0$	$IniDisp := 0$
$PseuPL2H := \begin{bmatrix} TimeHelix_{1,0} & NormDisp_{1,0} \end{bmatrix}$	$IniTimePL2H := DispIniTime(TimeHelix)_{1,0} = 500.76$	
$PseuPL3H := \begin{bmatrix} TimeHelix_{2,0} & NormDisp_{2,0} \end{bmatrix}$	$IniTimePL3H := DispIniTime(TimeHelix)_{2,0} = 1.367 \cdot 10^3$	
$PseuPL4H := \begin{bmatrix} TimeHelix_{3,0} & NormDisp_{3,0} \end{bmatrix}$	$IniTimePL4H := DispIniTime(TimeHelix)_{3,0} = 3.331 \cdot 10^3$	
$PseuCLH := \begin{bmatrix} TimeHelix_{4,0} & NormDisp_{4,0} \end{bmatrix}$	$IniTimeCLH := DispIniTime(TimeHelix)_{4,0} = 7.124 \cdot 10^3$	
$PseuPL1S := \begin{bmatrix} TimeShaft_{0,0} & NormDisp_{0,0} \end{bmatrix}$	$IniTimePL1S := DispIniTime(TimeShaft)_{0,0} = 0$	$IniDisp := 0$
$PseuPL2S := \begin{bmatrix} TimeShaft_{1,0} & NormDisp_{1,0} \end{bmatrix}$	$IniTimePL2S := DispIniTime(TimeShaft)_{1,0} = 256.92$	
$PseuPL3S := \begin{bmatrix} TimeShaft_{2,0} & NormDisp_{2,0} \end{bmatrix}$	$IniTimePL3S := DispIniTime(TimeShaft)_{2,0} = 635.76$	
$PseuPL4S := \begin{bmatrix} TimeShaft_{3,0} & NormDisp_{3,0} \end{bmatrix}$	$IniTimePL4S := DispIniTime(TimeShaft)_{3,0} = 1.38 \cdot 10^3$	
$PseuCLS := \begin{bmatrix} TimeShaft_{4,0} & NormDisp_{4,0} \end{bmatrix}$	$IniTimeCLS := DispIniTime(TimeShaft)_{4,0} = 2.735 \cdot 10^3$	

Function for calculating time required for each cycle of the pseudostatic loads

```

TimeCycLoop(Pseu1per, IniTimeHelix, IniDisp) :=
  for j ∈ 0, 1..3
    for i ∈ 0, 1..40000
      q0,0 ← IniTimeHelix
      diff ← 0.1
      qi+1,0 ← qi,0 + diff
      q0,1 ← IniDisp
      Lag ← 5
      LagCyc ← 100
      k0,0 ← q0,0
      k1,0 ← ((q0,0 + 4 · Pseu1per0,0) + (2 · Lag))
      k2,0 ← ((q0,0 + 8 · Pseu1per0,0) + (4 · Lag))
      k3,0 ← ((q0,0 + 12 · Pseu1per0,0) + (6 · Lag))
      k4,0 ← ((q0,0 + 16 · Pseu1per0,0) + (7 · Lag) + LagCyc)
    k
  
```


Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

Function for calculating displacement increments for each cycles of the pseudostatic loads

```

DispCyc(Pseu1per, IniTimeHelix, IniDisp) :=
  for j ∈ 0, 1..3
  for i ∈ 0, 1..40000
    q0,0 ← IniTimeHelix
    diff ← 0.1
    qi+1,0 ← qi,0 + diff
    q0,1 ← IniDisp
    Lag ← 5
    LagCyc ← 100
    qi+1,0 ← if qi+1,0 ≤ ((q0,0 + 16 • Pseu1per0,0) + (7 • Lag) + LagCyc)
      || qi+1,0
    else if qi+1,0 > ((q0,0 + 16 • Pseu1per0,0) + (7 • Lag) + LagCyc)
      || break
    qi+1,1 ← if (qi+1,0) ≤ (q0,0 + 2 • Pseu1per0,0)
      ||  $\frac{(q_{i+1,0} - q_{0,0})}{((q_{0,0} + 2 \cdot Pseu1per_{0,0}) - q_{0,0})} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if (q0,0 + 2 • Pseu1per0,0) < qi+1,0 ≤ ((q0,0 + 2 • Pseu1per0,0) + Lag)
      || 2 • Pseu1per0,1
    else if ((q0,0 + 2 • Pseu1per0,0) + Lag) < qi+1,0 ≤ ((q0,0 + 4 • Pseu1per0,0) + Lag)
      ||  $\frac{(((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + Lag) - q_{i+1,0})}{(((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + Lag) - ((q_{0,0} + 2 \cdot Pseu1per_{0,0}) + Lag))} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if ((q0,0 + 4 • Pseu1per0,0) + Lag) < qi+1,0 ≤ ((q0,0 + 4 • Pseu1per0,0) + (2 • Lag))
      || q0,1
    else if ((q0,0 + 4 • Pseu1per0,0) + (2 • Lag)) < qi+1,0 ≤ ((q0,0 + 6 • Pseu1per0,0) + (2 • Lag))
      ||  $\frac{(q_{i+1,0} - ((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + (2 \cdot Lag)))}{(((q_{0,0} + 6 \cdot Pseu1per_{0,0}) + 2 \cdot Lag) - ((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + (2 \cdot Lag)))} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if ((q0,0 + 6 • Pseu1per0,0) + (2 • Lag)) < qi+1,0 ≤ ((q0,0 + 6 • Pseu1per0,0) + (3 • Lag))
      || 2 • Pseu1per0,1
    else if ((q0,0 + 6 • Pseu1per0,0) + (3 • Lag)) < qi+1,0 ≤ ((q0,0 + 8 • Pseu1per0,0) + (3 • Lag))
      ||  $\frac{(((q_{0,0} + 8 \cdot Pseu1per_{0,0}) + (3 \cdot Lag)) - q_{i+1,0})}{(((q_{0,0} + 8 \cdot Pseu1per_{0,0}) + (3 \cdot Lag)) - ((q_{0,0} + 6 \cdot Pseu1per_{0,0}) + (3 \cdot Lag)))} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if ((q0,0 + 8 • Pseu1per0,0) + (3 • Lag)) < qi+1,0 ≤ ((q0,0 + 8 • Pseu1per0,0) + (4 • Lag))
      || q0,1
    else if ((q0,0 + 8 • Pseu1per0,0) + (4 • Lag)) < qi+1,0 ≤ ((q0,0 + 10 • Pseu1per0,0) + (4 • Lag))

```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

8

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

Function for calculating displacement for the monotonic loads

```

DispComp(Pseu1per, IniTime, IniDisp) :=
  for j ∈ 0, 1..3
    for i ∈ 0, 1..40000
      q0,0 ← IniTime
      diff ← 0.1
      qi+1,0 ← qi,0 + diff
      qi+1,0 ← if (qi+1,0) ≤ (q0,0 + Pseu1per0,0)
                || qi+1,0
                || else if qi+1,0 > (q0,0 + Pseu1per0,0)
                || break
      q0,1 ← IniDisp
      qi+1,1 ← if (qi+1,0) ≤ (q0,0 + Pseu1per0,0)
                ||  $\frac{(q_{i+1,0} - q_{0,0})}{((q_{0,0} + Pseu1per_{0,0}) - q_{0,0})} \cdot (Pseu1per_{0,1})$ 
                || else
                || qi+1,1
  q

```

$LdTimePL1H := DispCyc(PseuPL1H, IniTimePL1H, IniDisp)$

$LdTimePL2H := DispCyc(PseuPL2H, IniTimePL2H, IniDisp)$

$LdTimePL3H := DispCyc(PseuPL3H, IniTimePL3H, IniDisp)$

$LdTimePL4H := DispCyc(PseuPL4H, IniTimePL4H, IniDisp)$

$LdTimeCLH := DispComp(PseuCLH, IniTimeCLH, IniDisp)$

Appendix B

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

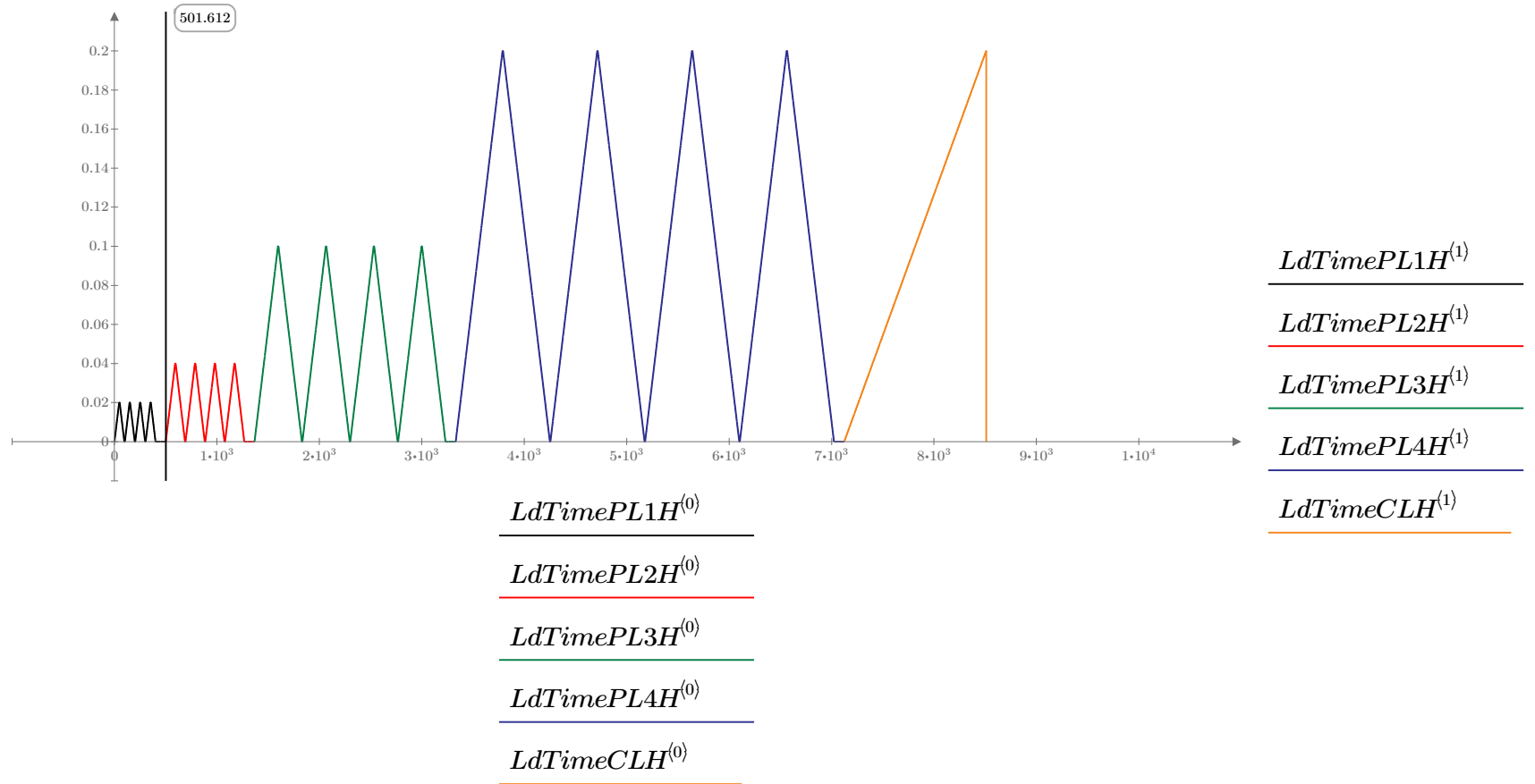


Fig B 1. DisplacementTime History for the Helix Piles

$$LdTimePL1S := DispCyc(PseuPL1S, IniTimePL1S, IniDisp)$$

$$LdTimePL2S := DispCyc(PseuPL2S, IniTimePL2S, IniDisp)$$

$$LdTimePL3S := DispCyc(PseuPL3S, IniTimePL3S, IniDisp)$$

$$LdTimePL4S := DispCyc(PseuPL4S, IniTimePL4S, IniDisp)$$

$$LdTimeCLS := DispComp(PseuCLS, IniTimeCLS, IniDisp)$$

Appendix B

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

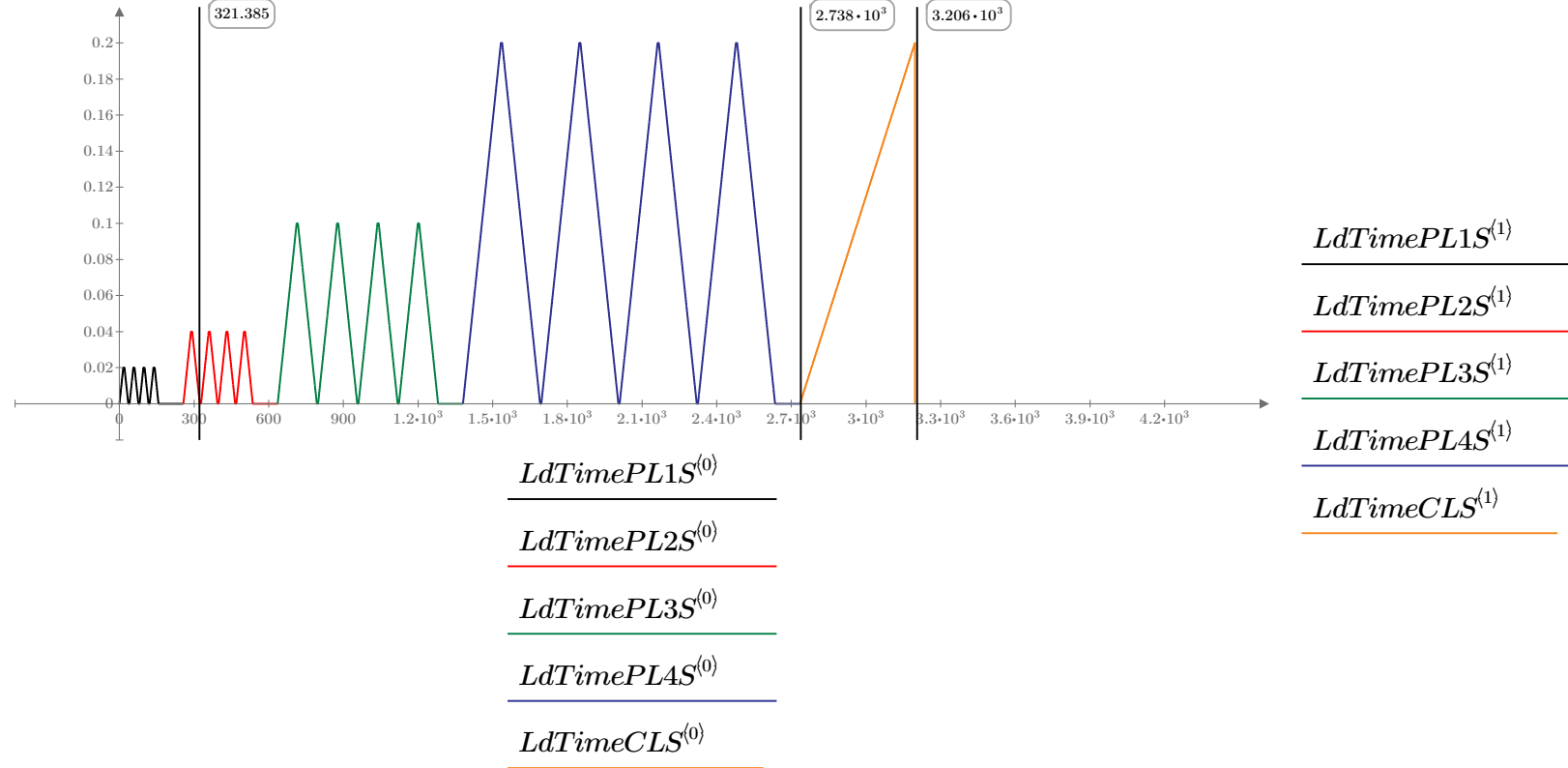


Fig B 2. DisplacementTime History for the Smooth Pile.

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

2.3.2 Axial Load vs Time

Function for determining the Axial Load Distribution in each pile

```

AxLd (Rawdata ,PileNum) :=
  for i ∈ 0,1..rows(Rawdata) - 1
    for j ∈ 0,1..cols(Rawdata) - 1
       $q_{i,j} \leftarrow \text{Rawdata}_{i,j} - \text{Rawdata}_{0,j}$ 
       $SG1_{i,0} \leftarrow q_{i,0} \cdot \text{mean}(\text{submatrix}(CF, 0, 2, \text{PileNum}, \text{PileNum})) \cdot Nscale^{sclfac_{0,1}}$ 
       $SG2_{i,1} \leftarrow q_{i,1} \cdot \text{mean}(\text{submatrix}(CF, 3, 5, \text{PileNum}, \text{PileNum})) \cdot Nscale^{sclfac_{0,1}}$ 
       $SG3_{i,2} \leftarrow q_{i,2} \cdot \text{mean}(\text{submatrix}(CF, 6, 8, \text{PileNum}, \text{PileNum})) \cdot Nscale^{sclfac_{0,1}}$ 
       $SG4_{i,3} \leftarrow q_{i,3} \cdot \text{mean}(\text{submatrix}(CF, 9, 11, \text{PileNum}, \text{PileNum})) \cdot Nscale^{sclfac_{0,1}}$ 
    augment(SG1(0), SG2(1), SG3(2), SG4(3))
  
```

Function for determining the Time, Displacement Input to Time Axial Load Distribution output in each pile

```

TDispTLd (LdTime1perS ,TimeP0 ,AxLdP0 ,LdNo) :=
  m ← TimeP0
  n ← AxLdP0
  p ← LdTime1perS
  q ← if LdNo = 1
     $m_0$ 
  else if LdNo = 2
     $m_1$ 
  else if LdNo = 3
     $m_2$ 
  else if LdNo = 4
     $m_3$ 
  else if LdNo = 5
     $m_4$ 
  k ← if LdNo = 1
     $n_0$ 
  else if LdNo = 2
     $n_1$ 
  else if LdNo = 3
     $n_2$ 
  else if LdNo = 4
     $n_3$ 
  else if LdNo = 5
     $n_4$ 
  
```


Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

$$\begin{aligned}
 & \left\| \begin{aligned} & o \leftarrow \begin{cases} \text{if rows}(p) > \text{rows}(q) \\ & q \\ \text{else if rows}(p) < \text{rows}(q) \\ & p \end{cases} \end{aligned} \right\| \\
 & tdisp \leftarrow \text{submatrix} \left(LdTime1perS^{(0)}, 0, \text{rows}(o) - 1, 0, 0 \right) \\
 & disp \leftarrow \text{submatrix} \left(-LdTime1perS^{(1)}, 0, \text{rows}(o) - 1, 0, 0 \right) \\
 & tld \leftarrow \left\| \text{submatrix} \left(\frac{q}{s}, 0, \text{rows}(o) - 1, 0, 0 \right) \right\| \\
 & ld1 \leftarrow \text{medsmooth} \left(\text{submatrix} \left(\frac{k^{(0)}}{kN}, 0, \text{rows}(o) - 1, 0, 0 \right), 11 \right) \\
 & ld2 \leftarrow \text{medsmooth} \left(\text{submatrix} \left(\frac{k^{(1)}}{kN}, 0, \text{rows}(o) - 1, 0, 0 \right), 11 \right) \\
 & ld3 \leftarrow \text{medsmooth} \left(\text{submatrix} \left(\frac{k^{(2)}}{kN}, 0, \text{rows}(o) - 1, 0, 0 \right), 11 \right) \\
 & ld4 \leftarrow \text{medsmooth} \left(\text{submatrix} \left(\frac{k^{(3)}}{kN}, 0, \text{rows}(o) - 1, 0, 0 \right), 11 \right) \\
 & \text{augment} \left(tdisp, disp, tld, ld1, ld2, ld3, ld4 \right)
 \end{aligned}$$

There were two strain gages placed within the P0 pile. The following sub sections provides the details on the load distributions:

$$P0HBM := \left[\begin{array}{l} \text{READEXCEL} \left(".\backslash \text{NI02 HBM Data.xlsx}", "P0_PL1!A1:E2756" \right) \\ \text{READEXCEL} \left(".\backslash \text{NI02 HBM Data.xlsx}", "P0_PL2!A1:E3941" \right) \\ \text{READEXCEL} \left(".\backslash \text{NI02 HBM Data.xlsx}", "P0_PL3!A1:E7570" \right) \\ \text{READEXCEL} \left(".\backslash \text{NI02 HBM Data.xlsx}", "P0_PL4!A1:E12971" \right) \\ \text{READEXCEL} \left(".\backslash \text{NI02 HBM Data.xlsx}", "P0_CL!A1:E6743" \right) \end{array} \right] = \left[\begin{array}{l} [2756 \times 5] \\ [3941 \times 5] \\ [7570 \times 5] \\ [12971 \times 5] \\ [6743 \times 5] \end{array} \right]$$

$$TimeP0 := \left\| \begin{aligned} & \text{for } i \in 0, 1 \dots 4 \\ & \left\| q_i \leftarrow \text{submatrix} \left(P0HBM_i, 0, \text{rows}(P0HBM_i) - 1, 0, 0 \right) s \right\| \end{aligned} \right\| = \left[\begin{array}{l} [2756 \times 1] s \\ [3941 \times 1] s \\ [7570 \times 1] s \\ [12971 \times 1] s \\ [6743 \times 1] s \end{array} \right] s$$

$$RawdataP0 := \left\| \begin{aligned} & \text{for } i \in 0, 1 \dots 4 \\ & \left\| q_i \leftarrow \text{submatrix} \left(P0HBM_i, 0, \text{rows}(P0HBM_i) - 1, 1, 4 \right) \frac{mV}{V} \right\| \end{aligned} \right\| = \left[\begin{array}{l} [2756 \times 4] \\ [3941 \times 4] \\ [7570 \times 4] \\ [12971 \times 4] \\ [6743 \times 4] \end{array} \right]$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

$$AxLdP0 := \left\| \begin{array}{l} \text{for } i \in 0, 1 \dots 4 \\ \left\| q_i \leftarrow AxLd \left(RawdataP0_i, 0 \right) \right\| \\ q \end{array} \right\| = \begin{bmatrix} [2756 \times 4] \\ [3941 \times 4] \\ [7570 \times 4] \\ [12971 \times 4] \\ [6743 \times 4] \end{bmatrix} \text{ kN}$$

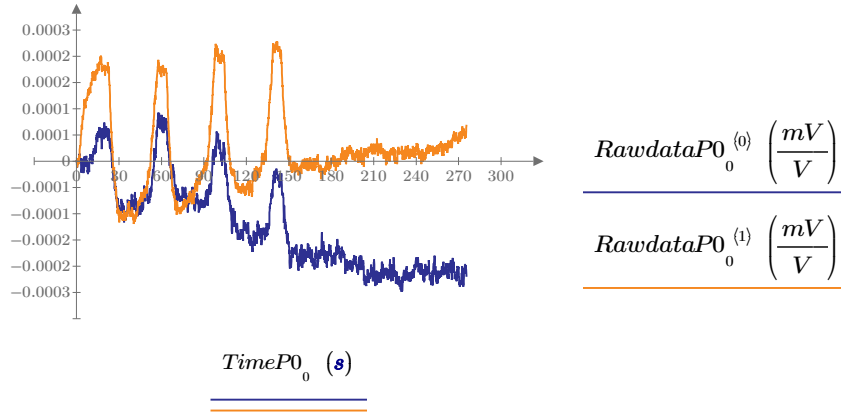


Fig B 3. Rawdata time history for compression pile P0 PL1

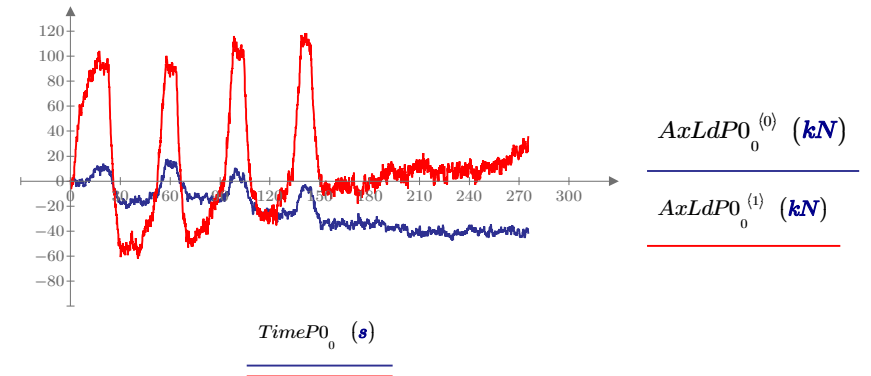


Fig B 4. Load time history for compression pile P0 PL1

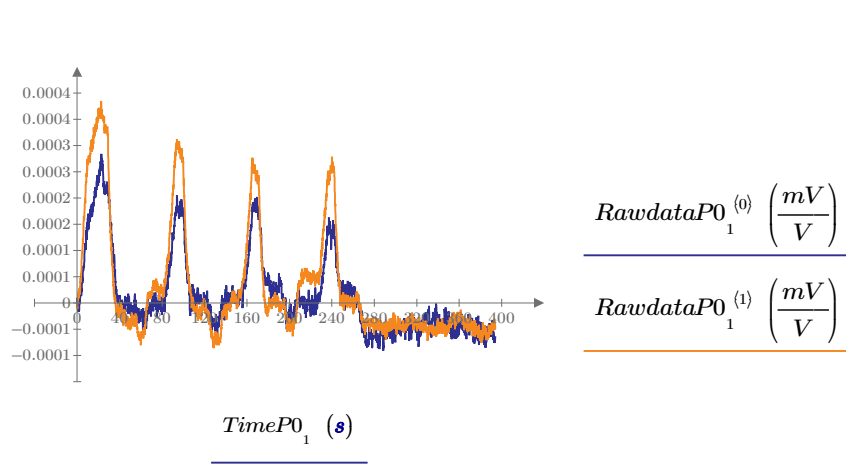


Fig B 5. Rawdata time history for compression pile P0 PL1

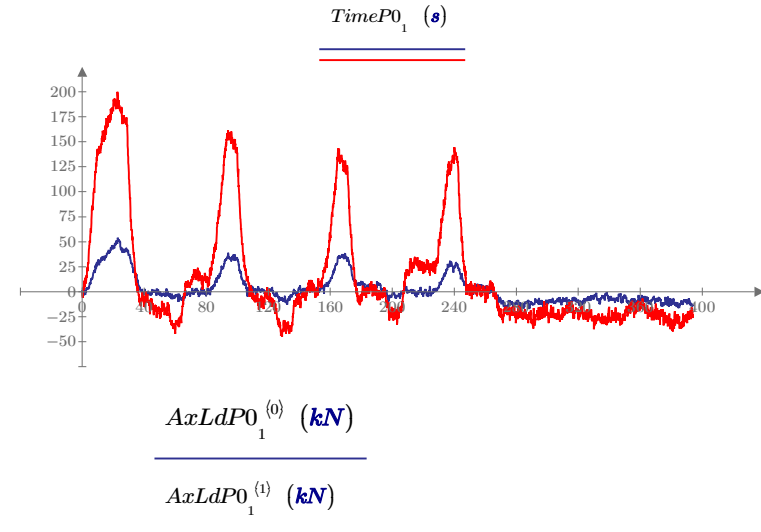


Fig B 6. Load time history for compression pile P0 PL1

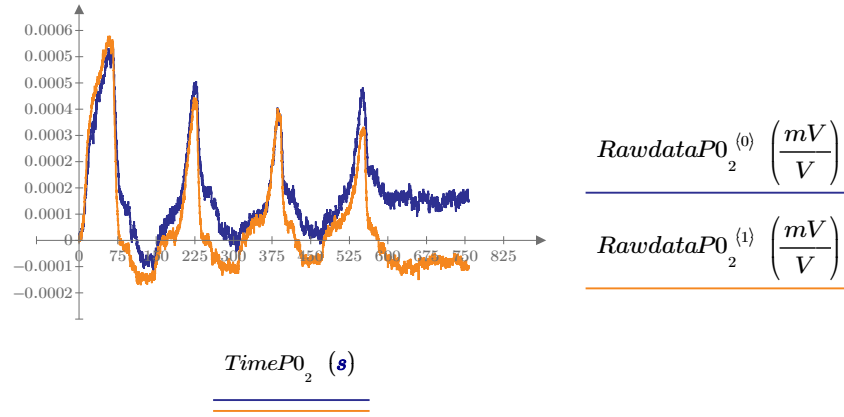


Fig B 7. Rawdata time history for compression pile P0 PL3

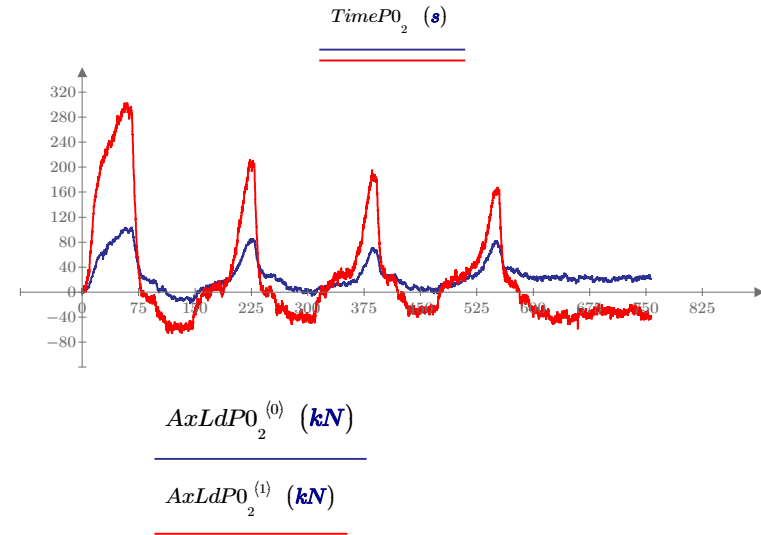


Fig B 8. Load time history for compression pile P0 PL3

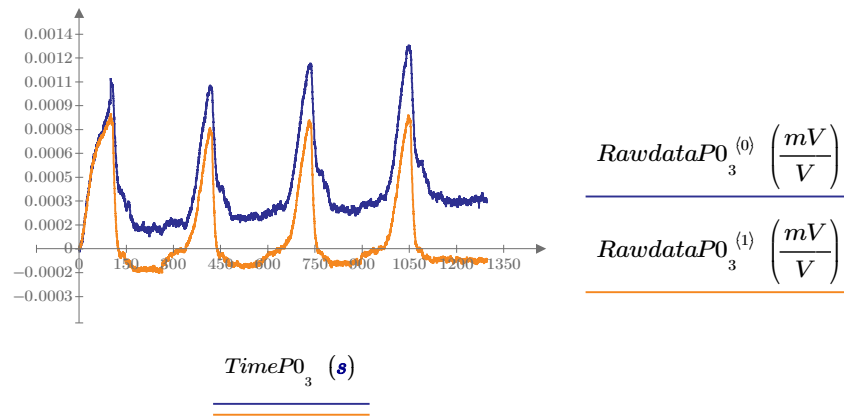


Fig B 9. Rawdata time history for compression pile P0 PL4

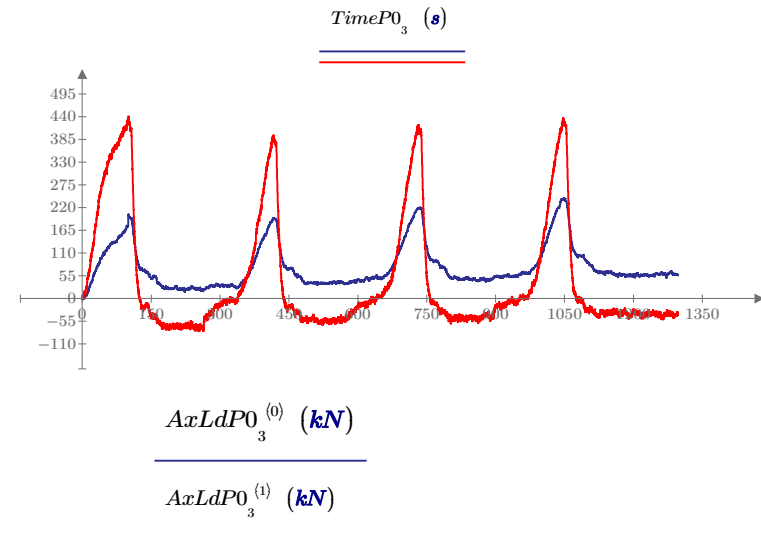


Fig B 10. Load time history for compression pile P0 PL4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

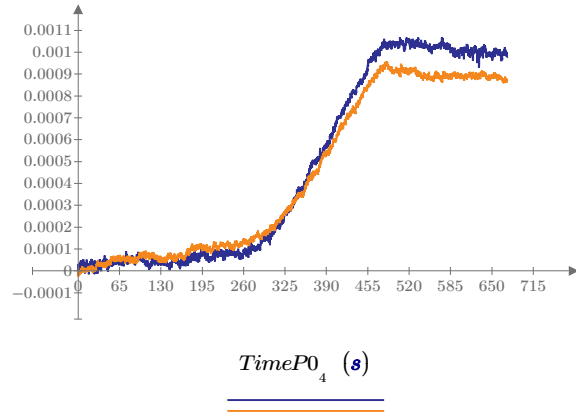


Fig B 11. Rawdata time history for compression pile P0 CL

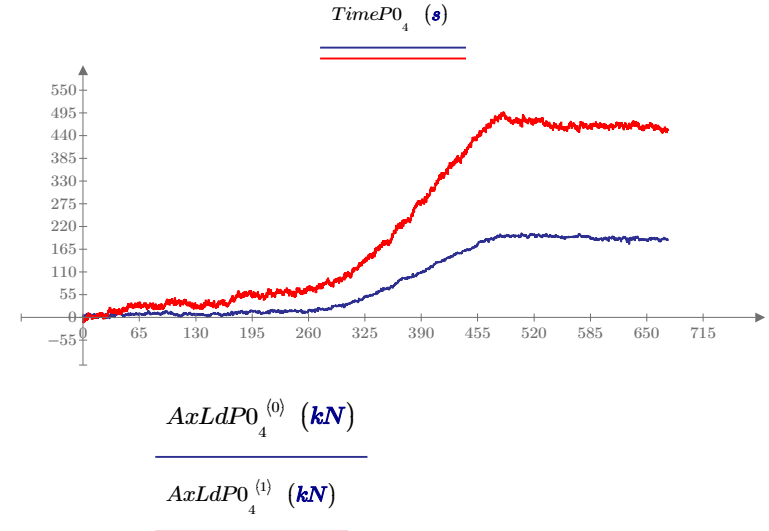


Fig B 12. Load time history for compression pile P0 CL

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for psuedostatic load PL1

$TDispTLdP0PL1 := TDispTLd(LdTimePL1S, TimeP0, AxLdP0, 1) =$

$$\begin{matrix} 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ \vdots \\ 2570 \end{matrix} \begin{bmatrix} 0 & 0 & 0 & -0.272 & -2.245 & 0 & 0 \\ 0.1 & -1.312 \cdot 10^{-4} & 0.1 & -0.544 & -4.491 & 0 & 0 \\ 0.2 & -2.625 \cdot 10^{-4} & 0.2 & -0.544 & -3.368 & 0 & 0 \\ 0.3 & -3.937 \cdot 10^{-4} & 0.3 & -0.544 & -3.742 & 0 & 0 \\ 0.4 & -5.249 \cdot 10^{-4} & 0.4 & -0.544 & -3.742 & 0 & 0 \\ 0.5 & -6.562 \cdot 10^{-4} & 0.5 & -0.544 & -3.742 & 0 & 0 \\ 0.6 & -7.874 \cdot 10^{-4} & 0.6 & -0.544 & -3.742 & 0 & 0 \\ 0.7 & -9.186 \cdot 10^{-4} & 0.7 & -0.544 & -3.742 & 0 & 0 \\ 0.8 & -0.001 & 0.8 & -0.272 & -3.742 & 0 & 0 \\ 0.9 & -0.001 & 0.9 & -0.272 & -2.245 & 0 & 0 \\ 1 & -0.001 & 1 & -0.272 & -2.245 & 0 & 0 \\ 1.1 & -0.001 & 1.1 & 0 & -2.245 & 0 & 0 \\ \vdots & & & & & & \vdots \end{bmatrix}$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

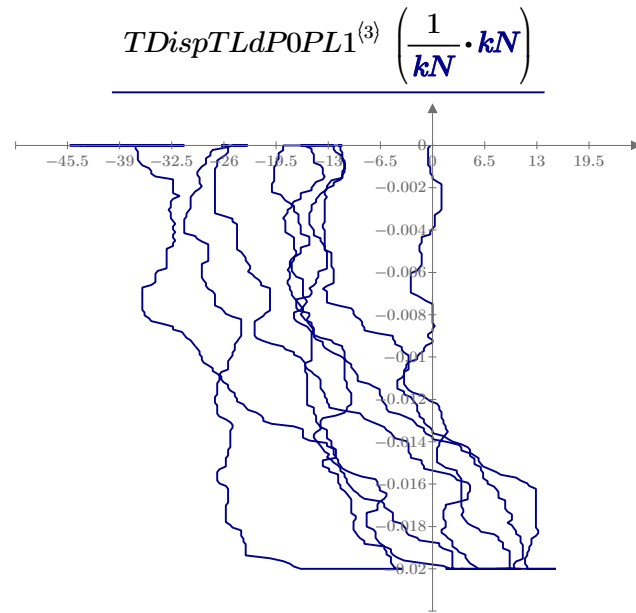


Fig B 13. Load displacement for compression pile P0PL1 SG1

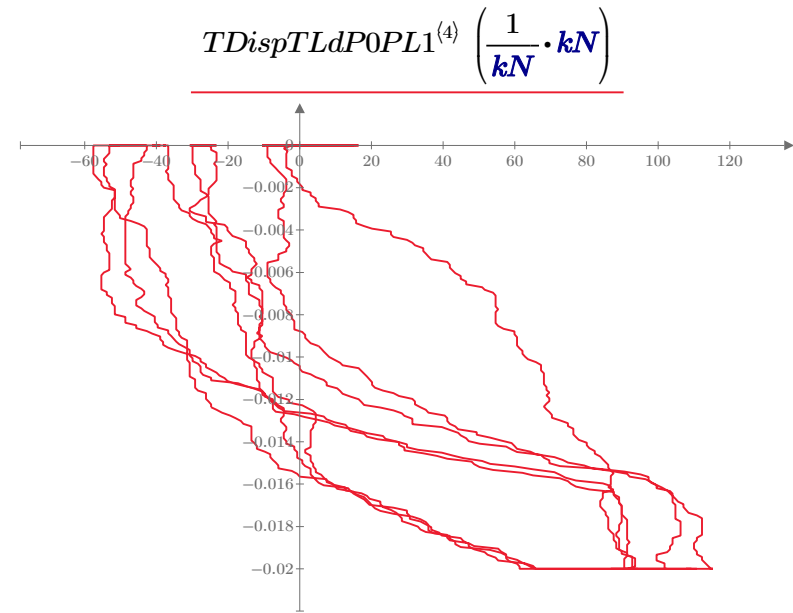


Fig B 14. Load displacement for compression pile P0PL1 SG2

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for psuedostatic load PL2

$$TDispTLdP0PL2 := TDispTLd(LdTimePL2S, TimeP0, AxLdP0, 2) =$$

0	256.92	0	0	0.274	-2.62	0	0
1	257.02	$-1.312 \cdot 10^{-4}$	0.1	0	-2.245	0	0
2	257.12	$-2.625 \cdot 10^{-4}$	0.2	0	-1.123	0	0
3	257.22	$-3.937 \cdot 10^{-4}$	0.3	0	0	0	0
4	257.32	$-5.249 \cdot 10^{-4}$	0.4	0	0	0	0
5	257.42	$-6.562 \cdot 10^{-4}$	0.5	0	0	0	0
6	257.52	$-7.874 \cdot 10^{-4}$	0.6	0	0.748	0	0
7	257.62	$-9.186 \cdot 10^{-4}$	0.7	0	2.245	0	0
8	257.72	-0.001	0.8	-0.274	2.245	0	0
9	257.82	-0.001	0.9	-1.097	2.994	0	0
10	257.92	-0.001	1	-2.193	5.239	0	0
11	258.02	-0.001	1.1	-2.193	5.239	0	0
⋮							⋮

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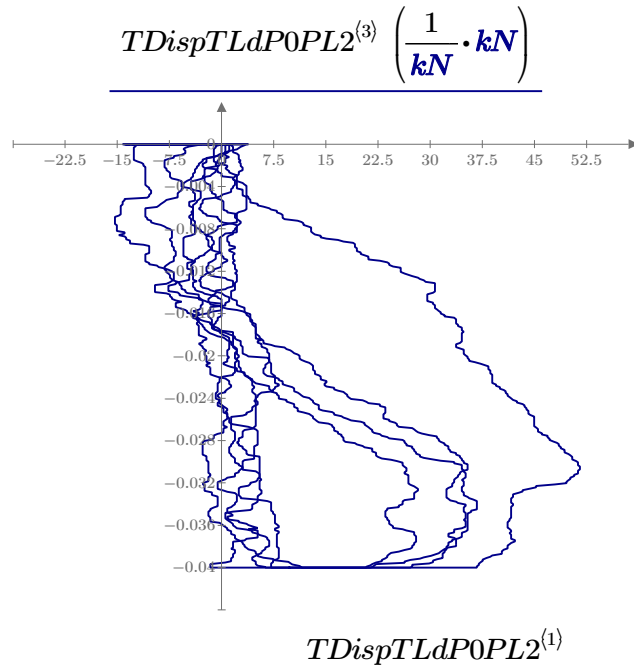


Fig B 15. Load displacement for compression pile P0PL2 SG1

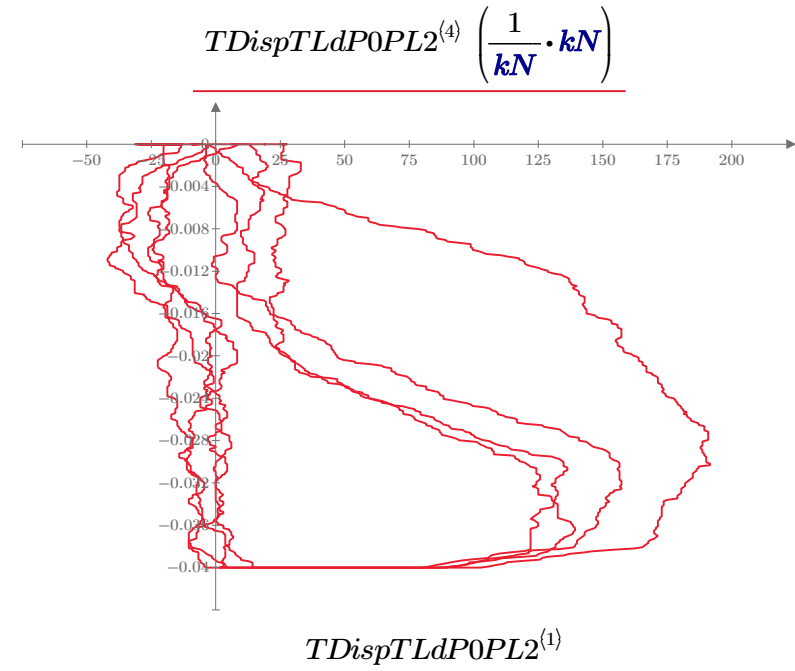


Fig B 16. Load displacement for compression pile P0PL2 SG2

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for psuedostatic load PL3

$$TDispTLdP0PL3 := TDispTLd(LdTimePL3S, TimeP0, AxLdP0, 3) =$$

0	635.76	0	0	0.274	4.117	0	0
1	635.86	$-1.312 \cdot 10^{-4}$	0.1	0.548	3.742	0	0
2	635.96	$-2.625 \cdot 10^{-4}$	0.2	0.548	4.117	0	0
3	636.06	$-3.937 \cdot 10^{-4}$	0.3	0.548	3.742	0	0
4	636.16	$-5.249 \cdot 10^{-4}$	0.4	0.822	2.994	0	0
5	636.26	$-6.562 \cdot 10^{-4}$	0.5	1.097	2.245	0	0
6	636.36	$-7.874 \cdot 10^{-4}$	0.6	1.371	2.245	0	0
7	636.46	$-9.186 \cdot 10^{-4}$	0.7	1.919	3.742	0	0
8	636.56	-0.001	0.8	1.919	3.742	0	0
9	636.66	-0.001	0.9	2.193	2.245	0	0
10	636.76	-0.001	1	2.193	2.245	0	0
11	636.86	-0.001	1.1	3.29	2.245	0	0
⋮							⋮

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Appendix B

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

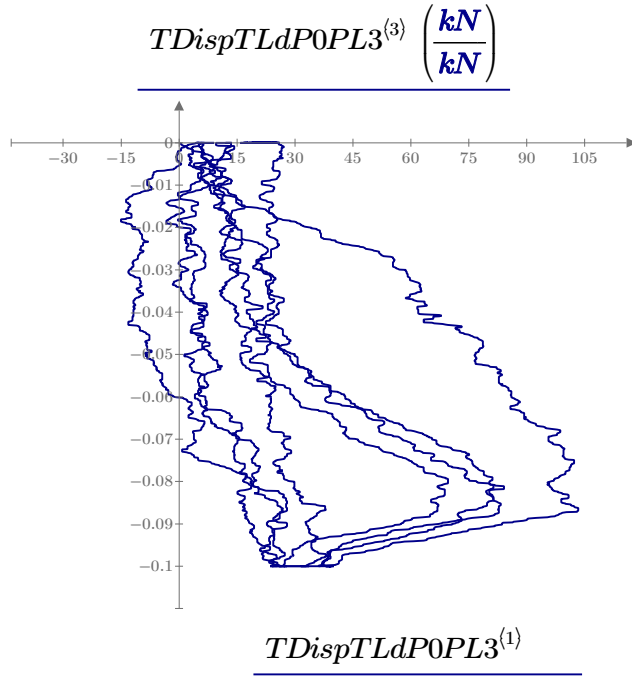


Fig B 17. Load displacement for compression pile P0PL3 SG1

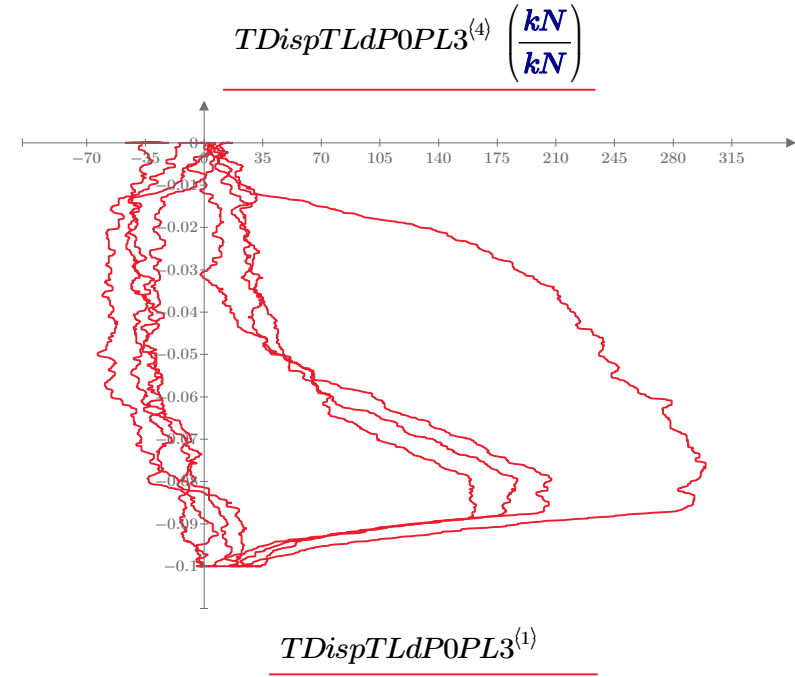


Fig B 18. Load displacement for compression pile P0PL3 SG2

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for pseudostatic load PL4

$$TDispTLdP0PL4 := TDispTLd(LdTimePL4S, TimeP0, AxLdP0, 4) =$$

0	$1.38 \cdot 10^3$	0	0	-0.137	0.374	0	0
1	$1.38 \cdot 10^3$	$-1.312 \cdot 10^{-4}$	0.1	-0.274	0.748	0	0
2	$1.381 \cdot 10^3$	$-2.625 \cdot 10^{-4}$	0.2	-0.548	0.374	0	0
3	$1.381 \cdot 10^3$	$-3.937 \cdot 10^{-4}$	0.3	-0.822	0.748	0	0
4	$1.381 \cdot 10^3$	$-5.249 \cdot 10^{-4}$	0.4	-0.822	1.497	0	0
5	$1.381 \cdot 10^3$	$-6.562 \cdot 10^{-4}$	0.5	-0.822	2.245	0	0
6	$1.381 \cdot 10^3$	$-7.874 \cdot 10^{-4}$	0.6	-0.822	2.245	0	0
7	$1.381 \cdot 10^3$	$-9.186 \cdot 10^{-4}$	0.7	-0.274	2.245	0	0
8	$1.381 \cdot 10^3$	-0.001	0.8	-0.274	2.245	0	0
9	$1.381 \cdot 10^3$	-0.001	0.9	0	3.742	0	0
10	$1.381 \cdot 10^3$	-0.001	1	0	3.742	0	0
11	$1.381 \cdot 10^3$	-0.001	1.1	-0.274	3.742	0	0
⋮							⋮

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

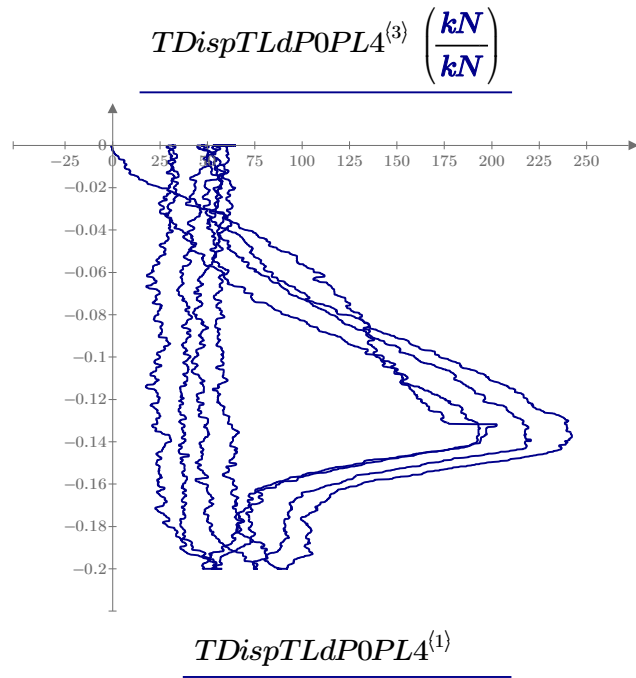


Fig B 19. Load displacement for compression pile P0PL4 SG1

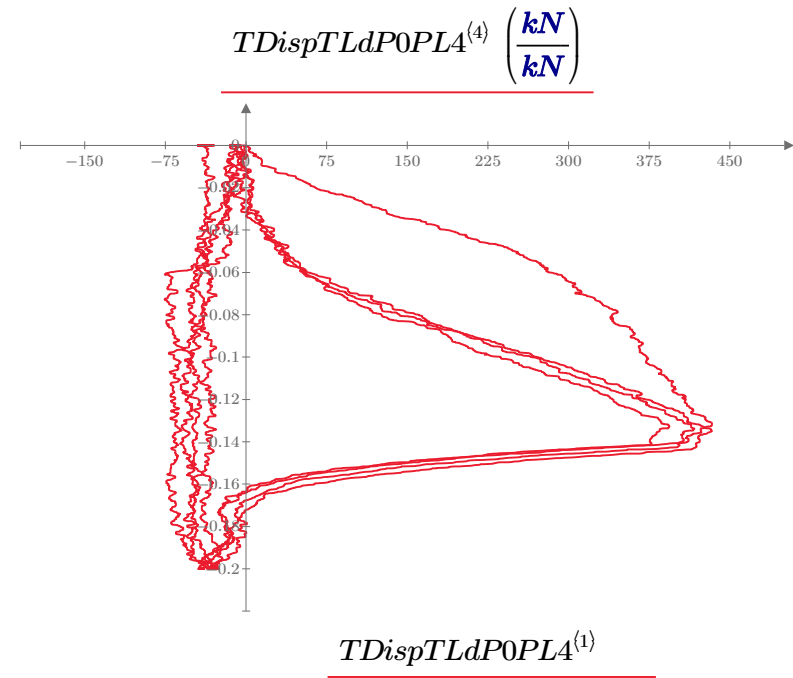


Fig B 20. Load displacement for compression pile P0PL4 SG2

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for post cyclic compressive load CL

$$TDispTLdP0CL := TDispTLd(LdTimeCLS, TimeP0, AxLdP0, 5) =$$

$$\begin{matrix} 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ \vdots \\ 1610 \end{matrix} \begin{bmatrix} 2.735 \cdot 10^3 & 0 & 0 & 4.66 & -4.491 & 0 & 0 \\ 2.735 \cdot 10^3 & -4.331 \cdot 10^{-5} & 0.1 & 4.66 & -4.491 & 0 & 0 \\ 2.735 \cdot 10^3 & -8.661 \cdot 10^{-5} & 0.2 & 3.838 & -4.491 & 0 & 0 \\ 2.735 \cdot 10^3 & -1.299 \cdot 10^{-4} & 0.3 & 3.015 & -4.491 & 0 & 0 \\ 2.735 \cdot 10^3 & -1.732 \cdot 10^{-4} & 0.4 & 2.878 & -4.491 & 0 & 0 \\ 2.735 \cdot 10^3 & -2.165 \cdot 10^{-4} & 0.5 & 2.741 & -4.491 & 0 & 0 \\ 2.735 \cdot 10^3 & -2.598 \cdot 10^{-4} & 0.6 & 3.015 & -4.491 & 0 & 0 \\ 2.735 \cdot 10^3 & -3.031 \cdot 10^{-4} & 0.7 & 3.564 & -6.736 & 0 & 0 \\ 2.735 \cdot 10^3 & -3.465 \cdot 10^{-4} & 0.8 & 3.564 & -6.736 & 0 & 0 \\ 2.735 \cdot 10^3 & -3.898 \cdot 10^{-4} & 0.9 & 3.564 & -6.736 & 0 & 0 \\ 2.736 \cdot 10^3 & -4.331 \cdot 10^{-4} & 1 & 3.564 & -5.988 & 0 & 0 \\ 2.736 \cdot 10^3 & -4.764 \cdot 10^{-4} & 1.1 & 3.564 & -5.239 & 0 & 0 \\ \vdots & & & & & & \vdots \end{bmatrix}$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

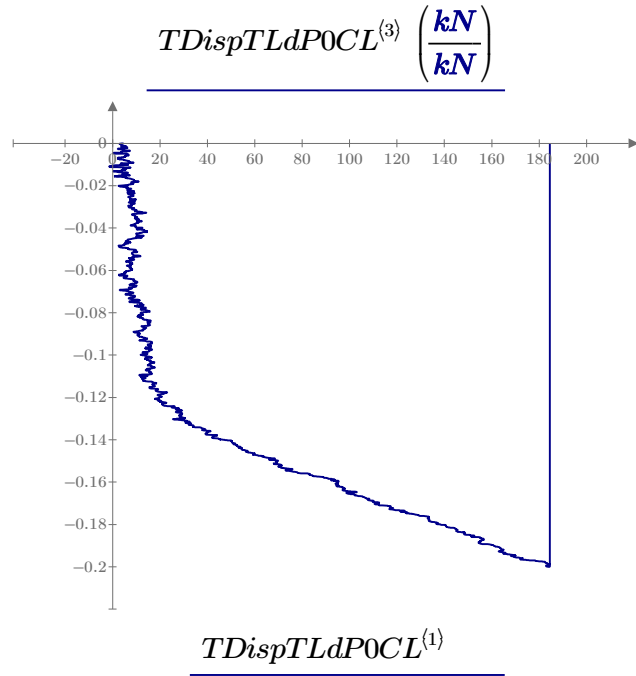


Fig B 21. Load displacement for compression pile P0CL SG1

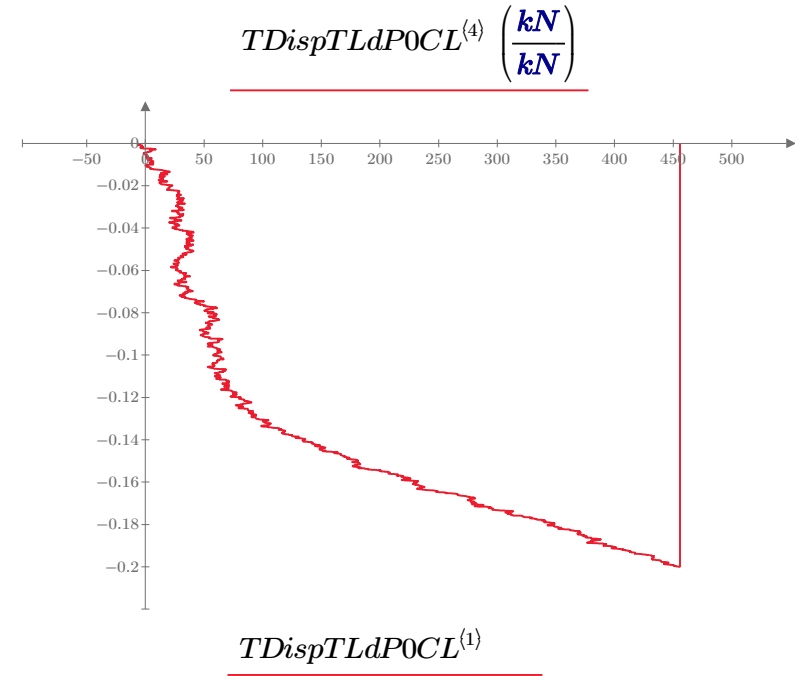


Fig B 22. Load displacement for compression pile P0CL SG2

Functions for determining the Qult profile from strain gauge location

TOL := 0.00000001

```
SGplotQP(TDispTLdP0CL, PileNum) :=
  QP0 ← if PileNum = 0
    || lookup(-0.15, TDispTLdP0CL(1), TDispTLdP0CL(3), "near")
  else
    || lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(3), "near")
  QP1 ← if PileNum = 0
    || lookup(-0.15, TDispTLdP0CL(1), TDispTLdP0CL(4), "near")
  else
    || lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(4), "near")
  QP2 ← lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(5), "near")
  QP3 ← lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(6), "near")
  combined ← if PileNum = 0
    || stack(QP0, QP1, QP1, QP1, QP1, QP1)
  else if PileNum = 1
    || stack(QP0, QP1, QP1, QP2, QP2, QP2)
  else
    || stack(QP0, QP1, QP1, QP2, QP2, QP3)
  combined
```

Appendix B Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

$$SGPlotQPOCL := SGplotQP(TDispTLdP0CL, 0) \text{ } \mathbf{kN} = \begin{bmatrix} 69.63 \\ 181.135 \\ 181.135 \\ 181.135 \\ 181.135 \\ 181.135 \end{bmatrix} \text{ } \mathbf{kN}$$

$$SGEmbDP := - \begin{bmatrix} 0.6 + 3.5 & 0.6 + 3.5 & 0.6 + 3.5 & 0.6 + 3.5 & 0.6 + 3.5 \\ 0.6 & 0.6 + 3 & 0.6 + 3 & 0.6 + 2 & 0.6 + 3 \\ 0 & 0.6 + 3 & 0.6 + 3 & 0.6 + 2 & 0.6 + 3 \\ 0 & 0.6 & 0.6 + 2 & 0.6 + 1 & 0.6 + 1 \\ 0 & 0 & 0.6 + 2 & 0.6 + 1 & 0.6 + 1 \\ 0 & 0 & 0.6 & 0.6 & 0.6 \end{bmatrix} \cdot D \cdot Nscale^{scale_{0,0}}$$

SG embedment depth in prototype scale. Here, colm 0-4 represents P0 to P4. Row 0 to 5 represents depth to strain SG 1 to 4

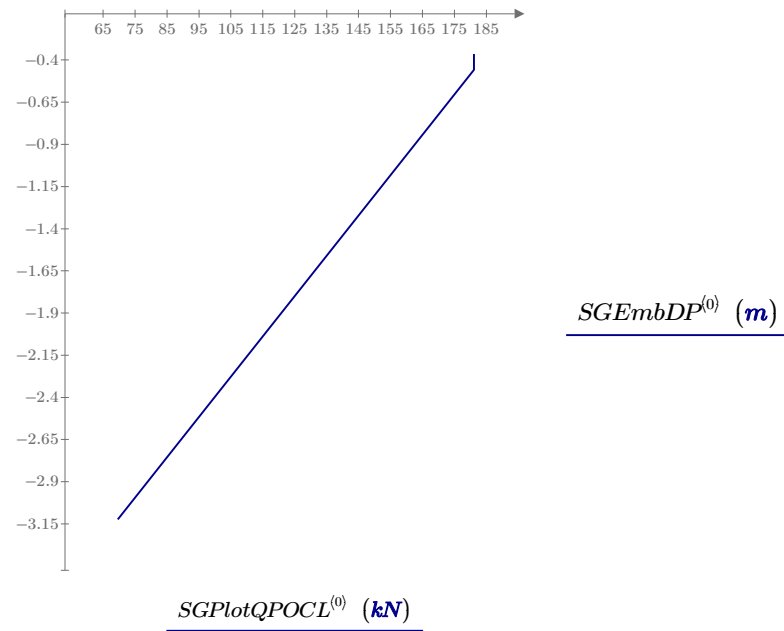


Fig B 23. SG Depth vs Axial Load for all compression piles

Appendix B

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

Functions for calculating EDR from the load displacement curve for each cycles and each pseudostatic loads

TOL := 0.00000001

```

EDR(TDispTLdP0PL1, Pseu1perS, IniTime, IniDisp, LoopNo, SGNo) :=
  m ← TDispTLdP0PL1
  o ← TimeCycLoop(Pseu1perS, IniTime, IniDisp) - IniTime
  w ← -m(1)
  wmax ← max(-m(1))
  if SGNo = 1
    q ← m(3)
    qmax ← max(m(3))
  else if SGNo = 2
    q ← m(4)
    qmax ← max(m(4))
  else if SGNo = 3
    q ← m(5)
    qmax ← max(m(5))
  else if SGNo = 4
    q ← m(6)
    qmax ← max(m(6))
  if LoopNo = 1
    t1 ← m1,0 - IniTime
    t2 ← o1
  else if LoopNo = 2
    t1 ← o1
    t2 ← o2
  else if LoopNo = 3
    t1 ← o2
    t2 ← o3
  else if LoopNo = 4
    t1 ← o3
    t2 ← o4
  tstart ← lookup(t1, (m(0) - IniTime), (m(0) - IniTime), "near")
  tend ← lookup(t2, (m(0) - IniTime), (m(0) - IniTime), "near")
  rowstart ← match(t1, (m(0) - IniTime), "near")
  rowend ← match(t2, (m(0) - IniTime), "near")
  for i ∈ rowstart0,0 .. rowend0,0
    ri ← ((wi - wi-1) * ((qi + qi-1)) / 2)

```

Appendix B

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

```

area ← ∑ r
EDR ← if qmax = 0
      if wmax = 0
        0
      else
        area
        qmax · wmax
s ← augment((tstart + IniTime), (tend + IniTime), rowstart, rowend, qmax, wmax, area, EDR)
EDR

```

Functions for combining EDR from the load displacement curve for each cycles and each pseudostatic loads

```

EDRPOPLSG(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, PileNo) :=
q1 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1)
q2 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1)
q3 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1)
q4 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1)
r1 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2)
r2 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2)
r3 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2)
r4 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2)
w1 ← if PileNo = 0
      0
    else
      EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 3)
w2 ← if PileNo = 0
      0
    else
      EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 3)
w3 ← if PileNo = 0
      0
    else
      EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 3)
w4 ← if PileNo = 0
      0
    else
      EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3)
s1 ← if PileNo = 0
      0
    else if PileNo = 1
      0
    else
      EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 4)

```

Appendix B

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

$$NoLoop := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

```

s2 ← if PileNo = 0
    0
else if PileNo = 1
    0
else
    EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 4)
s3 ← if PileNo = 0
    0
else if PileNo = 1
    0
else
    EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 4)
s4 ← if PileNo = 0
    0
else if PileNo = 1
    0
else
    EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 4)
augment(stack(q1, q2, q3, q4), stack(r1, r2, r3, r4), stack(w1, w2, w3, w4), stack(s1, s2, s3, s4))

```

$$EDRP0PL1 := EDRPOPLSG(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, 0) = \begin{bmatrix} 0.53 & 0.514 & 0 & 0 \\ -0.608 & -0.171 & 0 & 0 \\ 0.043 & -0.254 & 0 & 0 \\ -0.176 & -0.309 & 0 & 0 \end{bmatrix}$$

$$EDRP0PL2 := EDRPOPLSG(TDispTLdP0PL2, PseuPL2S, IniTimePL2S, 0) = \begin{bmatrix} 0.635 & 0.78 & 0 & 0 \\ 0.312 & 0.458 & 0 & 0 \\ 0.234 & 0.313 & 0 & 0 \\ 0.223 & 0.356 & 0 & 0 \end{bmatrix}$$

$$EDRP0PL3 := EDRPOPLSG(TDispTLdP0PL3, PseuPL3S, IniTimePL3S, 0) = \begin{bmatrix} 0.611 & 0.751 & 0 & 0 \\ 0.249 & 0.311 & 0 & 0 \\ 0.17 & 0.274 & 0 & 0 \\ 0.109 & 0.289 & 0 & 0 \end{bmatrix}$$

Appendix B

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

$$EDRP0PL4 := EDRPOPLSG(TDispTLdP0PL4, PseuPL4S, IniTimePL4S, 0) = \begin{bmatrix} 0.298 & 0.59 & 0 & 0 \\ 0.213 & 0.35 & 0 & 0 \\ 0.263 & 0.371 & 0 & 0 \\ 0.277 & 0.391 & 0 & 0 \end{bmatrix}$$

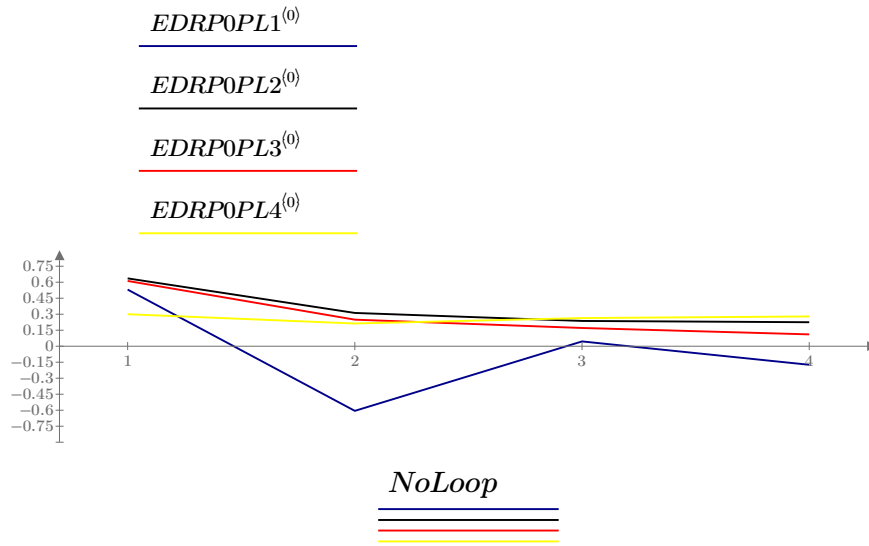


Fig B 24. EDR Load vs No of loops SG1

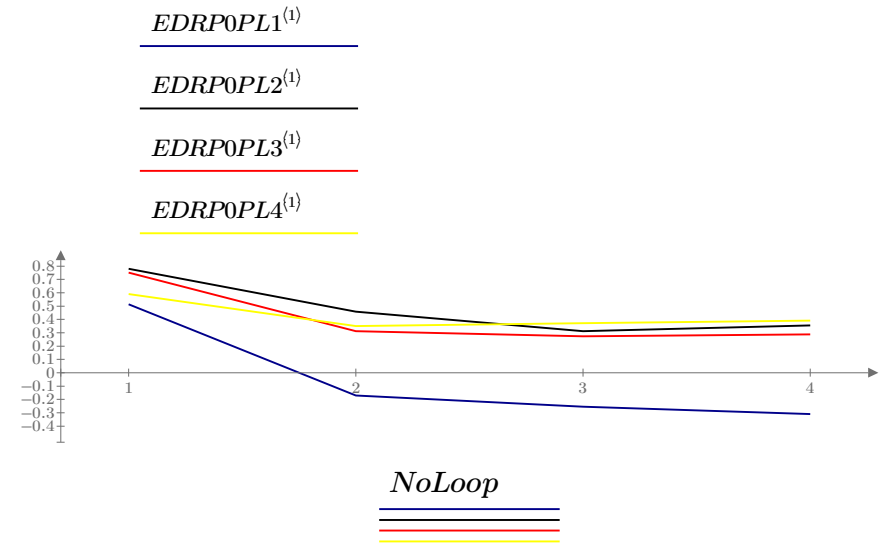


Fig B 25. EDR Load vs No of loops SG2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

Functions for disintegrating the load-displacement curves into separate cycles

```

DispLd (TDispTLdP0PL1, Pseu1perS, IniTime, IniDisp, LoopNo, SGNo) :=
    m ← TDispTLdP0PL1
    o ← TimeCycLoop(Pseu1perS, IniTime, IniDisp) – IniTime
    w ← m(1)
    if SGNo = 1
        q ← m(3)
    else if SGNo = 2
        q ← m(4)
    else if SGNo = 3
        q ← m(5)
    else if SGNo = 4
        q ← m(6)
    if LoopNo = 1
        t1 ← o0
        t2 ← o1
    else if LoopNo = 2
        t1 ← o1
        t2 ← o2
    else if LoopNo = 3
        t1 ← o2
        t2 ← o3
    else if LoopNo = 4
        t1 ← o3
        t2 ← o4
    tstart ← lookup(t1, (m(0) – IniTime), (m(0) – IniTime), “near”)
    tend ← lookup(t2, (m(0) – IniTime), (m(0) – IniTime), “near”)
    rowstart ← match(t1, (m(0) – IniTime), “near”)
    rowend ← match(t2, (m(0) – IniTime), “near”)
    for i ∈ rowstart0,0 .. rowend0,0
        di ← w
        ldi ← qi
    augment(d, ld • kN)

```

Appendix B
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

$DispLdP0PL1L1SG1 := DispLd(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1)$

$DispLdP0PL1L2SG1 := DispLd(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1)$

$DispLdP0PL1L3SG1 := DispLd(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1)$

$DispLdP0PL1L4SG1 := DispLd(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1)$

$DispLdP0PL2L1SG1 := DispLd(TDispTLdP0PL2, PseuPL2S, IniTimePL2S, IniDisp, 1, 1)$

$DispLdP0PL2L2SG1 := DispLd(TDispTLdP0PL2, PseuPL2S, IniTimePL2S, IniDisp, 2, 1)$

$DispLdP0PL2L3SG1 := DispLd(TDispTLdP0PL2, PseuPL2S, IniTimePL2S, IniDisp, 3, 1)$

$DispLdP0PL2L4SG1 := DispLd(TDispTLdP0PL2, PseuPL2S, IniTimePL2S, IniDisp, 4, 1)$

$DispLdP0PL3L1SG1 := DispLd(TDispTLdP0PL3, PseuPL3S, IniTimePL3S, IniDisp, 1, 1)$

$DispLdP0PL3L2SG1 := DispLd(TDispTLdP0PL3, PseuPL3S, IniTimePL3S, IniDisp, 2, 1)$

$DispLdP0PL3L3SG1 := DispLd(TDispTLdP0PL3, PseuPL3S, IniTimePL3S, IniDisp, 3, 1)$

$DispLdP0PL3L4SG1 := DispLd(TDispTLdP0PL3, PseuPL3S, IniTimePL3S, IniDisp, 4, 1)$

$DispLdP0PL4L1SG1 := DispLd(TDispTLdP0PL4, PseuPL4S, IniTimePL4S, IniDisp, 1, 1)$

$DispLdP0PL4L2SG1 := DispLd(TDispTLdP0PL4, PseuPL4S, IniTimePL4S, IniDisp, 2, 1)$

$DispLdP0PL4L3SG1 := DispLd(TDispTLdP0PL4, PseuPL4S, IniTimePL4S, IniDisp, 3, 1)$

$DispLdP0PL4L4SG1 := DispLd(TDispTLdP0PL4, PseuPL4S, IniTimePL4S, IniDisp, 4, 1)$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

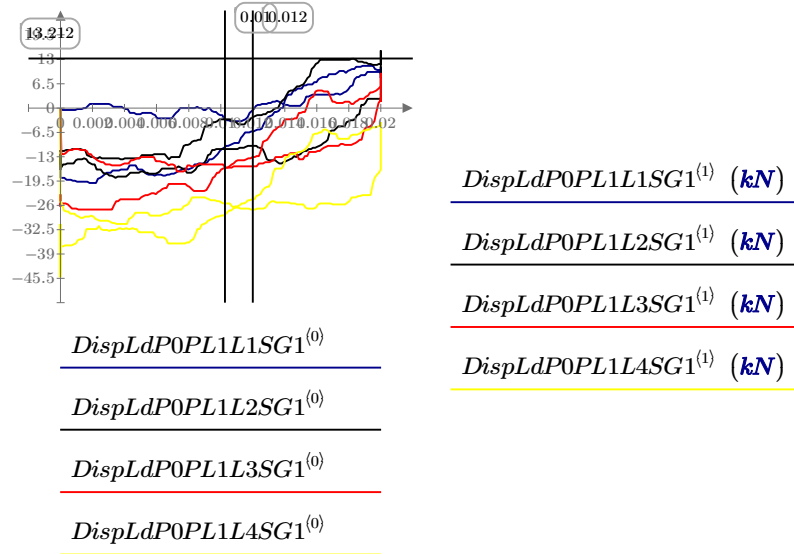


Fig B 26. Load-Displacement for P0 PL1 SG1

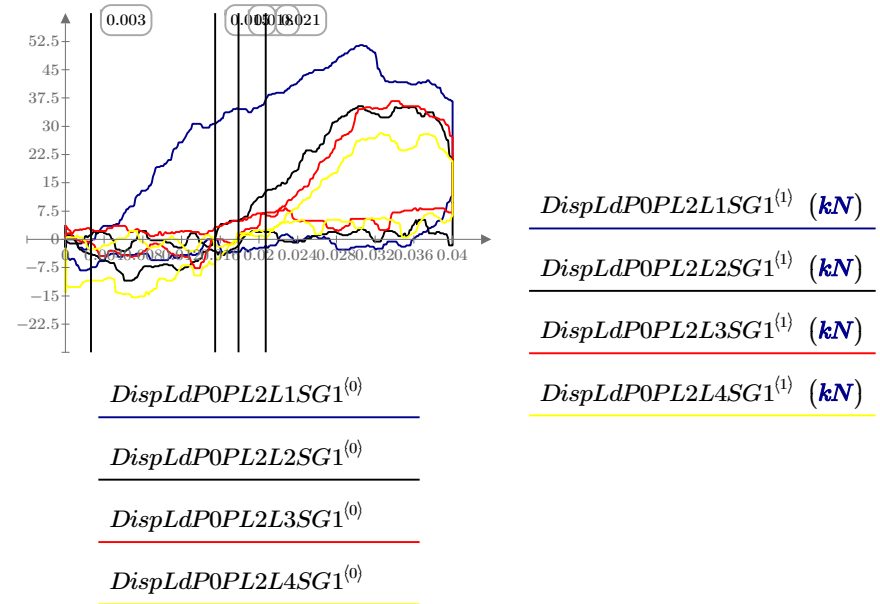


Fig B 27. Load-Displacement for P0 PL2 SG1

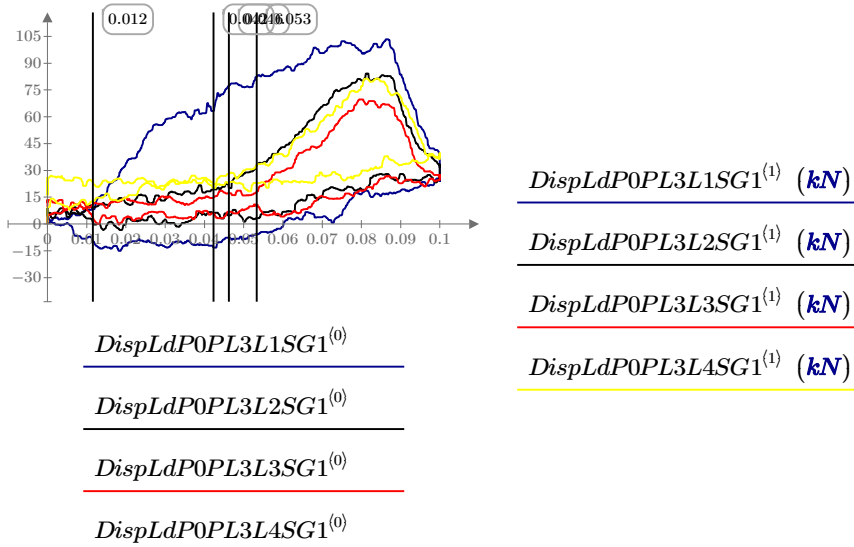


Fig B 28. Load-Displacement for P0 PL3 SG1

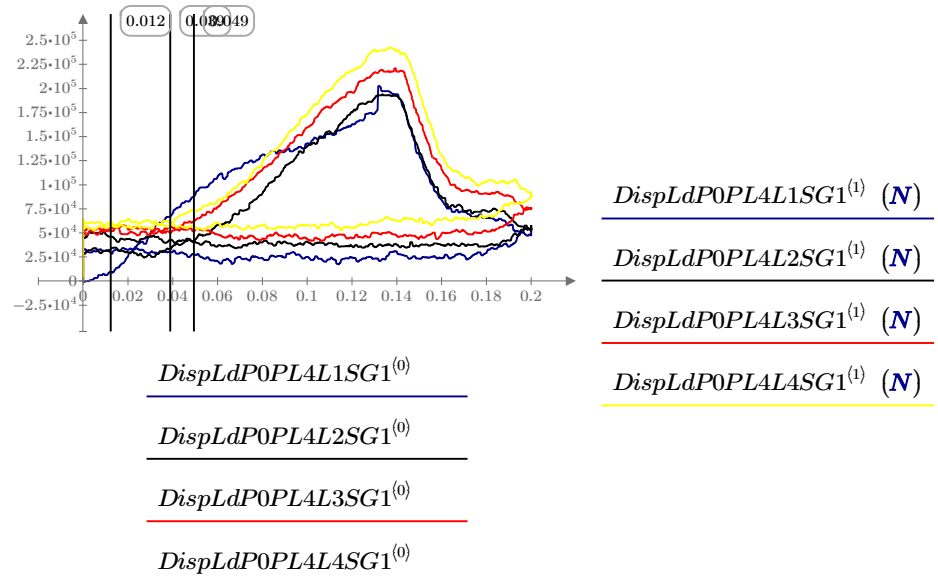


Fig B 29. Load-Displacement for P0 PL4 SG1

Appendix B

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

$DispLdP0PL1L1SG2 := DispLd(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2)$

$DispLdP0PL1L2SG2 := DispLd(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2)$

$DispLdP0PL1L3SG2 := DispLd(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2)$

$DispLdP0PL1L4SG2 := DispLd(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2)$

$DispLdP0PL2L1SG2 := DispLd(TDispTLdP0PL2, PseuPL2S, IniTimePL2S, IniDisp, 1, 2)$

$DispLdP0PL2L2SG2 := DispLd(TDispTLdP0PL2, PseuPL2S, IniTimePL2S, IniDisp, 2, 2)$

$DispLdP0PL2L3SG2 := DispLd(TDispTLdP0PL2, PseuPL2S, IniTimePL2S, IniDisp, 3, 2)$

$DispLdP0PL2L4SG2 := DispLd(TDispTLdP0PL2, PseuPL2S, IniTimePL2S, IniDisp, 4, 2)$

$DispLdP0PL3L1SG2 := DispLd(TDispTLdP0PL3, PseuPL3S, IniTimePL3S, IniDisp, 1, 2)$

$DispLdP0PL3L2SG2 := DispLd(TDispTLdP0PL3, PseuPL3S, IniTimePL3S, IniDisp, 2, 2)$

$DispLdP0PL3L3SG2 := DispLd(TDispTLdP0PL3, PseuPL3S, IniTimePL3S, IniDisp, 3, 2)$

$DispLdP0PL3L4SG2 := DispLd(TDispTLdP0PL3, PseuPL3S, IniTimePL3S, IniDisp, 4, 2)$

$DispLdP0PL4L1SG2 := DispLd(TDispTLdP0PL4, PseuPL4S, IniTimePL4S, IniDisp, 1, 2)$

$DispLdP0PL4L2SG2 := DispLd(TDispTLdP0PL4, PseuPL4S, IniTimePL4S, IniDisp, 2, 2)$

$DispLdP0PL4L3SG2 := DispLd(TDispTLdP0PL4, PseuPL4S, IniTimePL4S, IniDisp, 3, 2)$

$DispLdP0PL4L4SG2 := DispLd(TDispTLdP0PL4, PseuPL4S, IniTimePL4S, IniDisp, 4, 2)$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

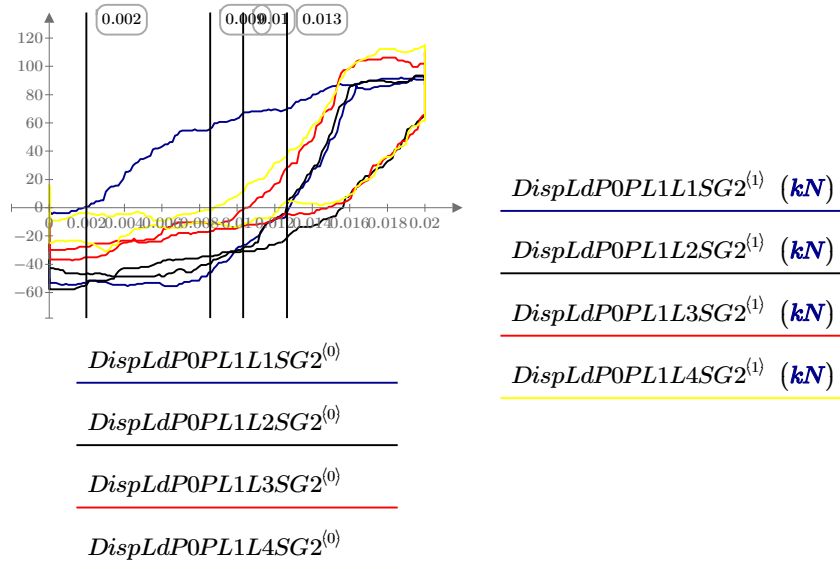


Fig B 30. Load-Displacement for P0 PL1 SG2

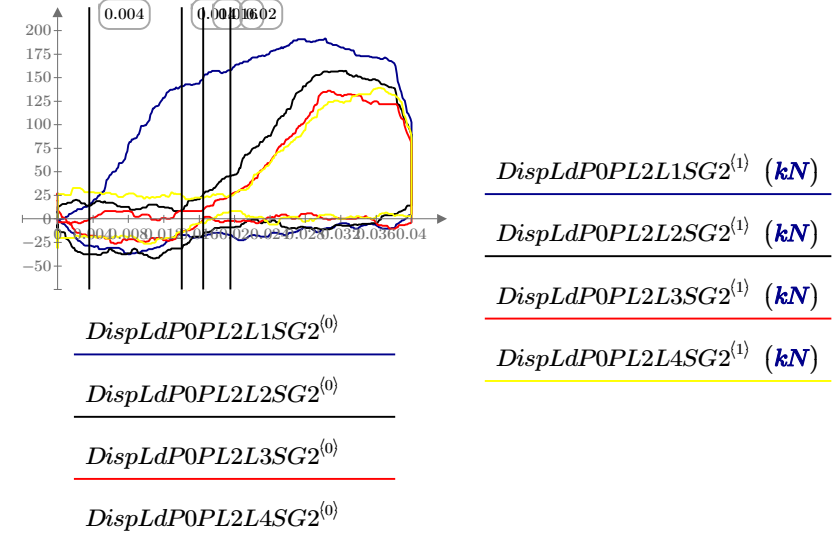


Fig B 31. Load-Displacement for P0 PL2 SG2

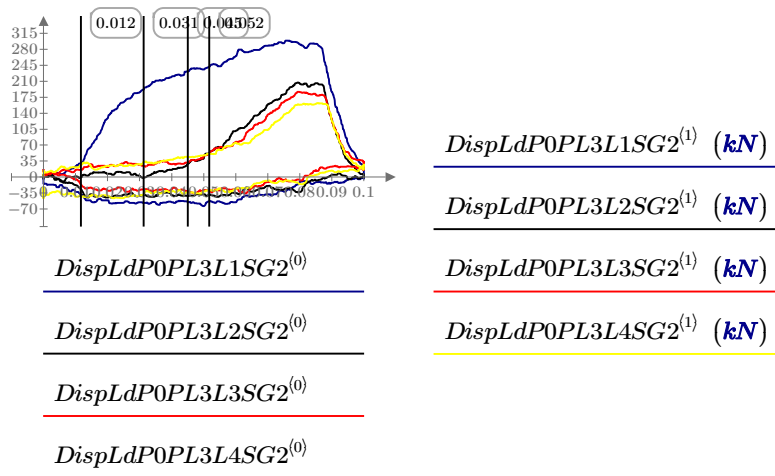


Fig B 32. Load-Displacement for P0 PL3 SG2

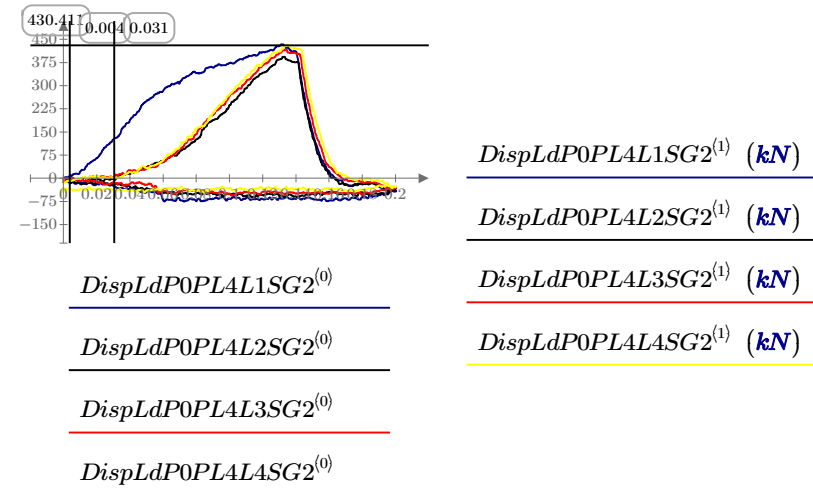


Fig B 33. Load-Displacement for P0 PL4 SG2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

Functions for determining the Qmax profile from each loads

TOL := 0.00000001

$$Q_{maxSG}(TDispTLdP2PL1, PileNum) := \begin{cases} QP0 \leftarrow \max(TDispTLdP2PL1^{(3)}) \\ QP1 \leftarrow \max(TDispTLdP2PL1^{(4)}) \\ QP2 \leftarrow \max(TDispTLdP2PL1^{(5)}) \\ QP3 \leftarrow \max(TDispTLdP2PL1^{(6)}) \\ combined \leftarrow \text{if } PileNum = 0 \\ \quad \text{stack}(QP0, QP1, QP1, QP1, QP1, QP1) \\ \text{else if } PileNum = 1 \\ \quad \text{stack}(QP0, QP1, QP1, QP2, QP2, QP2) \\ \text{else} \\ \quad \text{stack}(QP0, QP1, QP1, QP2, QP2, QP3) \\ combined \end{cases}$$

$$Q_{maxP0PL1} := Q_{maxSG}(TDispTLdP0PL1, 0) \cdot kN$$

$$Q_{maxP0PL2} := Q_{maxSG}(TDispTLdP0PL2, 0) \cdot kN$$

$$Q_{maxP0PL3} := Q_{maxSG}(TDispTLdP0PL3, 0) \cdot kN$$

$$Q_{maxP0PL4} := Q_{maxSG}(TDispTLdP0PL4, 0) \cdot kN$$

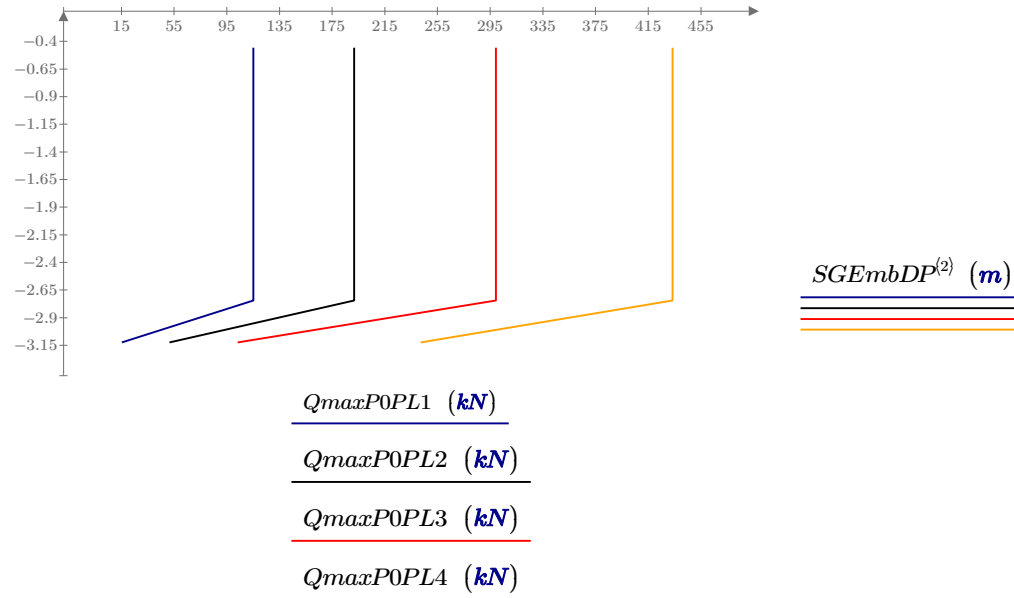
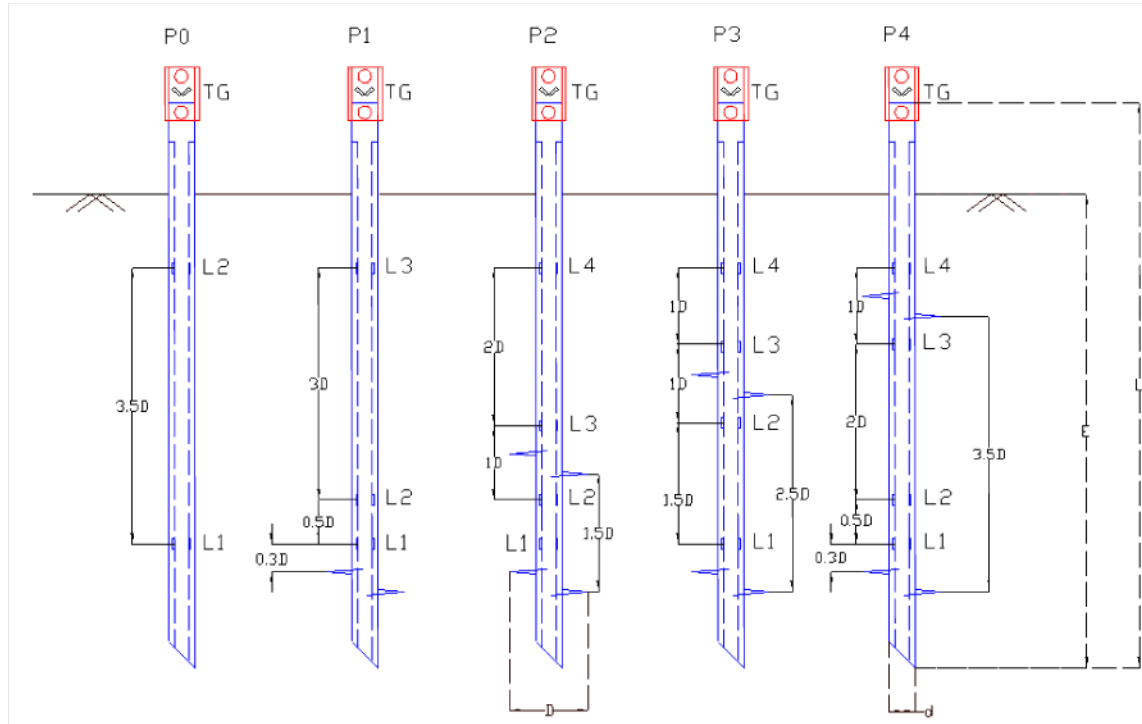


Fig B 34. SG Depth vs Q max from each load amplitude for P0 pile

2.3.3 Skin Friction vs Depth



Strain gauge locations in model piles.

$$HgtShaft := \begin{bmatrix} 3.5 & 0.5 & 0.5 & 1.5 & 0.5 \\ 0 & 3 & 1 & 1 & 2 \\ 0 & 0 & 2 & 1 & 1 \end{bmatrix} \cdot D \cdot Nscale^{sclfac_{0,0}} = \begin{bmatrix} 2.667 & 0.381 & 0.381 & 1.143 & 0.381 \\ 0 & 2.286 & 0.762 & 0.762 & 1.524 \\ 0 & 0 & 1.524 & 0.762 & 0.762 \end{bmatrix} m$$

Height in the shaft segment between two stations in prototype scale. Here, colm 0-4 represents P0 to P4. Row 0 to 2 represents height between SG 1-2, 2-3 & 3-4

$$SurfArea := HgtShaft \cdot \pi \cdot d \cdot Nscale^{sclfac_{0,0}} = \begin{bmatrix} 2.128 & 0.304 & 0.304 & 0.912 & 0.304 \\ 0 & 1.824 & 0.608 & 0.608 & 1.216 \\ 0 & 0 & 1.216 & 0.608 & 0.608 \end{bmatrix} m^2$$

Surface Area of the shaft segment between two stations in prototype scale. Here, colm 0-4 represents P0 to P4. Row 0 to 2 represents surface area between SG 1-2, 2-3 & 3-4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

Function for determining the Unit Shaft Resistance within the shaft segment

```

UntShtRes(LdP, PileNum) := for i ∈ 0, 1..rows(LdP) - 1
    for j ∈ 0, 1..cols(LdP) - 1
        shaft12i,0 ←  $\frac{(LdP_{i,4} - LdP_{i,3}) \text{ kN}}{\text{submatrix}(\text{SurfArea}, 0, 2, \text{PileNum}, \text{PileNum})_{0,0}}$ 
        shaft23i,1 ← if submatrix(SurfArea, 0, 2, PileNum, PileNum)1 = 0
            0
        else
             $\frac{(LdP_{i,5} - LdP_{i,4}) \text{ kN}}{\text{submatrix}(\text{SurfArea}, 0, 2, \text{PileNum}, \text{PileNum})_1}$ 
        shaft34i,2 ← if submatrix(SurfArea, 0, 2, PileNum, PileNum)2 = 0
            0
        else
             $\frac{(LdP_{i,6} - LdP_{i,5}) \text{ kN}}{\text{submatrix}(\text{SurfArea}, 0, 2, \text{PileNum}, \text{PileNum})_2}$ 
    augment(shaft12(0), shaft23(1), shaft34(2))

```

$ShftResP0PL1 := UntShtRes(TDispTLdP0PL1, 0)$

$ShftResP0PL2 := UntShtRes(TDispTLdP0PL2, 0)$

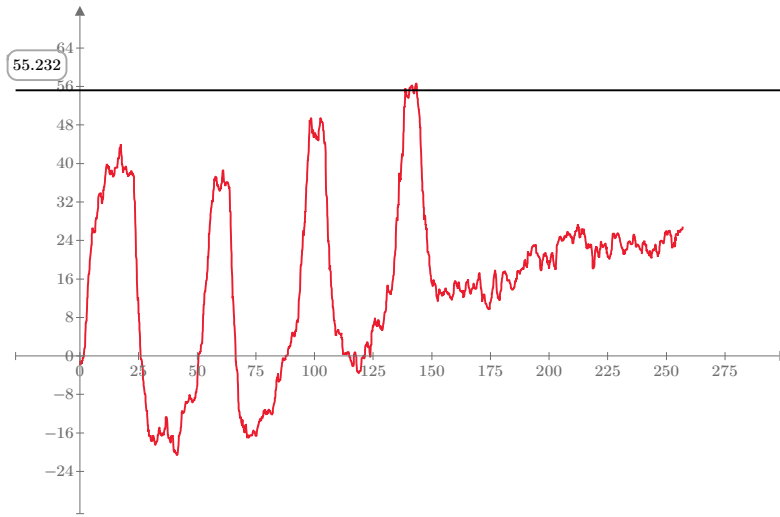
$ShftResP0PL3 := UntShtRes(TDispTLdP0PL3, 0)$

$ShftResP0PL4 := UntShtRes(TDispTLdP0PL4, 0)$

$ShftResP0CL := UntShtRes(TDispTLdP0CL, 0)$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

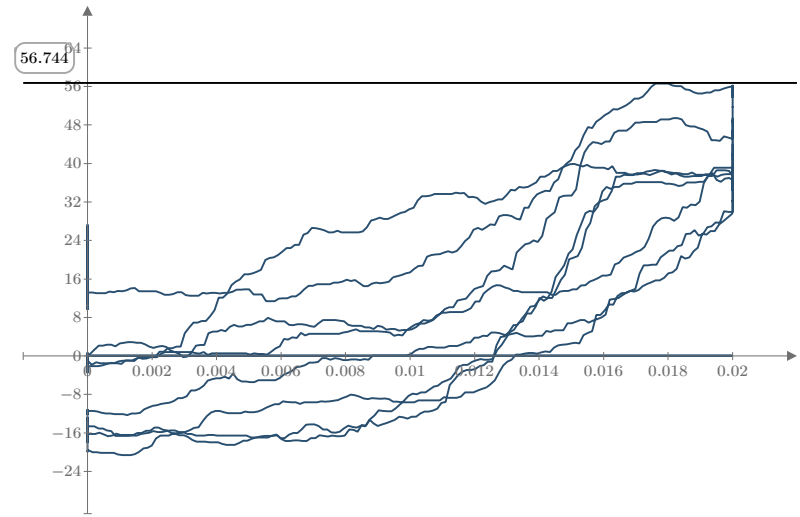
$TD_{DispTLdP0PL1}^{(0)}$



$ShftResP0PL1^{(0)}$ (kPa)

Fig B 35. Shaft Resistances vs Time, P0 PL1

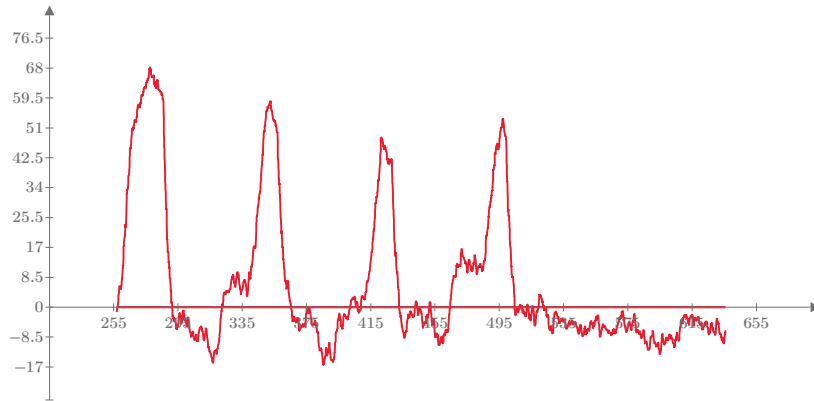
$-TD_{DispTLdP0PL1}^{(1)}$



$ShftResP0PL1$ (kPa)

Fig B 36. Shaft Resistances vs Displacement, P0 PL1

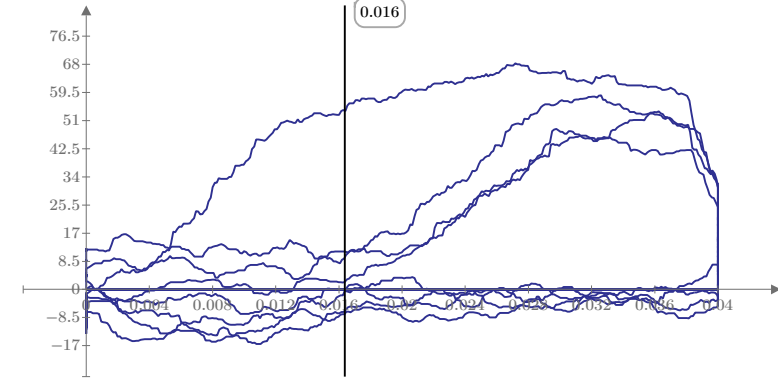
$TD_{DispTLdP0PL2}^{(0)}$



$ShftResP0PL2$ (kPa)

Fig B 37. Shaft Resistances vs Time, P0 PL2

$-TD_{DispTLdP0PL2}^{(1)}$

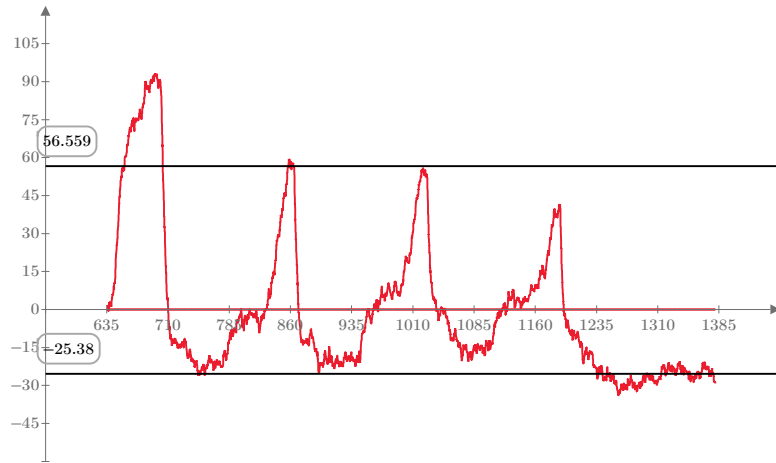


$ShftResP0PL2$ (kPa)

Fig B 38. Shaft Resistances vs Displacement, P0 PL2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

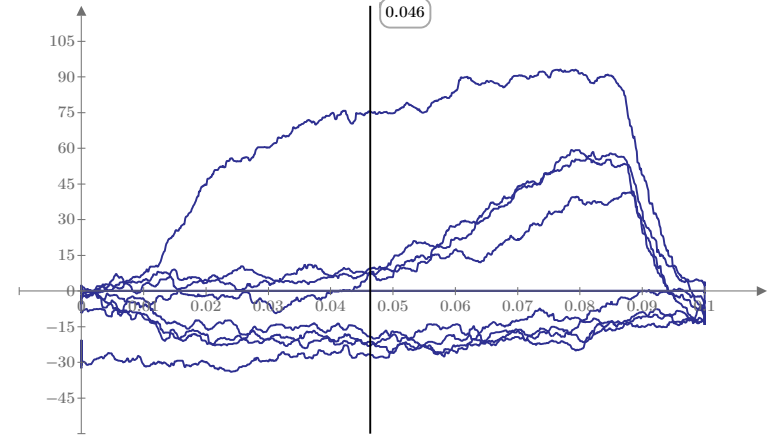
$TDispTLdP0PL3^{(0)}$



$ShftResP0PL3$ (kPa)

Fig B 39. Shaft Resistances vs Time, P0 PL3

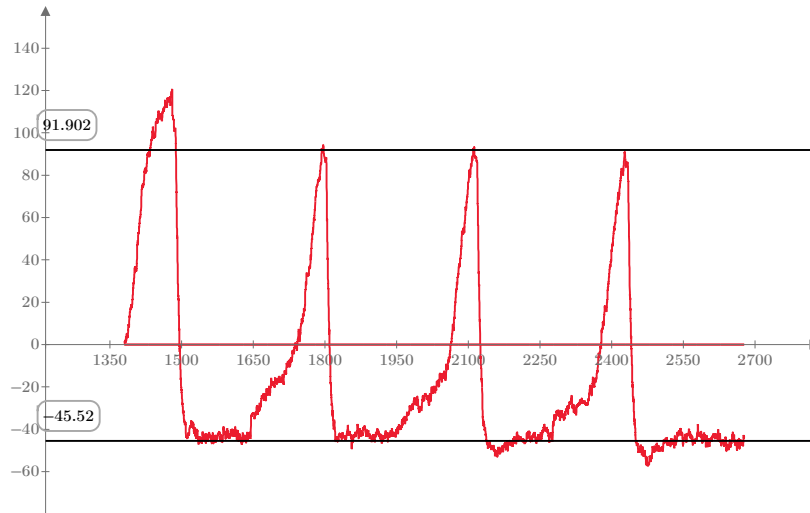
$-TDispTLdP0PL3^{(1)}$



$ShftResP0PL3$ (kPa)

Fig B 40. Shaft Resistances vs Displacement, P0 PL3

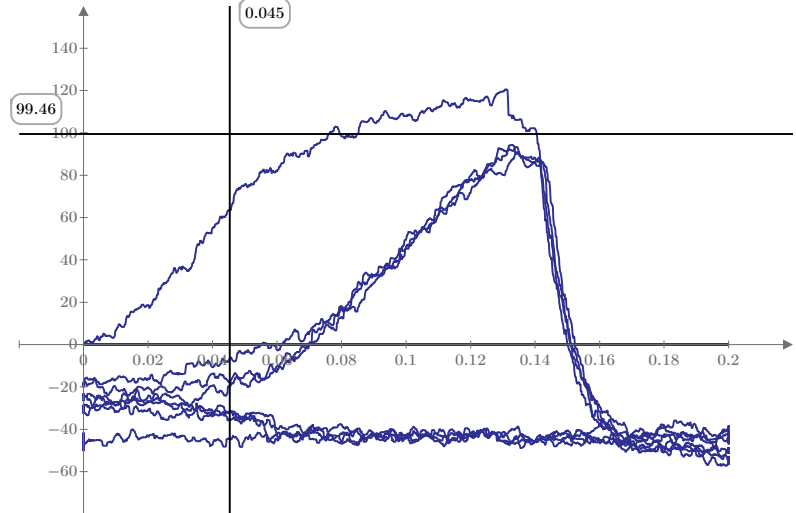
$TDispTLdP0PL4^{(0)}$



$ShftResP0PL4$ (kPa)

Fig B 41. Shaft Resistances vs Time, P0 PL4

$-TDispTLdP0PL4^{(1)}$



$ShftResP0PL4$ (kPa)

Fig B 42. Shaft Resistances vs Displacement, P0 PL4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

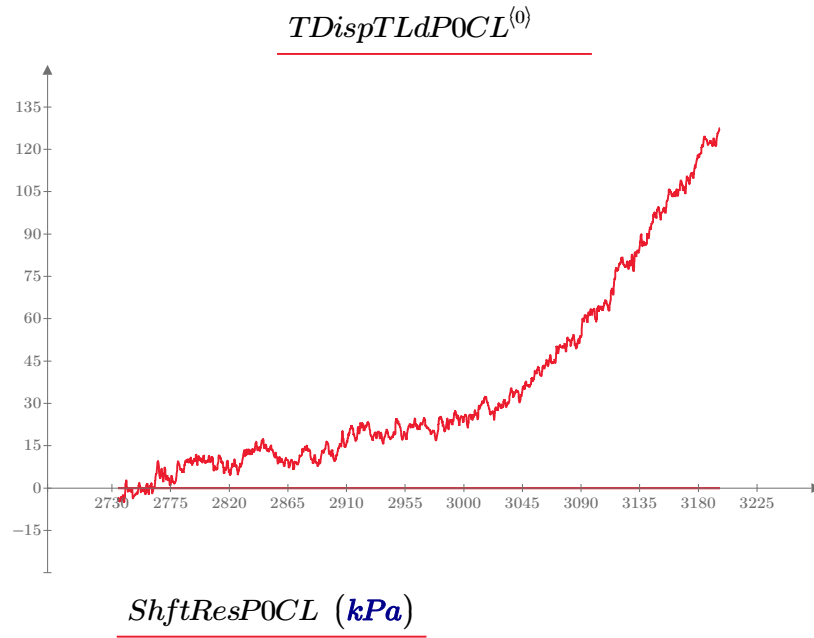


Fig B 43. Shaft Resistances vs Time, P0 CL

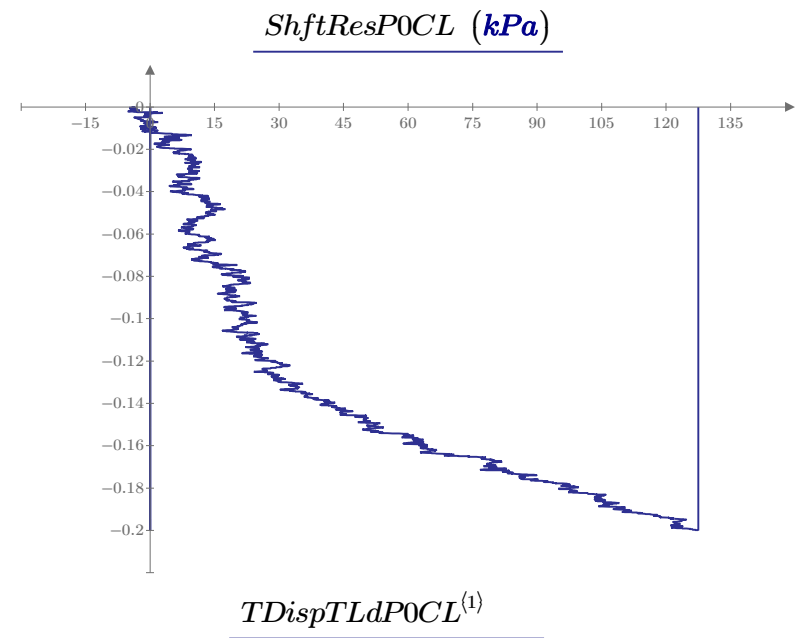


Fig B 44. Shaft Resistances vs Displacement, P0 CL

$$ShftP0CL := \text{augment} \left(TDispTLdP0CL^{(1)}, \frac{ShftResP0CL}{kPa} \right)$$

$$UltShReP0_0 := \text{lookup} \left(-0.15, ShftP0CL^{(0)}, ShftP0CL^{(1)}, \text{"near"} \right) = [52.395]$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

Functions for calculating the ultimate unit shaft resistance along the depth

```

ShftResplot (ShftP0CL, PileNum) := for i ∈ 0, 1 .. cols (ShftP0CL) - 1
    ||
    || UltShReP0 ← if PileNum = 0
    ||     || lookup (-0.15, ShftP0CL(0), ShftP0CL(1), "near")
    ||     || else
    ||     || lookup (-0.05, ShftP0CL(0), ShftP0CL(1), "near")
    ||
    || UltShReP1 ← if PileNum = 0
    ||     || 0
    ||     || else
    ||     || lookup (-0.05, ShftP0CL(0), ShftP0CL(2), "near")
    ||
    || UltShReP2 ← if PileNum = 0
    ||     || 0
    ||     || else if PileNum = 1
    ||     || 0
    ||     || else
    ||     || lookup (-0.05, ShftP0CL(0), ShftP0CL(3), "near")
    ||
    || combined ← if PileNum = 0
    ||     || stack (UltShReP0, UltShReP0, UltShReP0, UltShReP0, UltShReP0, UltShReP0)
    ||     || else if PileNum = 1
    ||     || stack (UltShReP0, UltShReP0, UltShReP1, UltShReP1, UltShReP1, UltShReP1)
    ||     || else
    ||     || stack (UltShReP0, UltShReP0, UltShReP1, UltShReP1, UltShReP2, UltShReP2)

```

$$ShftResPlotP0CL := ShftResplot (ShftP0CL, 0) \text{ } \mathbf{kPa} = \begin{bmatrix} 52.395 \\ 52.395 \\ 52.395 \\ 52.395 \\ 52.395 \\ 52.395 \end{bmatrix} \text{ } \mathbf{kPa}$$

$ShftResplotP_C (ShftResPlotP0CL) := \text{augment} (ShftResPlotP0CL, ShftResPlotP0CL, ShftResPlotP0CL, ShftResPlotP0CL, ShftResPlotP0CL)$
 Ultimate Shaft resistance on the five compression piles between SGS

Appendix B
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

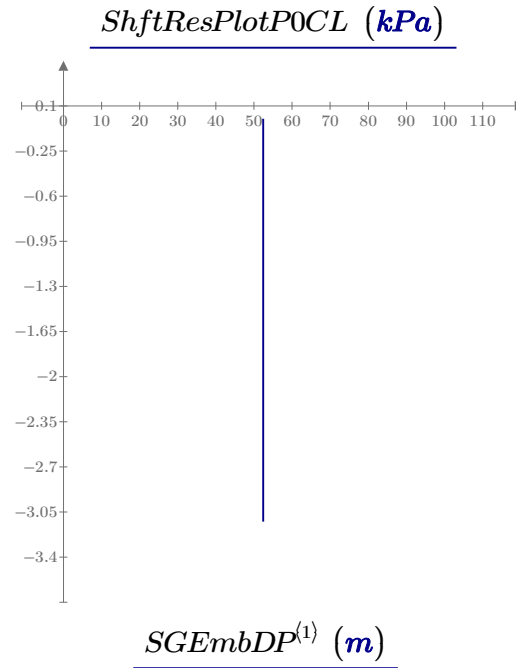


Fig B 45. Strain Gauge Depth vs Unit Shaft Resistance for post cyclic pile P0.

Function for estimating Mid depth of SGs on each piles

```
MidDSGsgmt(PileNum) :=
    shaft12 ← mean(submatrix(SGEmbDP, 0, 1, PileNum, PileNum))
    shaft23 ← if mean(submatrix(SGEmbDP, 2, 3, PileNum, PileNum)) = 0
                0
            else
                mean(submatrix(SGEmbDP, 2, 3, PileNum, PileNum))
    shaft34 ← if mean(submatrix(SGEmbDP, 4, 5, PileNum, PileNum)) = 0
                0
            else
                mean(submatrix(SGEmbDP, 4, 5, PileNum, PileNum))
    stack(shaft12, shaft23, shaft34)
```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

Function for estimating Ks of each piles

$$\begin{aligned}
 Ks(ShftResplotP, PileNum) := & \begin{aligned} & shaft12 \leftarrow \frac{\text{mean}(\text{submatrix}(ShftResplotP, 0, 1, PileNum, PileNum))}{\text{mean}(\text{submatrix}(SGEmbDP, 0, 1, PileNum, PileNum)) \cdot \gamma \cdot \tan(\delta)} \\ & shaft23 \leftarrow \begin{aligned} & \text{if } PileNum = 2 \\ & \quad 0 \\ & \text{else if } PileNum = 3 \\ & \quad 0 \\ & \text{else} \\ & \quad \text{if } \text{mean}(\text{submatrix}(SGEmbDP, 2, 3, PileNum, PileNum)) = 0 \\ & \quad \quad 0 \\ & \quad \text{else} \\ & \quad \quad \frac{\text{mean}(\text{submatrix}(ShftResplotP, 2, 3, PileNum, PileNum))}{\text{mean}(\text{submatrix}(SGEmbDP, 2, 3, PileNum, PileNum)) \cdot \gamma \cdot \tan(\delta)} \end{aligned} \\ & shaft34 \leftarrow \begin{aligned} & \text{if } PileNum = 4 \\ & \quad 0 \\ & \text{else} \\ & \quad \text{if } \text{mean}(\text{submatrix}(SGEmbDP, 4, 5, PileNum, PileNum)) = 0 \\ & \quad \quad 0 \\ & \quad \text{else} \\ & \quad \quad \frac{\text{mean}(\text{submatrix}(ShftResplotP, 4, 5, PileNum, PileNum))}{\text{mean}(\text{submatrix}(SGEmbDP, 4, 5, PileNum, PileNum)) \cdot \gamma \cdot \tan(\delta)} \end{aligned} \\ & \text{stack}(-shaft12, -shaft23, -shaft34) \end{aligned}
 \end{aligned}$$

$$KsP_C := Ks(ShftResplotP_C(ShftResPlotP0CL), 0)$$

$$MidDSGsgmtP := \text{augment}(MidDSGsgmt(0), MidDSGsgmt(1), MidDSGsgmt(2), MidDSGsgmt(3), MidDSGsgmt(4))$$

$$\begin{aligned}
 Ko &:= \begin{bmatrix} 1 - \sin(\varphi) & 1 - \sin(\varphi) \end{bmatrix} & Kp &:= \begin{bmatrix} \frac{1 + \sin(\varphi)}{1 - \sin(\varphi)} & \frac{1 + \sin(\varphi)}{1 - \sin(\varphi)} \end{bmatrix} & Ka &:= \begin{bmatrix} \frac{1 - \sin(\varphi)}{1 + \sin(\varphi)} & \frac{1 - \sin(\varphi)}{1 + \sin(\varphi)} \end{bmatrix} = \begin{bmatrix} 0.317 & 0.317 \end{bmatrix}
 \end{aligned}$$

$$K := \begin{bmatrix} 0.09 \cdot e^{0.08 \cdot \left(\varphi \cdot \frac{180}{\pi}\right)} & 0.09 \cdot e^{0.08 \cdot \left(\varphi \cdot \frac{180}{\pi}\right)} \end{bmatrix}$$

Mitsch and Clemence 1985

$$ProtEmbed := \begin{bmatrix} 0 & -E \cdot Nscale^{selfac_{0,0}} \end{bmatrix} = \begin{bmatrix} 0 & -3.382 \end{bmatrix} \mathbf{m} \quad \text{Pile Embedment in prototype scale unit}$$

$$KsP_C = \begin{bmatrix} 4.2 \\ 0 \\ 0 \end{bmatrix}$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

$$MidDSGsgmtP = \begin{bmatrix} -1.791 & -2.934 & -2.934 & -2.553 & -2.934 \\ 0 & -1.6 & -2.362 & -1.6 & -1.981 \\ 0 & 0 & -1.219 & -0.838 & -0.838 \end{bmatrix} \mathbf{m}$$

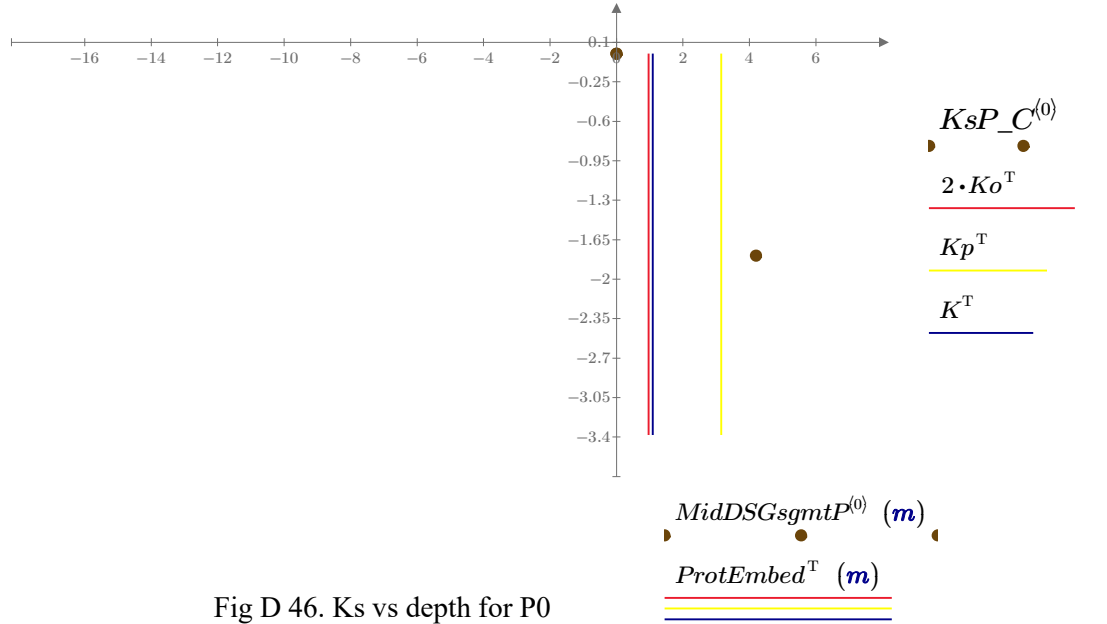


Fig D 46. Ks vs depth for P0

Function for estimating the shaft resistance EDR

```
ShftEDR (TDispTLdP0PL1, ShftResP2PL1, Pseu1perS, IniTime, IniDisp, LoopNo, ShftNo) :=
    m ← TDispTLdP0PL1
    n ←  $\frac{ShftResP2PL1}{kPa}$ 
    o ← TimeCycLoop (Pseu1perS, IniTime, IniDisp) – IniTime
    w ←  $-m^{(1)}$ 
    wmax ← max ( $-m^{(1)}$ )
    if ShftNo = 1
        q ←  $n^{(0)}$ 
        qmax ← max ( $n^{(0)}$ )
    else if ShftNo = 2
        q ←  $n^{(1)}$ 
        qmax ← max ( $n^{(1)}$ )
    else if ShftNo = 3
        q ←  $n^{(2)}$ 
        qmax ← max ( $n^{(2)}$ )
    if LoopNo = 1
        ||
```

Appendix B

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

```

|||  $t1 \leftarrow m_{1,0} - IniTime$  |||
|||  $t2 \leftarrow o_1$  |||
||| else if  $LoopNo = 2$  |||
|||  $t1 \leftarrow o_1$  |||
|||  $t2 \leftarrow o_2$  |||
||| else if  $LoopNo = 3$  |||
|||  $t1 \leftarrow o_2$  |||
|||  $t2 \leftarrow o_3$  |||
||| else if  $LoopNo = 4$  |||
|||  $t1 \leftarrow o_3$  |||
|||  $t2 \leftarrow o_4$  |||
|||
|||  $tstart \leftarrow \text{lookup}(t1, (m^{(0)} - IniTime), (m^{(0)} - IniTime), \text{"near"})$  |||
|||  $tend \leftarrow \text{lookup}(t2, (m^{(0)} - IniTime), (m^{(0)} - IniTime), \text{"near"})$  |||
|||  $rowstart \leftarrow \text{match}(t1, (m^{(0)} - IniTime), \text{"near"})$  |||
|||  $rowend \leftarrow \text{match}(t2, (m^{(0)} - IniTime), \text{"near"})$  |||
||| for  $i \in rowstart_{0,0} \dots rowend_{0,0}$  |||
|||  $r_i \leftarrow \left( (w_i - w_{i-1}) \cdot \left( \frac{q_i + q_{i-1}}{2} \right) \right)$  |||
|||
|||  $area \leftarrow \sum r$  |||
|||
|||  $EDR \leftarrow$  |||
||| if  $qmax = 0$  |||
||| 0 |||
||| else if  $wmax = 0$  |||
||| 0 |||
||| else if  $area = 0$  |||
||| 0 |||
||| else |||
|||  $\frac{area}{qmax \cdot wmax}$  |||
|||
|||  $s \leftarrow \text{augment}((tstart + IniTime), (tend + IniTime), rowstart, rowend, qmax, wmax, area, EDR)$  |||
|||  $EDR$  |||

```

Function for combining the shaft resistance EDR

```

ShftEDRPOPLSG (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, PileNo) :=
|||  $q1 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1)$  |||
|||  $q2 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1)$  |||
|||  $q3 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1)$  |||
|||  $q4 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1)$  |||
|||  $r1 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2)$  |||
|||  $r2 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2)$  |||
|||  $r3 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2)$  |||
|||  $r4 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2)$  |||
|||  $w1 \leftarrow$  if  $PileNo = 0$  |||
||| 0 |||
||| else |||
|||  $ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 3)$  |||
|||  $w2 \leftarrow$  if  $PileNo = 0$  |||
||| 0 |||
||| else |||
|||  $ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 3)$  |||
|||
|||  $EDR \leftarrow$  |||
||| if  $w1 = 0$  |||
||| 0 |||
||| else |||
|||  $\frac{w2}{w1}$  |||
|||
|||  $EDR$  |||

```

Appendix B

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

$$NoLoop := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

```

w3 ← if PileNo = 0
    0
else
    ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 3)
w4 ← if PileNo = 0
    0
else
    ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3)
augment (stack (q1, q2, q3, q4), stack (r1, r2, r3, r4), stack (w1, w2, w3, w4))

```

$$ShftEDRP0PL1 := ShftEDRPOPLSG(TDispTLdP0PL1, ShftResP0PL1, PseuPL1S, IniTimePL1S, 0) = \begin{bmatrix} 0.425 & 0 & 0 \\ -0.086 & 0 & 0 \\ -0.248 & 0 & 0 \\ -0.273 & 0 & 0 \end{bmatrix}$$

$$ShftEDRP0PL2 := ShftEDRPOPLSG(TDispTLdP0PL2, ShftResP0PL2, PseuPL2S, IniTimePL2S, 0) = \begin{bmatrix} 0.803 & 0 & 0 \\ 0.493 & 0 & 0 \\ 0.329 & 0 & 0 \\ 0.39 & 0 & 0 \end{bmatrix}$$

$$ShftEDRP0PL3 := ShftEDRPOPLSG(TDispTLdP0PL3, ShftResP0PL3, PseuPL3S, IniTimePL3S, 0) = \begin{bmatrix} 0.815 & 0 & 0 \\ 0.34 & 0 & 0 \\ 0.325 & 0 & 0 \\ 0.379 & 0 & 0 \end{bmatrix}$$

$$ShftEDRP0PL4 := ShftEDRPOPLSG(TDispTLdP0PL4, ShftResP0PL4, PseuPL4S, IniTimePL4S, 0) = \begin{bmatrix} 0.714 & 0 & 0 \\ 0.39 & 0 & 0 \\ 0.377 & 0 & 0 \\ 0.397 & 0 & 0 \end{bmatrix}$$

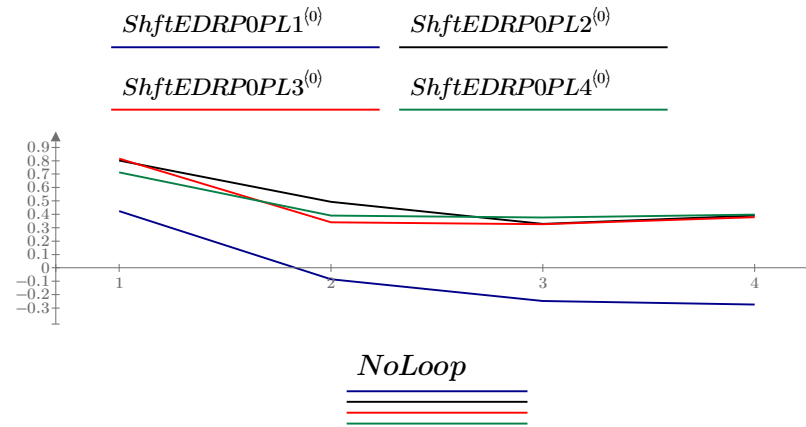


Fig B 47. Shaft EDR vs No of loops Seg1

2.3.4 End Bearing vs Depth

$$A_b := \pi \cdot \frac{(D \cdot Nscale^{scale_{0,0}})^2}{4} = 0.456 \text{ m}^2$$

Total area at the helix in prototype scale

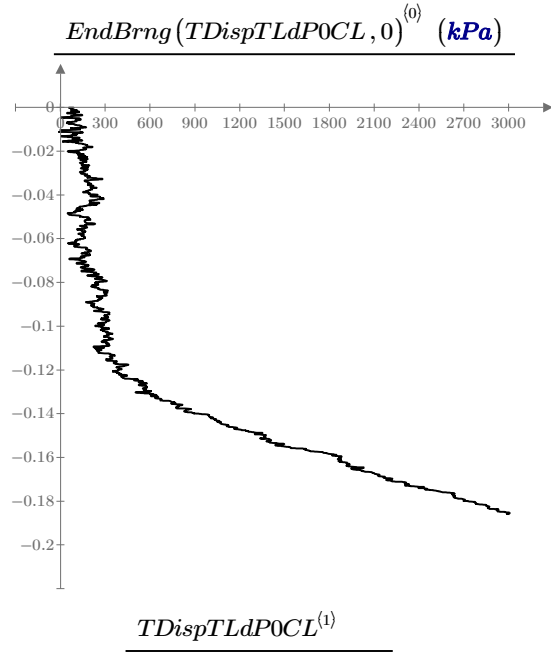
$$A_d := \pi \cdot \frac{(d \cdot Nscale^{scale_{0,0}})^2}{4} = 0.051 \text{ m}^2$$

Total area at the shaft in prototype scale

Function for determining the end bearing

```

EndBrng(TDispTLdP0CL, PileNum) :=
  for i ∈ 0, 1..rows(TDispTLdP0CL) - 1
    for j ∈ 0, 1..cols(TDispTLdP0CL) - 1
      qb1i,0 ← if PileNum = 0
                (TDispTLdP0CLi,3) kN
                -----
                Ad
            else
                (TDispTLdP0CLi,3) kN
                -----
                Ab - Ad
      qb23i,1 ← if PileNum = 2
                (TDispTLdP0CLi,5 - TDispTLdP0CLi,4) kN
                -----
                Ab
            else if PileNum = 3
                (TDispTLdP0CLi,5 - TDispTLdP0CLi,4) kN
                -----
                Ab - Ad
            else
                0
      qb34i,2 ← if PileNum = 4
                (TDispTLdP0CLi,6 - TDispTLdP0CLi,5) kN
                -----
                Ab - Ad
            else
                0
    augment(qb1(0), qb23(1), qb34(2))
  
```



$$EndBrng(TDispTLdP0CL, 0)^{(0)} = \begin{matrix} 0 & 91.972 \\ 1 & 91.972 \\ 2 & 75.742 \\ 3 & 59.512 \\ 4 & 56.806 \\ 5 & 54.101 \\ 6 & 59.512 \\ 7 & 70.332 \\ 8 & 70.332 \\ 9 & 70.332 \\ 10 & 70.332 \\ 11 & 70.332 \\ \vdots & \vdots \\ 4619 & \end{matrix} \text{ kPa}$$

Fig B 48. Depth vs End Bearing for post cyclic compression pile P0

$$UltEndBrngP0_0 := \text{lookup} \left(-0.15, TDispTLdP0CL^{(1)}, EndBrng(TDispTLdP0CL, 0)^{(0)}, \text{"near"} \right) = [1374.175] \text{ kPa}$$

$$HelixLoc := - \begin{bmatrix} 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 \\ 0 & 0 & 0.6 + 2 + 0.3 + 0.17 & 0.6 + 1 + 0.3 + 0.17 & 0.6 + 0.3 + 0.17 \end{bmatrix} \cdot D \cdot Nscale^{selfac_{0,0}}$$

$$\text{stack} \left(\frac{UltEndBrngP0_0}{-HelixLoc_{0,0} \cdot \gamma}, 0 \right) = \begin{bmatrix} 24.51 \\ 0 \end{bmatrix}$$

$$HelixLoc = \begin{bmatrix} -3.482 & -3.482 & -3.482 & -3.482 & -3.482 \\ 0 & 0 & -2.339 & -1.577 & -0.815 \end{bmatrix} m$$

$$BrngP0PL1 := EndBrng(TDispTLdP0PL1, 0)$$

$$BrngP0PL2 := EndBrng(TDispTLdP0PL2, 0)$$

$$BrngP0PL3 := EndBrng(TDispTLdP0PL3, 0)$$

$$BrngP0PL4 := EndBrng(TDispTLdP0PL4, 0)$$

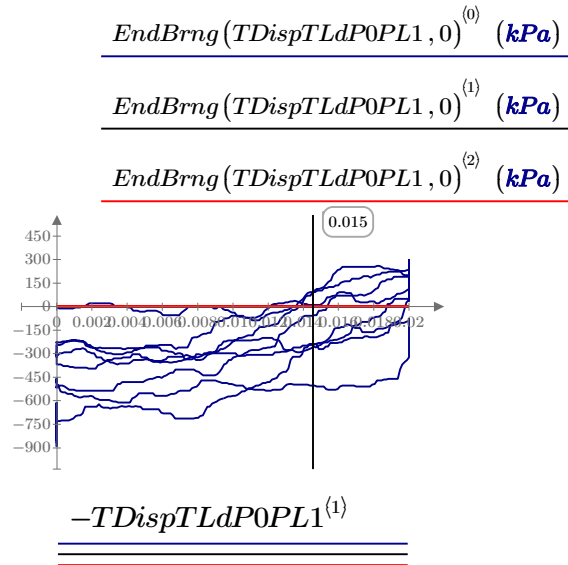


Fig B 49. End Bearing vs Depth for P0 PL1

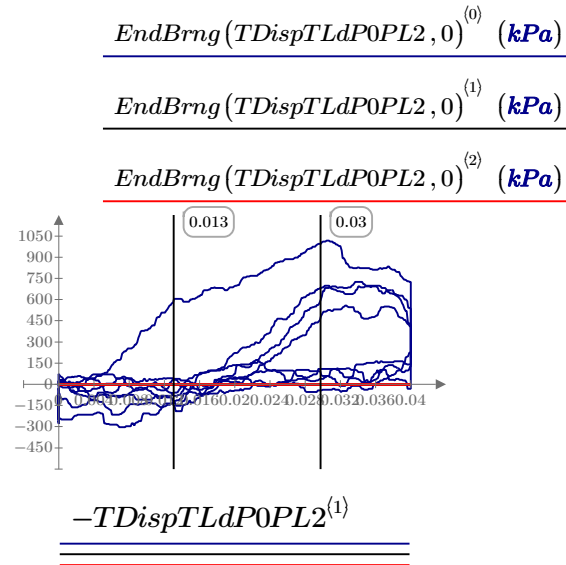


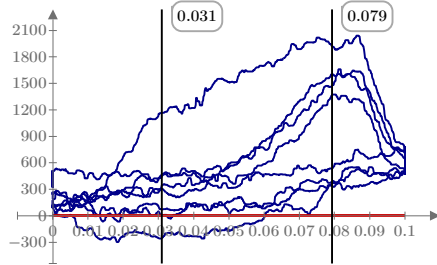
Fig B 50. End Bearing vs Depth for P0 PL2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

$$\underline{\underline{EndBrng(TDispTLdP0PL3, 0)^{(0)}} \text{ (kPa)}}$$

$$\underline{\underline{EndBrng(TDispTLdP0PL3, 0)^{(1)}} \text{ (kPa)}}$$

$$\underline{\underline{EndBrng(TDispTLdP0PL3, 0)^{(2)}} \text{ (kPa)}}$$



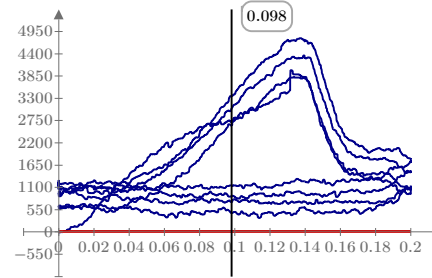
$$\underline{\underline{-TDispTLdP0PL3^{(1)}}}$$

Fig B 51. End Bearing vs Depth for P0 PL3

$$\underline{\underline{EndBrng(TDispTLdP0PL4, 0)^{(0)}} \text{ (kPa)}}$$

$$\underline{\underline{EndBrng(TDispTLdP0PL4, 0)^{(1)}} \text{ (kPa)}}$$

$$\underline{\underline{EndBrng(TDispTLdP0PL4, 0)^{(2)}} \text{ (kPa)}}$$



$$\underline{\underline{-TDispTLdP0PL4^{(1)}}}$$

Fig B 52. End Bearing vs Depth for P0 PL4

Functions for calculating the EDR from the bearing resistances

```

BrngEDR(TDispTLdP0PL1, BrngP2PL1, Pseu1perS, IniTime, IniDisp, LoopNo, ShftNo) :=
    m ← TDispTLdP0PL1
    n ← BrngP2PL1
    n ← kPa
    o ← TimeCycLoop(Pseu1perS, IniTime, IniDisp) - IniTime
    w ← -n(1)
    wmax ← max(-n(1))
    if ShftNo = 1
        q ← n(0)
        qmax ← max(n(0))
    else if ShftNo = 2
        q ← n(1)
        qmax ← max(n(1))
    else if ShftNo = 3
        q ← n(2)
        qmax ← max(n(2))
    if LoopNo = 1
        t1 ← m1,0 - IniTime
        t2 ← o1
    else if LoopNo = 2
        t1 ← o1
        t2 ← o2
    else if LoopNo = 3
        t1 ← o2
        t2 ← o3
    else if LoopNo = 4
        t1 ← o3
        t2 ← o4

```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

```

||| ||| t1 ← o
||| ||| 3
||| ||| t2 ← o
||| ||| 4
|||
tstart ← lookup (t1, (m(0) - IniTime), (m(0) - IniTime), "near")
tend ← lookup (t2, (m(0) - IniTime), (m(0) - IniTime), "near")
rowstart ← match (t1, (m(0) - IniTime), "near")
rowend ← match (t2, (m(0) - IniTime), "near")
for i ∈ rowstart0,0 .. rowend0,0
|||
||| ri ← ⎛⎜⎝ (wi - wi-1) · ⎛⎜⎝ (qi + qi-1) / 2 ⎛⎜⎝
|||
area ← ∑ r
|||
EDR ← ||| if qmax = 0
||| ||| 0
||| ||| else if wmax = 0
||| ||| 0
||| ||| else if area = 0
||| ||| 0
||| ||| else
||| ||| area
||| ||| qmax · wmax
|||
s ← augment ((tstart + IniTime), (tend + IniTime), rowstart, rowend, qmax, wmax, area, EDR)
EDR

```

Function for compiling EDR for the end bearing in loading cycles

```

BrngEDRPOPLSG (TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, PileNo) :=
||| q1 ← BrngEDR (TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1)
||| q2 ← BrngEDR (TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1)
||| q3 ← BrngEDR (TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1)
||| q4 ← BrngEDR (TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1)
||| r1 ← BrngEDR (TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2)
||| r2 ← BrngEDR (TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2)
||| r3 ← BrngEDR (TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2)
||| r4 ← BrngEDR (TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2)
||| w1 ← if PileNo = 0
||| ||| 0
||| ||| else
||| ||| BrngEDR (TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 3)
||| w2 ← if PileNo = 0
||| ||| 0
||| ||| else
||| ||| BrngEDR (TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 3)
||| w3 ← if PileNo = 0
||| ||| 0
||| ||| else
||| ||| BrngEDR (TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 3)
||| w4 ← if PileNo = 0
||| ||| 0
||| ||| else
||| ||| BrngEDR (TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3)
||| augment (stack (q1, q2, q3, q4), stack (r1, r2, r3, r4), stack (w1, w2, w3, w4))

```

$NoLoop := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$

Appendix B

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P0 smooth pile

$$BrngEDRP0PL1 := BrngEDRPOPLSG(TDispTLdP0PL1, BrngP0PL1, PseuPL1S, IniTimePL1S, 0) = \begin{bmatrix} 0.53 & 0 & 0 \\ -0.608 & 0 & 0 \\ 0.043 & 0 & 0 \\ -0.176 & 0 & 0 \end{bmatrix}$$

$$BrngEDRP0PL2 := BrngEDRPOPLSG(TDispTLdP0PL2, BrngP0PL2, PseuPL2S, IniTimePL2S, 0) = \begin{bmatrix} 0.635 & 0 & 0 \\ 0.312 & 0 & 0 \\ 0.234 & 0 & 0 \\ 0.223 & 0 & 0 \end{bmatrix}$$

$$BrngEDRP0PL3 := BrngEDRPOPLSG(TDispTLdP0PL3, BrngP0PL3, PseuPL3S, IniTimePL3S, 0) = \begin{bmatrix} 0.611 & 0 & 0 \\ 0.249 & 0 & 0 \\ 0.17 & 0 & 0 \\ 0.109 & 0 & 0 \end{bmatrix}$$

$$BrngEDRP0PL4 := BrngEDRPOPLSG(TDispTLdP0PL4, BrngP0PL4, PseuPL4S, IniTimePL4S, 0) = \begin{bmatrix} 0.298 & 0 & 0 \\ 0.213 & 0 & 0 \\ 0.263 & 0 & 0 \\ 0.277 & 0 & 0 \end{bmatrix}$$

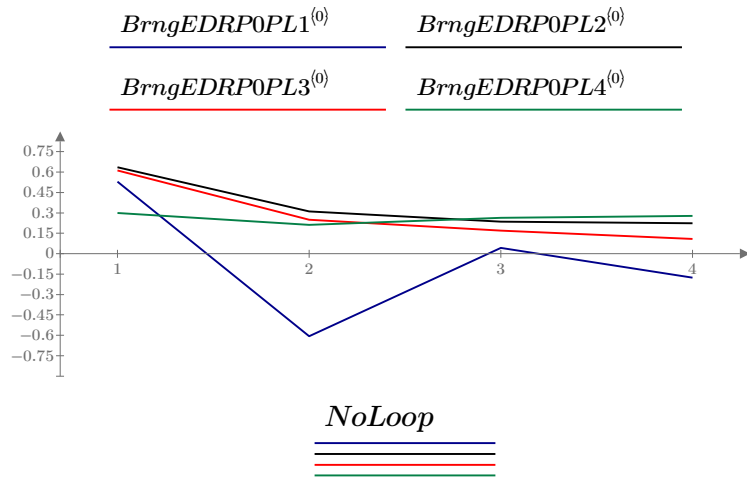


Fig B 53. Shaft EDR vs No of loops Helix Location 1 SG 1

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

1. Introduction

The series of sheets in Appendix B contains the data conversion and processing procedures specifically for the NI02 centrifuge test series. For the data conversion procedures, the raw data files were first corrected by subtracting the initial value of pre spin data depending on file index. The data were then converted into engineering units through recalibrations of the strain gauges in the centrifuge data logger.

2. HBM Data Conversion

HBM data were recorded by the HBM Data Logger connected to the main computer unit of the GeoCerf centrifuge.

2.1 General Information

2.1.1 Model Pile Dimensions

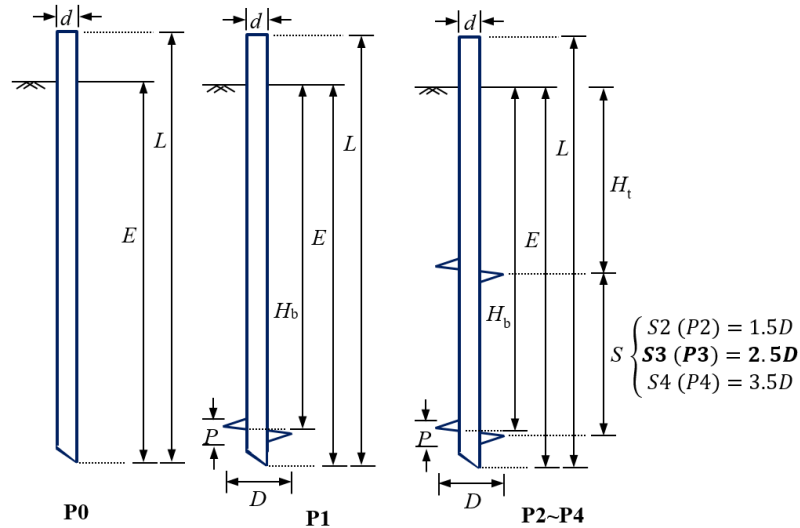
$L := 271.8 \text{ mm}$	Length of the Pile
$d := 12.7 \text{ mm}$	Diameter of the shaft
$D := 38.1 \text{ mm}$	Diameter of the helix
$E := 169.1 \text{ mm}$	Embedment depth of pile
$H_b := 150 \text{ mm}$	Depth to bottom helix
$H_t := [150] \text{ mm}$	Depth to top helix
$P_s := \pi \cdot D = 0.12 \text{ m}$	Perimeter of the Helical Pile Shaft
$H_{eff} := (H_b - D)$	Effective Shaft Length
$P := 12.7 \text{ mm}$	Pitch of the helix

2.1.2 Properties of Sand

$\gamma := 16.1 \frac{\text{kN}}{\text{m}^3}$	Unit Weight
$\varphi := 31.2 \text{ deg}$	CV Friction Angle
$\delta := \left(\frac{3}{4} \cdot \varphi\right) = 23.4 \text{ deg}$	CV Dilation Angle

2.1.3 Centrifuge Scale

$NoSGages := 4$	1 refers to the Strain Gage at the bottom and 4 the Strain Gage at the top of the pile; Total No of Strain Gages: P0=2, P1=3, P2 to P4= 4
$Nscale := 20$	Centrifuge g-level



Schematic of the model piles

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

$sclfac := [1 \ 2 \ 3]$ Centrifuge scale factor $N^{\wedge}scale$, 1 for displacement, 2 for force, 3 for Torque

2.1.5 Pseudostatic Loading Stages

2.1.5.1 Actuator Scale Factors

$$RateScale := \frac{8}{\frac{mm}{sec}} \quad \leq 1V8 = 1mm/sec$$

$$DistanScale := \frac{64000}{mm} \quad \leq 1D64000 = 1mm$$

2.1.5.2 Pseudostatic Loading Stages for Helix Piles (P1 to P4)

$$LDisp := \begin{bmatrix} 0.01 \\ 0.02 \\ 0.05 \\ 0.10 \\ 0.10 \end{bmatrix} \quad LNoLoop := \begin{bmatrix} 8 \\ 8 \\ 8 \\ 8 \\ 1 \end{bmatrix} \quad PsdoTLag := 5 \text{ s} \quad LRate := \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 0.33 \end{bmatrix} \frac{mm}{min}$$

$$LTime(Dia) := \left\| \begin{array}{l} \text{for } i \in 0, 1 \dots \text{rows}(LDisp) - 1 \\ \left\| \begin{array}{l} 2 \cdot LDisp_i \cdot Dia \cdot LNoLoop_i \\ k_i \leftarrow \frac{\quad}{LRate_i} + (PsdoTLag \cdot (LNoLoop_i - 1)) \end{array} \right\| \\ k \end{array} \right\|$$

$$LTime(D) = \begin{bmatrix} 400.76 \\ 766.52 \\ 1863.8 \\ 3692.6 \\ 1385.455 \end{bmatrix} \text{ s} \quad LTime(d) = \begin{bmatrix} 156.92 \\ 278.84 \\ 644.6 \\ 1254.2 \\ 461.818 \end{bmatrix} \text{ s}$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

2.2 Calibration of the Strain Gages in HBM Data Logger

2.2.1 Calibration of Axial Strain Gages

RawDataCalib := READEXCEL (“..\Finalized NI01\Calibration SGages HBM Centrifuge Corrected.xlsx”, “Sheet1!A1:G12”)

$$\text{RawDataCalib} = \begin{bmatrix} 4.427 & 1 & 0.076 & 0.104 & 0.149 & 0.098 & 0.132 \\ 7.97 & 1 & 0.152 & 0.171 & 0.23 & 0.195 & 0.244 \\ 13.606 & 1 & 0.391 & 0.295 & 0.343 & 0.287 & 0.336 \\ 4.427 & 2 & 0.048 & 0.06 & 0.078 & 0.091 & 0.1 \\ 7.97 & 2 & 0.053 & 0.114 & 0.114 & 0.136 & 0.194 \\ 13.606 & 2 & 0.088 & 0.214 & 0.161 & 0.225 & 0.231 \\ 4.427 & 3 & 0 & 0.043 & 0.028 & 0.052 & 0.037 \\ 7.97 & 3 & 0 & 0.063 & 0.151 & 0.087 & 0.078 \\ 13.606 & 3 & 0 & 0.127 & 0.199 & 0.149 & 0.112 \\ 4.427 & 4 & 0 & 0 & 0.089 & 0.035 & 0.028 \\ 7.97 & 4 & 0 & 0 & 0.109 & 0.067 & 0.055 \\ 13.606 & 4 & 0 & 0 & 0.145 & 0.127 & 0.141 \end{bmatrix}$$

Colm 0 represents calibration loads in kg, Colm 1 represents Strain Gage Number, Colm 2-6 represents Strain Gage HBM readings for piles P0,P1,P2,P3 and P4 respectively

CmbLdAx := RawDataCalib⁽⁰⁾ **kg • g** Load Combinations

CalibdataPile := submatrix (RawDataCalib, 0, rows (RawDataCalib) – 1, 2, 6) • 10⁻³ • $\frac{mV}{V}$ HBM Strain Gage Data

Function for Calibration factor for all strain gages in each pile

$$CF := \begin{array}{l} \text{for } i \in 0, 1 \dots \text{rows}(\text{CalibdataPile}) - 1 \\ \quad \text{for } j \in 0, 1 \dots \text{cols}(\text{CalibdataPile}) - 1 \\ \quad \quad k_{i,j} \leftarrow \text{CmbLdAx}_{i,0} \\ \quad \quad q_{i,j} \leftarrow \text{CalibdataPile}_{i,j} \\ \quad \quad m_{i,j} \leftarrow \text{if } q_{i,j} = 0 \\ \quad \quad \quad 0 \\ \quad \quad \quad \text{else} \\ \quad \quad \quad \frac{k_{i,j}}{q_{i,j}} \end{array} = \begin{bmatrix} 571.237 & 417.443 & 291.369 & 443 & 328.894 \\ 514.204 & 457.07 & 339.822 & 400.815 & 320.324 \\ 341.251 & 452.303 & 389.007 & 464.91 & 397.111 \\ 904.459 & 723.567 & 556.59 & 477.077 & 434.14 \\ 1474.698 & 685.605 & 685.605 & 574.699 & 402.881 \\ 1516.242 & 623.501 & 828.753 & 593.019 & 577.616 \\ 0 & 1009.629 & 1550.501 & 834.885 & 1173.352 \\ 0 & 1240.619 & 517.609 & 898.379 & 1002.038 \\ 0 & 1050.624 & 670.499 & 895.499 & 1191.333 \\ 0 & 0 & 487.798 & 1240.401 & 1550.501 \\ 0 & 0 & 717.055 & 1166.552 & 1421.073 \\ 0 & 0 & 920.202 & 1050.624 & 946.307 \end{bmatrix} \frac{kN}{mV}$$

Calibration Factor: Here, the columns represents the Piles from P0 to P4 (left to right) and the rows represents the Strain Gage readings SG1 to SG4 (top to bottom) for three load combinations

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

2.2.1 Calibration of Torque Strain Gages

RawDataTorque := READEXCEL (“..\Finalized NI01\Calibration Torque S Gages HBM Centrifuge .xlsx”, “Sheet1!J34:K36”)

$$\text{RawDataTorque} = \begin{bmatrix} 0.144 & 0.022 \\ 0.206 & 0.03 \\ 0.35 & 0.052 \end{bmatrix} \quad \text{CmbLdTr} := \text{RawDataTorque}^{(0)} \mathbf{N} \cdot \mathbf{m} \quad \text{CalibdataTr} := \text{RawDataTorque}^{(1)} \cdot 10^{-3} \cdot \frac{\mathbf{mV}}{\mathbf{V}}$$

Function for Calibration factor for all torsional load on strain gages in each pile

$$\text{CFTr} := \left\| \begin{array}{l} \text{for } i \in 0, 1 \dots \text{rows}(\text{CalibdataTr}) - 1 \\ \quad \left\| \begin{array}{l} \text{for } j \in 0, 1 \dots \text{cols}(\text{CalibdataTr}) - 1 \\ \quad \left\| \begin{array}{l} k_{i,j} \leftarrow \text{CmbLdTr}_{i,0} \\ q_{i,j} \leftarrow \text{CalibdataTr}_{i,j} \\ m_{i,j} \leftarrow \text{if } q_{i,j} = 0 \\ \quad \left\| 0 \\ \quad \text{else} \\ \quad \quad \left\| \frac{k_{i,j}}{q_{i,j}} \end{array} \right\| \end{array} \right\| \end{array} \right\| \end{array} \right\| = \begin{bmatrix} 6.674 \\ 6.813 \\ 6.763 \end{bmatrix} \mathbf{m} \cdot \frac{\mathbf{kN}}{\frac{\mathbf{mV}}{\mathbf{V}}}$$

2.3 Pseudostatic Cyclic Centrifuge Test on Piles

Five piles were tested in compression and four piles were tested in tension in two separate model boxes two ascertain the axial load transfer mechanism within the pile.

2.3.1 Pseudostatic Cyclic Displacement Time History

$$\text{Lag} := 5 \quad \text{LagCyc} := 100 \quad \text{LoadCycRate} := 1 \frac{\mathbf{mm}}{\mathbf{min}} = 0.017 \frac{\mathbf{mm}}{\mathbf{s}} \quad \text{LoadCompRate} := 0.33 \frac{\mathbf{mm}}{\mathbf{min}} = 0.006 \frac{\mathbf{mm}}{\mathbf{s}}$$

Actuator Loading rate in cyclic Actuator Loading rate in compression

$$\text{NormDisp} := \begin{bmatrix} 0.01 \\ 0.02 \\ 0.05 \\ 0.1 \\ 0.2 \end{bmatrix} \quad \text{NormDispPeakCycles} := 2 \cdot \begin{bmatrix} \text{NormDisp}_0 \\ \text{NormDisp}_1 \\ \text{NormDisp}_2 \\ \text{NormDisp}_3 \end{bmatrix} = \begin{bmatrix} 0.02 \\ 0.04 \\ 0.1 \\ 0.2 \end{bmatrix}$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Function for calculating time required for each pseudostatic load

```

Time(Dia) := for j ∈ 0,1..3
  for i ∈ 0,1..4
    k ← NormDisp
    p ←  $\frac{Dia}{m}$ 
    z ←  $\frac{LoadCycRate}{s}$ 
    x ←  $\frac{LoadCompRate}{m}$ 
     $q_{0,0} \leftarrow k_{0,0} \cdot \frac{p}{z}$ 
     $q_{1,0} \leftarrow k_{1,0} \cdot \frac{p}{z}$ 
     $q_{2,0} \leftarrow k_{2,0} \cdot \frac{p}{z}$ 
     $q_{3,0} \leftarrow k_{3,0} \cdot \frac{p}{z}$ 
     $q_{4,0} \leftarrow k_{4,0} \cdot \frac{p}{x}$ 
  end for
end for

```

$$TimeHelix := Time(D) = \begin{bmatrix} 22.86 \\ 45.72 \\ 114.3 \\ 228.6 \\ 1385.455 \end{bmatrix}$$

$$TimeShaft := Time(d) = \begin{bmatrix} 7.62 \\ 15.24 \\ 38.1 \\ 76.2 \\ 461.818 \end{bmatrix}$$

Function for calculating initial time required for each pseudostatic load

```

DispIniTime(DispHelixShaft) := for j ∈ 0,1..3
  for i ∈ 0,1..5
     $q_{0,0} \leftarrow 0$ 
     $q_{1,0} \leftarrow \left( (16 \cdot DispHelixShaft_{0,0}) + (7 \cdot Lag) + LagCyc \right)$ 
     $q_{2,0} \leftarrow q_{1,0} + \left( (16 \cdot DispHelixShaft_{1,0}) + (7 \cdot Lag) + (LagCyc) \right)$ 
     $q_{3,0} \leftarrow q_{2,0} + \left( (16 \cdot DispHelixShaft_{2,0}) + (7 \cdot Lag) + (LagCyc) \right)$ 
     $q_{4,0} \leftarrow q_{3,0} + \left( (16 \cdot DispHelixShaft_{3,0}) + (7 \cdot Lag) + (LagCyc) \right)$ 
  end for
end for

```

$$IniTimeHelix := DispIniTime(TimeHelix) = \begin{bmatrix} 0 \\ 500.76 \\ 1367.28 \\ 3331.08 \\ 7123.68 \end{bmatrix}$$

$$IniTimeShaft := DispIniTime(TimeShaft) = \begin{bmatrix} 0 \\ 256.92 \\ 635.76 \\ 1380.36 \\ 2734.56 \end{bmatrix}$$

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

$PseuPL1H := \begin{bmatrix} TimeHelix_{0,0} & NormDisp_{0,0} \end{bmatrix}$	$IniTimePL1H := DispIniTime(TimeHelix)_{0,0} = 0$	$IniDisp := 0$
$PseuPL2H := \begin{bmatrix} TimeHelix_{1,0} & NormDisp_{1,0} \end{bmatrix}$	$IniTimePL2H := DispIniTime(TimeHelix)_{1,0} = 500.76$	
$PseuPL3H := \begin{bmatrix} TimeHelix_{2,0} & NormDisp_{2,0} \end{bmatrix}$	$IniTimePL3H := DispIniTime(TimeHelix)_{2,0} = 1.367 \cdot 10^3$	
$PseuPL4H := \begin{bmatrix} TimeHelix_{3,0} & NormDisp_{3,0} \end{bmatrix}$	$IniTimePL4H := DispIniTime(TimeHelix)_{3,0} = 3.331 \cdot 10^3$	
$PseuCLH := \begin{bmatrix} TimeHelix_{4,0} & NormDisp_{4,0} \end{bmatrix}$	$IniTimeCLH := DispIniTime(TimeHelix)_{4,0} = 7.124 \cdot 10^3$	
$PseuPL1S := \begin{bmatrix} TimeShaft_{0,0} & NormDisp_{0,0} \end{bmatrix}$	$IniTimePL1S := DispIniTime(TimeShaft)_{0,0} = 0$	$IniDisp := 0$
$PseuPL2S := \begin{bmatrix} TimeShaft_{1,0} & NormDisp_{1,0} \end{bmatrix}$	$IniTimePL2S := DispIniTime(TimeShaft)_{1,0} = 256.92$	
$PseuPL3S := \begin{bmatrix} TimeShaft_{2,0} & NormDisp_{2,0} \end{bmatrix}$	$IniTimePL3S := DispIniTime(TimeShaft)_{2,0} = 635.76$	
$PseuPL4S := \begin{bmatrix} TimeShaft_{3,0} & NormDisp_{3,0} \end{bmatrix}$	$IniTimePL4S := DispIniTime(TimeShaft)_{3,0} = 1.38 \cdot 10^3$	
$PseuCLS := \begin{bmatrix} TimeShaft_{4,0} & NormDisp_{4,0} \end{bmatrix}$	$IniTimeCLS := DispIniTime(TimeShaft)_{4,0} = 2.735 \cdot 10^3$	

Function for calculating time required for each cycle of the pseudostatic loads

```

TimeCycLoop(Pseu1per, IniTimeHelix, IniDisp) :=
  for j ∈ 0, 1 .. 3
    for i ∈ 0, 1 .. 40000
      q0,0 ← IniTimeHelix
      diff ← 0.1
      qi+1,0 ← qi,0 + diff
      q0,1 ← IniDisp
      Lag ← 5
      LagCyc ← 100
      k0,0 ← q0,0
      k1,0 ← ((q0,0 + 4 · Pseu1per0,0) + (2 · Lag))
      k2,0 ← ((q0,0 + 8 · Pseu1per0,0) + (4 · Lag))
      k3,0 ← ((q0,0 + 12 · Pseu1per0,0) + (6 · Lag))
      k4,0 ← ((q0,0 + 16 · Pseu1per0,0) + (7 · Lag) + LagCyc)
    k
  
```

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Function for calculating displacement increments for each cycles of the pseudostatic loads

```

DispCyc(Pseu1per, IniTimeHelix, IniDisp) :=
  for j ∈ 0, 1..3
  for i ∈ 0, 1..40000
    q0,0 ← IniTimeHelix
    diff ← 0.1
    qi+1,0 ← qi,0 + diff
    q0,1 ← IniDisp
    Lag ← 5
    LagCyc ← 100
    qi+1,0 ← if qi+1,0 ≤ ((q0,0 + 16 • Pseu1per0,0) + (7 • Lag) + LagCyc)
      qi+1,0
    else if qi+1,0 > ((q0,0 + 16 • Pseu1per0,0) + (7 • Lag) + LagCyc)
      break
    qi+1,1 ← if (qi+1,0) ≤ (q0,0 + 2 • Pseu1per0,0)
      (qi+1,0 - q0,0) / ((q0,0 + 2 • Pseu1per0,0) - q0,0) • (2 • Pseu1per0,1)
    else if (q0,0 + 2 • Pseu1per0,0) < qi+1,0 ≤ ((q0,0 + 2 • Pseu1per0,0) + Lag)
      2 • Pseu1per0,1
    else if ((q0,0 + 2 • Pseu1per0,0) + Lag) < qi+1,0 ≤ ((q0,0 + 4 • Pseu1per0,0) + Lag)
      ((q0,0 + 4 • Pseu1per0,0) + Lag - qi+1,0) / (((q0,0 + 4 • Pseu1per0,0) + Lag) - ((q0,0 + 2 • Pseu1per0,0) + Lag)) • (2 • Pseu1per0,1)
    else if ((q0,0 + 4 • Pseu1per0,0) + Lag) < qi+1,0 ≤ ((q0,0 + 4 • Pseu1per0,0) + (2 • Lag))
      q0,1
    else if ((q0,0 + 4 • Pseu1per0,0) + (2 • Lag)) < qi+1,0 ≤ ((q0,0 + 6 • Pseu1per0,0) + (2 • Lag))
      (qi+1,0 - ((q0,0 + 4 • Pseu1per0,0) + (2 • Lag))) / (((q0,0 + 6 • Pseu1per0,0) + 2 • Lag) - ((q0,0 + 4 • Pseu1per0,0) + (2 • Lag))) • (2 • Pseu1per0,1)
    else if ((q0,0 + 6 • Pseu1per0,0) + (2 • Lag)) < qi+1,0 ≤ ((q0,0 + 6 • Pseu1per0,0) + (3 • Lag))
      2 • Pseu1per0,1
    else if ((q0,0 + 6 • Pseu1per0,0) + (3 • Lag)) < qi+1,0 ≤ ((q0,0 + 8 • Pseu1per0,0) + (3 • Lag))
      (((q0,0 + 8 • Pseu1per0,0) + (3 • Lag)) - qi+1,0) / (((q0,0 + 8 • Pseu1per0,0) + (3 • Lag)) - ((q0,0 + 6 • Pseu1per0,0) + (3 • Lag))) • (2 • Pseu1per0,1)
    else if ((q0,0 + 8 • Pseu1per0,0) + (3 • Lag)) < qi+1,0 ≤ ((q0,0 + 8 • Pseu1per0,0) + (4 • Lag))
      q0,1
    else if ((q0,0 + 8 • Pseu1per0,0) + (4 • Lag)) < qi+1,0 ≤ ((q0,0 + 10 • Pseu1per0,0) + (4 • Lag))

```


Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

8

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Function for calculating displacement for the monotonic loads

```

DispComp(Pseu1per,IniTime,IniDisp):=
  for j ∈ 0,1..3
  for i ∈ 0,1..40000
    q0,0 ← IniTime
    diff ← 0.1
    qi+1,0 ← qi,0 + diff
    qi+1,0 ← if (qi+1,0) ≤ (q0,0 + Pseu1per0,0)
              || qi+1,0
              || else if qi+1,0 > (q0,0 + Pseu1per0,0)
              || break
    q0,1 ← IniDisp
    qi+1,1 ← if (qi+1,0) ≤ (q0,0 + Pseu1per0,0)
              ||  $\frac{(q_{i+1,0} - q_{0,0})}{((q_{0,0} + Pseu1per_{0,0}) - q_{0,0})} \cdot (Pseu1per_{0,1})$ 
              || else
              || qi+1,1
  q

```

$LdTimePL1H := DispCyc(PseuPL1H, IniTimePL1H, IniDisp)$

$LdTimePL2H := DispCyc(PseuPL2H, IniTimePL2H, IniDisp)$

$LdTimePL3H := DispCyc(PseuPL3H, IniTimePL3H, IniDisp)$

$LdTimePL4H := DispCyc(PseuPL4H, IniTimePL4H, IniDisp)$

$LdTimeCLH := DispComp(PseuCLH, IniTimeCLH, IniDisp)$

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

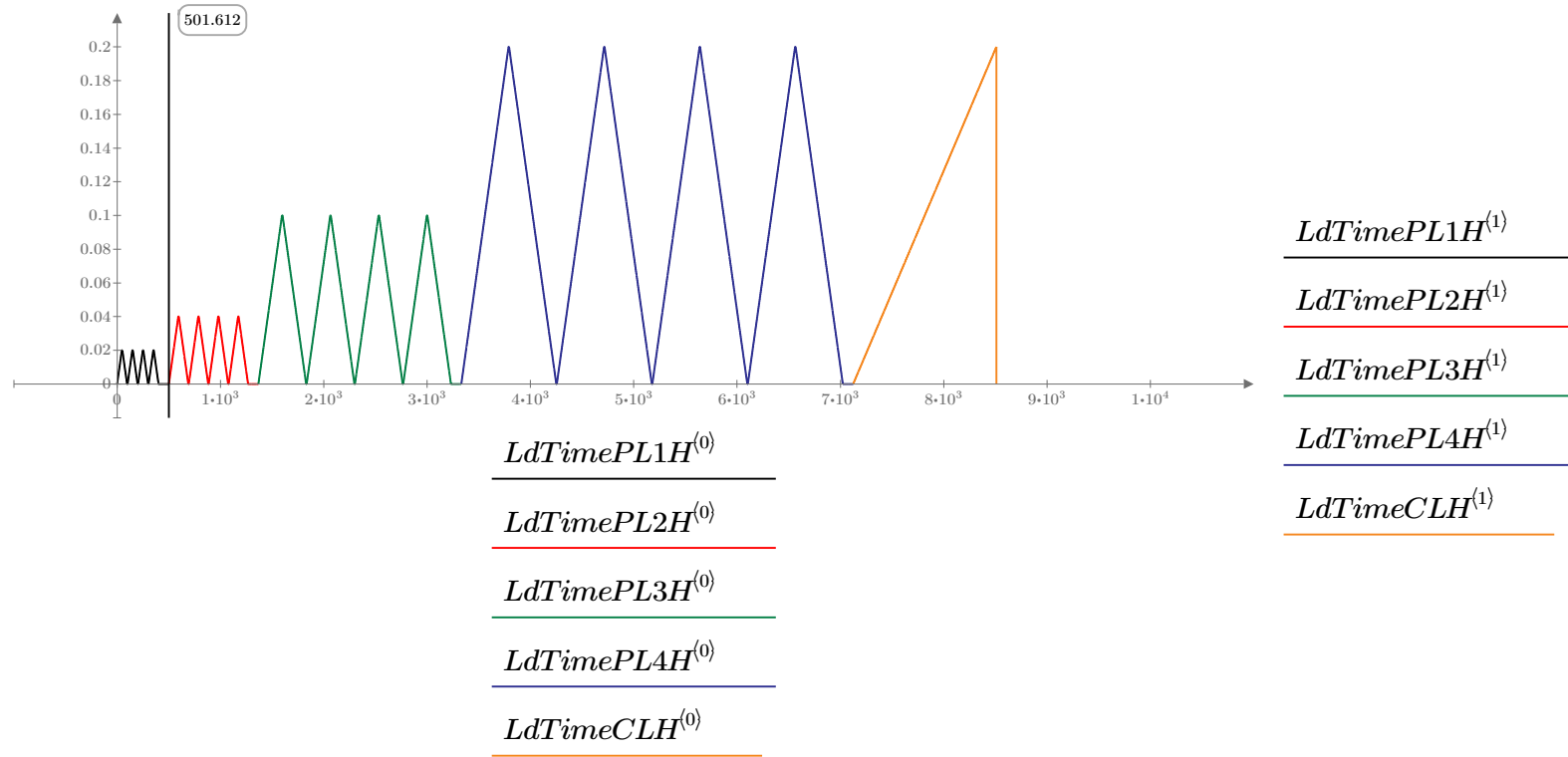


Fig C 1. DisplacementTime History for the Helix Piles

$$LdTimePL1S := DispCyc(PseuPL1S, IniTimePL1S, IniDisp)$$

$$LdTimePL2S := DispCyc(PseuPL2S, IniTimePL2S, IniDisp)$$

$$LdTimePL3S := DispCyc(PseuPL3S, IniTimePL3S, IniDisp)$$

$$LdTimePL4S := DispCyc(PseuPL4S, IniTimePL4S, IniDisp)$$

$$LdTimeCLS := DispComp(PseuCLS, IniTimeCLS, IniDisp)$$

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

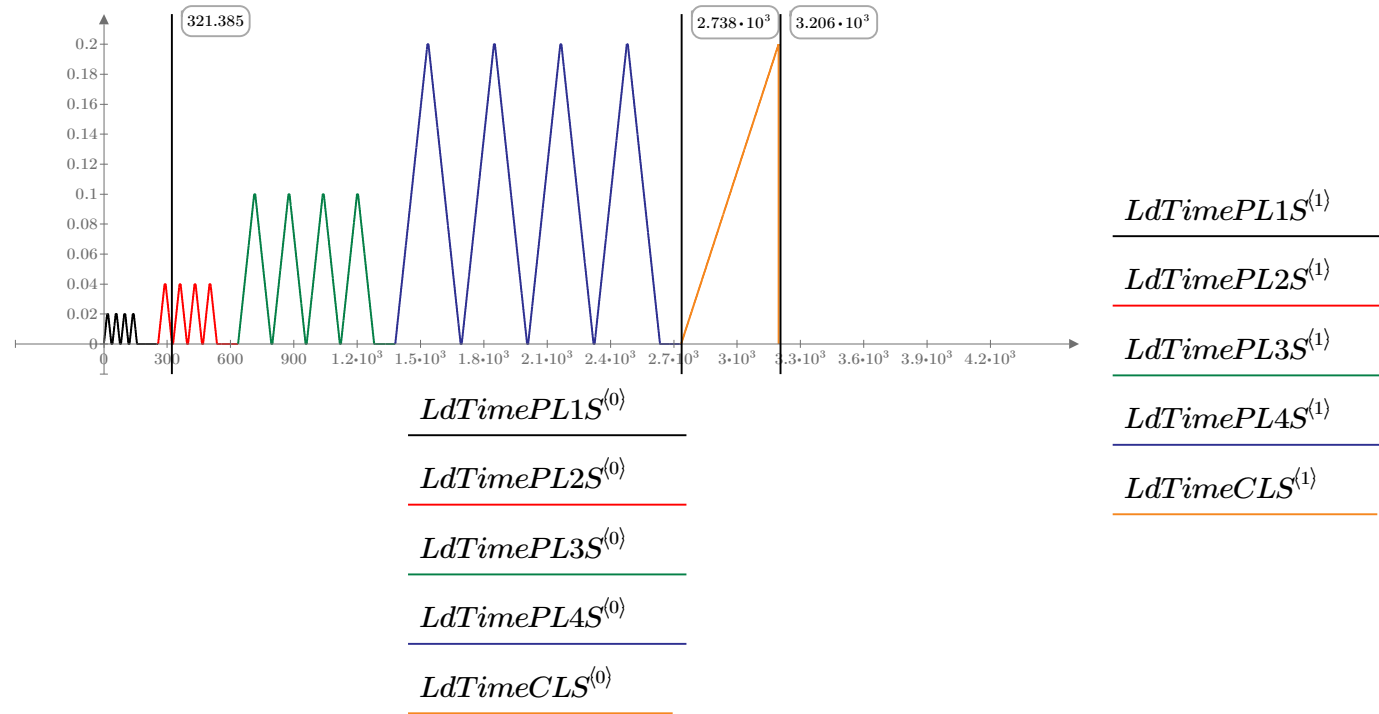


Fig C 2. DisplacementTime History for the smooth pile.

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

2.3.2 Axial Load vs Time

Function for determining the Axial Load Distribution in each pile

```

AxlLd (Rawdata ,PileNum) :=
  for i ∈ 0,1..rows(Rawdata) - 1
    for j ∈ 0,1..cols(Rawdata) - 1
      qi,j ← Rawdatai,j - Rawdata0,j
      SG1i,0 ← qi,0 • mean(submatrix(CF,0,2,PileNum,PileNum)) • Nscalesclfac0,1
      SG2i,1 ← qi,1 • mean(submatrix(CF,3,5,PileNum,PileNum)) • Nscalesclfac0,1
      SG3i,2 ← qi,2 • mean(submatrix(CF,6,8,PileNum,PileNum)) • Nscalesclfac0,1
      SG4i,3 ← qi,3 • mean(submatrix(CF,9,11,PileNum,PileNum)) • Nscalesclfac0,1
  augment(SG1(0),SG2(1),SG3(2),SG4(3))

```

Function for determining the Time, Displacement Input to Time Axial Load Distribution output in each pile

```

TDispTld (LdTime1perS ,TimeP0 ,AxLdP0 ,LdNo) :=
  m ← TimeP0
  n ← AxLdP0
  p ← LdTime1perS
  q ←
    if LdNo = 1
      m0
    else if LdNo = 2
      m1
    else if LdNo = 3
      m2
    else if LdNo = 4
      m3
    else if LdNo = 5
      m4
  k ←
    if LdNo = 1
      n0
    else if LdNo = 2
      n1
    else if LdNo = 3
      n2
    else if LdNo = 4
      n3
    else if LdNo = 5
      n

```

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

$$\begin{aligned}
 & \text{if } \text{rows}(p) > \text{rows}(q) \\
 & \quad q \\
 & \text{else if } \text{rows}(p) < \text{rows}(q) \\
 & \quad p \\
 & tdisp \leftarrow \text{submatrix}(LdTime1perS^{(0)}, 0, \text{rows}(o) - 1, 0, 0) \\
 & disp \leftarrow \text{submatrix}(-LdTime1perS^{(1)}, 0, \text{rows}(o) - 1, 0, 0) \\
 & tld \leftarrow \text{submatrix}\left(\frac{q}{s}, 0, \text{rows}(o) - 1, 0, 0\right) \\
 & ld1 \leftarrow \text{medsmooth}\left(\text{submatrix}\left(\frac{k^{(0)}}{kN}, 0, \text{rows}(o) - 1, 0, 0\right), 11\right) \\
 & ld2 \leftarrow \text{medsmooth}\left(\text{submatrix}\left(\frac{k^{(1)}}{kN}, 0, \text{rows}(o) - 1, 0, 0\right), 11\right) \\
 & ld3 \leftarrow \text{medsmooth}\left(\text{submatrix}\left(\frac{k^{(2)}}{kN}, 0, \text{rows}(o) - 1, 0, 0\right), 11\right) \\
 & ld4 \leftarrow \text{medsmooth}\left(\text{submatrix}\left(\frac{k^{(3)}}{kN}, 0, \text{rows}(o) - 1, 0, 0\right), 11\right) \\
 & \text{augment}(tdisp, disp, tld, ld1, ld2, ld3, ld4)
 \end{aligned}$$

There were three strain gages placed within the P1 pile. The following sub sections provides the details on the load distributions:

$$\begin{aligned}
 P1HBM &:= \begin{bmatrix} \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P1_PL1!A1:E6092"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P1_PL2!A1:E8913"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P1_PL3!A1:E21391"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P1_PL4!A1:E38818"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P1_CL!A1:E15799"}) \end{bmatrix} \\
 TimeP1 &:= \begin{bmatrix} \text{for } i \in 0, 1..4 \\ \quad q_i \leftarrow \text{submatrix}(P1HBM_i, 0, \text{rows}(P1HBM_i) - 1, 0, 0) \end{bmatrix} s = \begin{bmatrix} [6092 \times 1] \text{ } s \\ [8913 \times 1] \text{ } s \\ [21391 \times 1] \text{ } s \\ [38818 \times 1] \text{ } s \\ [15799 \times 1] \text{ } s \end{bmatrix} \\
 RawdataP1 &:= \begin{bmatrix} \text{for } i \in 0, 1..4 \\ \quad q_i \leftarrow \text{submatrix}(P1HBM_i, 0, \text{rows}(P1HBM_i) - 1, 1, 4) \frac{mV}{V} \end{bmatrix} = \begin{bmatrix} [6092 \times 4] \\ [8913 \times 4] \\ [21391 \times 4] \\ [38818 \times 4] \\ [15799 \times 4] \end{bmatrix}
 \end{aligned}$$

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

$$AxLdP1 := \left\| \begin{array}{l} \text{for } i \in 0, 1 \dots 4 \\ \left\| q_i \leftarrow AxLd \left(RawdataP1_i, 1 \right) \right\| \\ q \end{array} \right\| = \begin{bmatrix} [6092 \times 4] \\ [8913 \times 4] \\ [21391 \times 4] \\ [38818 \times 4] \\ [15799 \times 4] \end{bmatrix} \text{ kN}$$

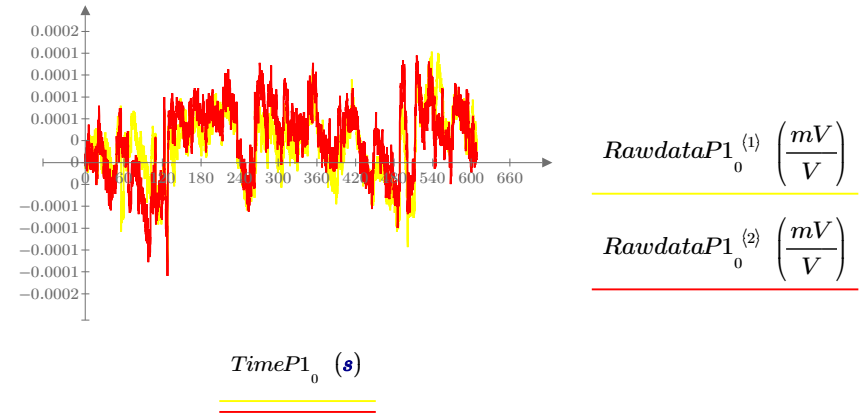
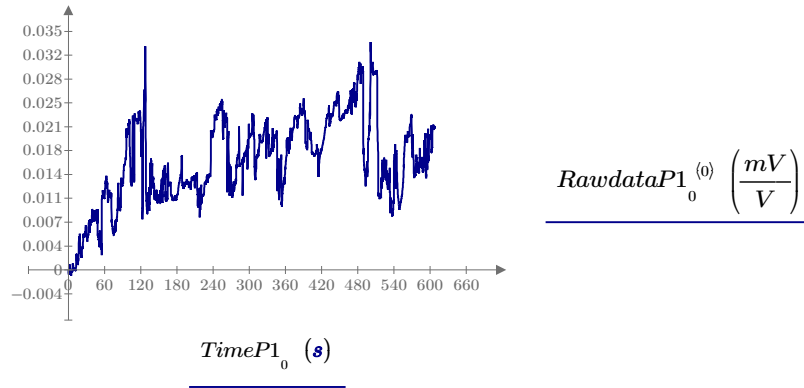


Fig C 3. Rawdata time history for compression pile P1 PL1

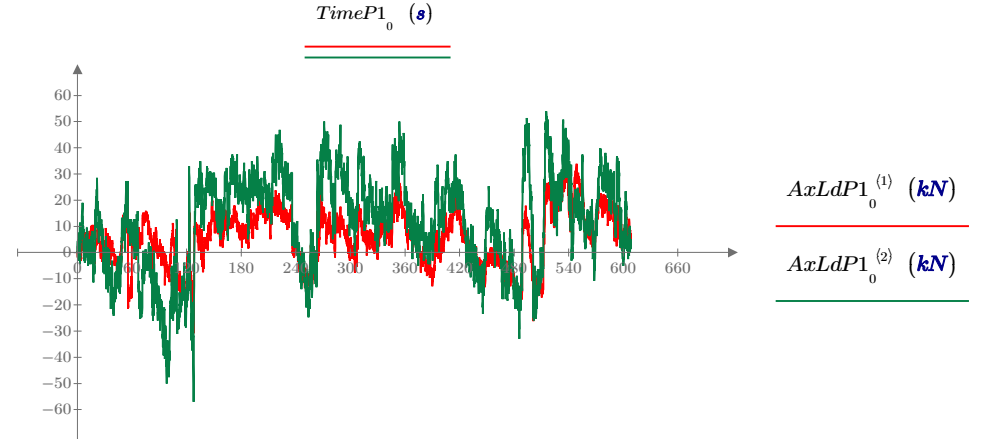
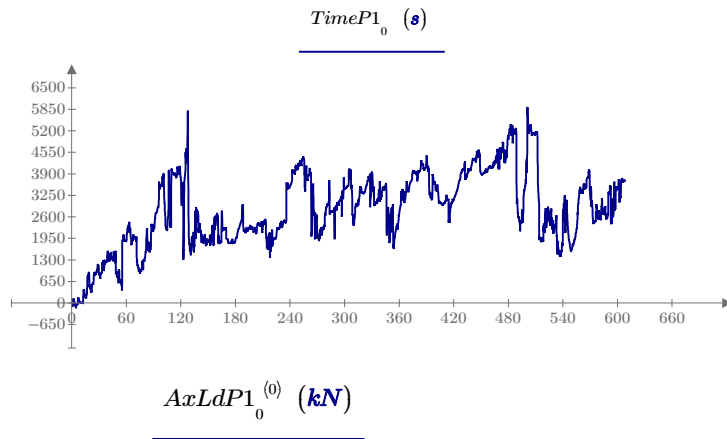


Fig C 4. Load time history for compression pile P1 PL1

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

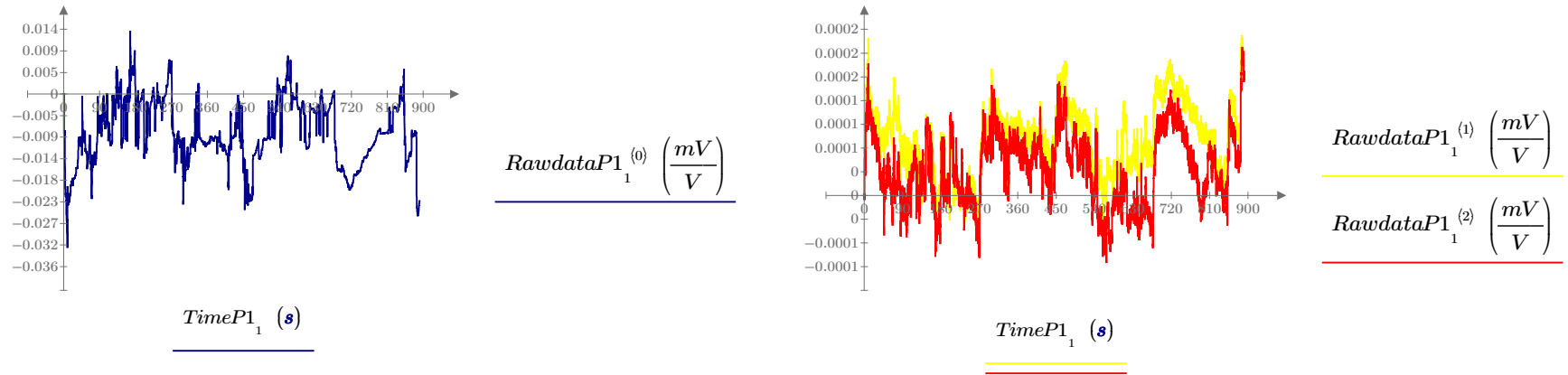


Fig C 5. Rawdata time history for compression pile P1 PL2

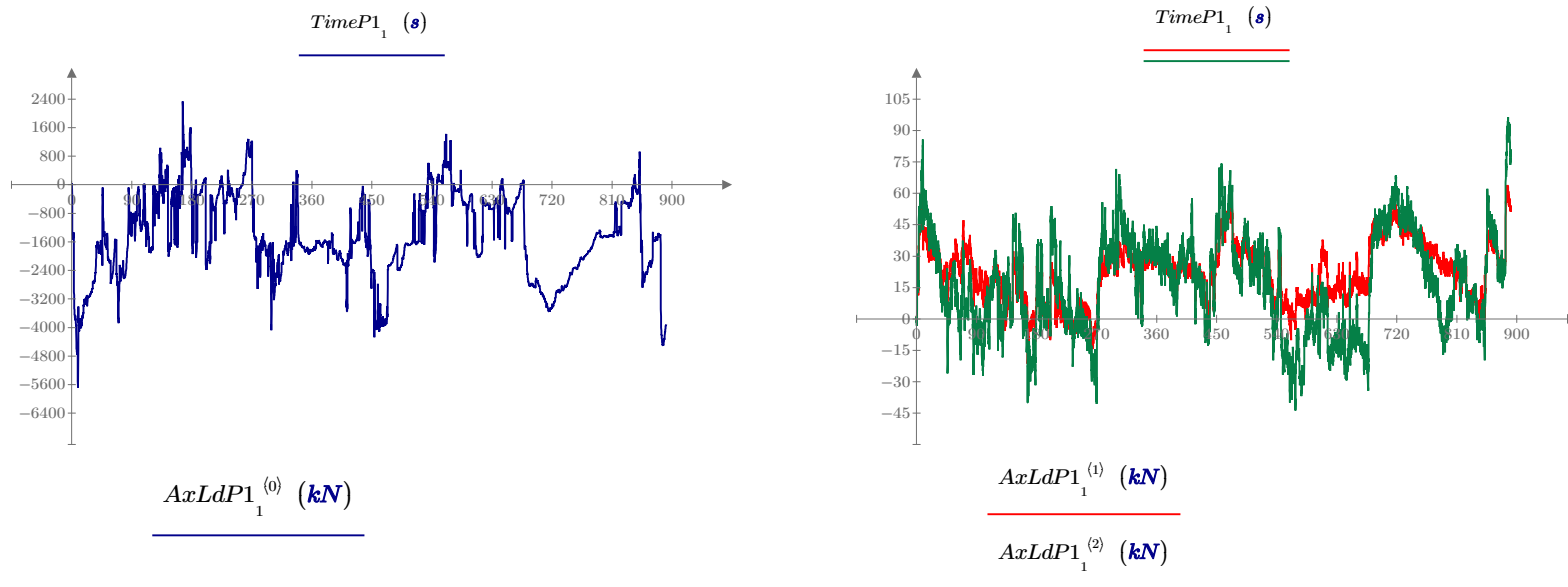


Fig C 6. Load time history for compression pile P1 PL2

0.045

0.0001

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

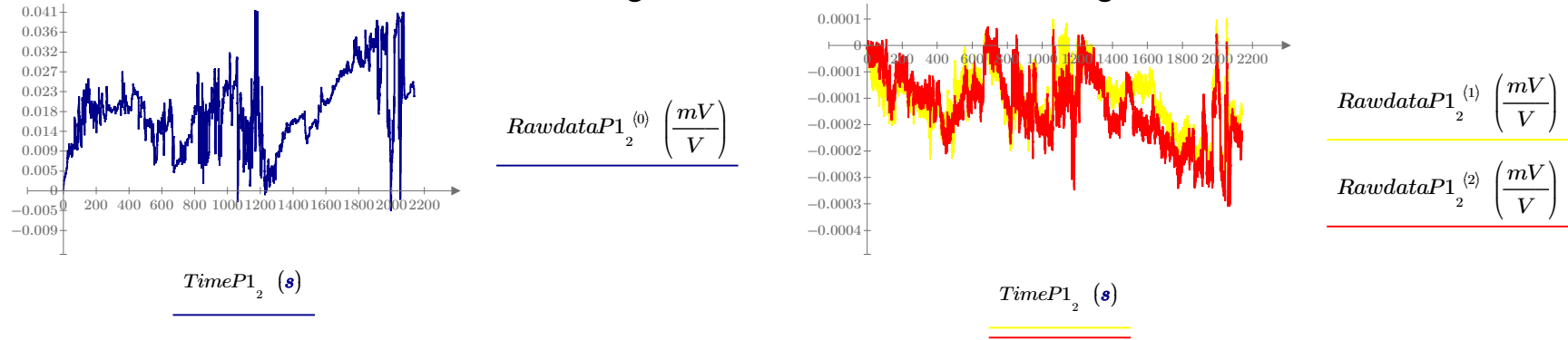


Fig C 7. Rawdata time history for compression pile P1 PL3

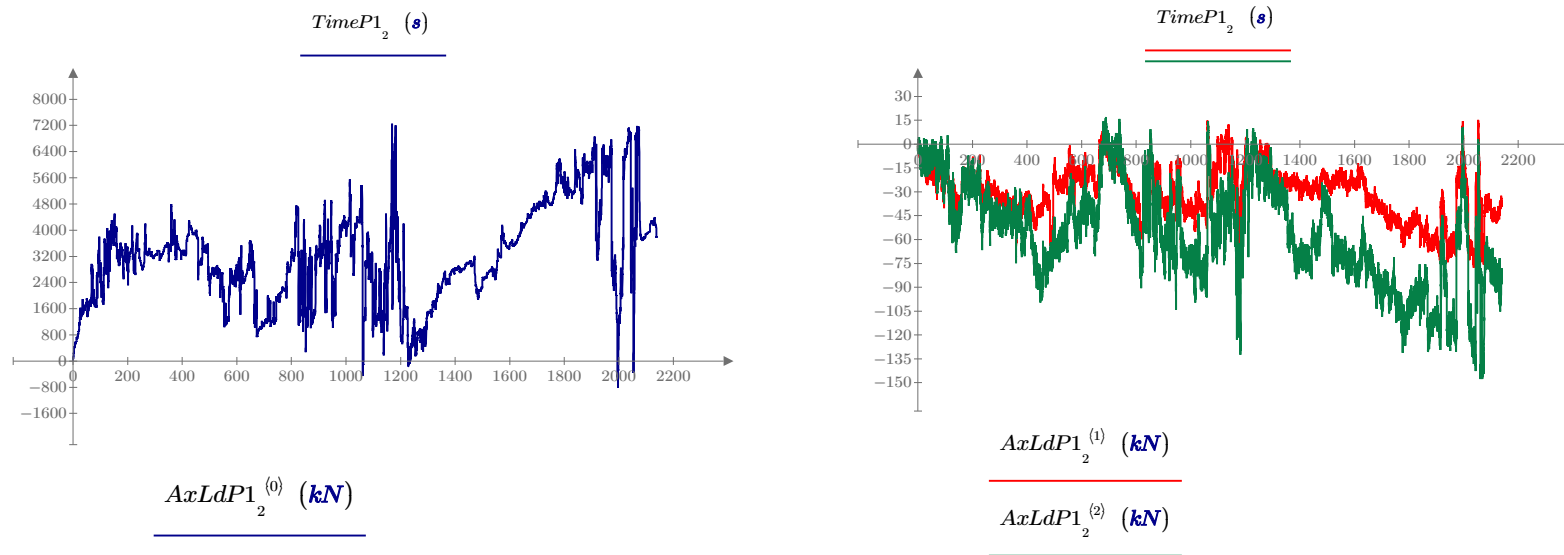


Fig C 8. Load time history for compression pile P1 PL3

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

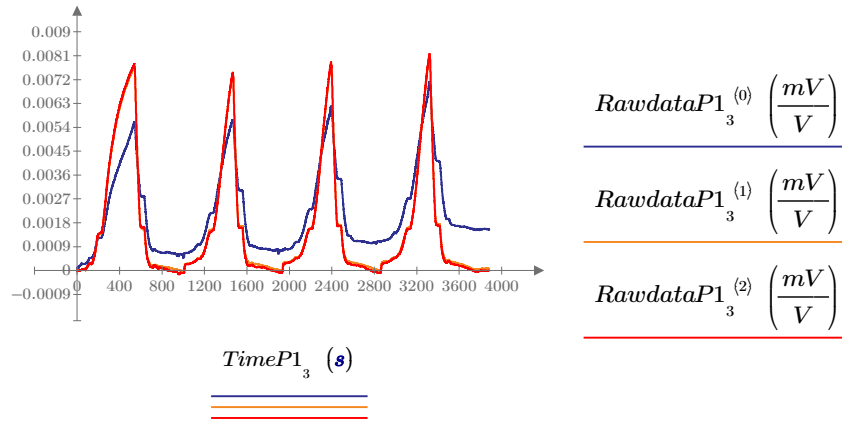


Fig C 9. Rawdata time history for compression pile P1 PL4

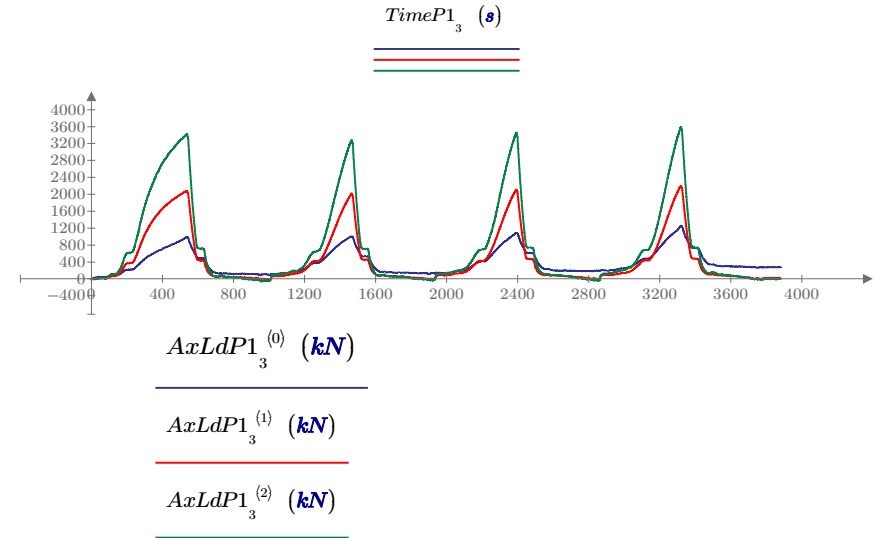


Fig C 10. Load time history for compression pile P1 PL4

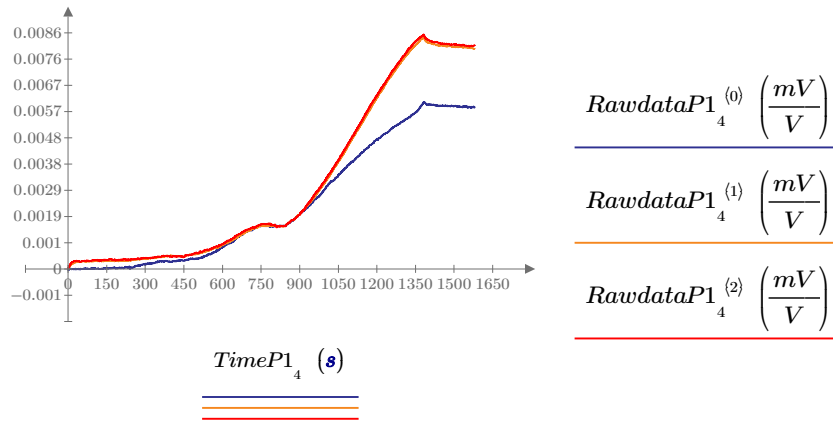


Fig C 11. Rawdata time history for compression pile P1 CL

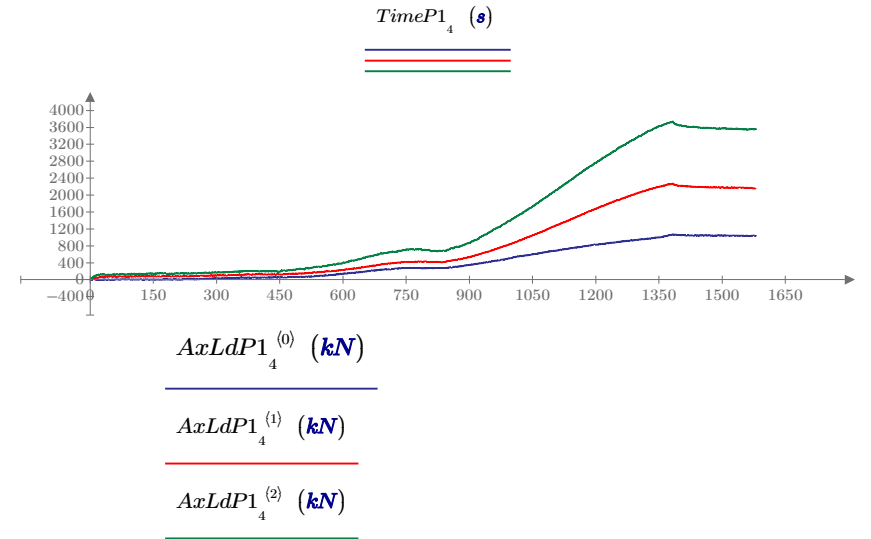


Fig C 12. Load time history for compression pile P1 CL

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for psuedostatic load PL1

$$TDispTLdP1PL1 := TDispTLd(LdTimePL1H, TimeP1, AxLdP1, 1) =$$

0	0	0	-55.323	0.195	0.317	0
1	0.1	$-4.374 \cdot 10^{-5}$	0.1	-63.736	0.391	0.634
2	0.2	$-8.749 \cdot 10^{-5}$	0.2	-69.09	0.781	1.269
3	0.3	$-1.312 \cdot 10^{-4}$	0.3	-74.444	1.172	0.634
4	0.4	$-1.75 \cdot 10^{-4}$	0.4	-69.09	1.367	0.317
5	0.5	$-2.187 \cdot 10^{-4}$	0.5	-70.365	1.172	0.634
6	0.6	$-2.625 \cdot 10^{-4}$	0.6	-70.365	1.172	1.903
7	0.7	$-3.062 \cdot 10^{-4}$	0.7	-70.365	1.172	0.634
8	0.8	$-3.5 \cdot 10^{-4}$	0.8	-70.365	1.172	0
9	0.9	$-3.937 \cdot 10^{-4}$	0.9	-63.736	1.172	0
10	1	$-4.374 \cdot 10^{-4}$	1	-48.694	1.172	0.634
11	1.1	$-4.812 \cdot 10^{-4}$	1.1	-46.91	1.172	0.634
⋮						⋮
5008						

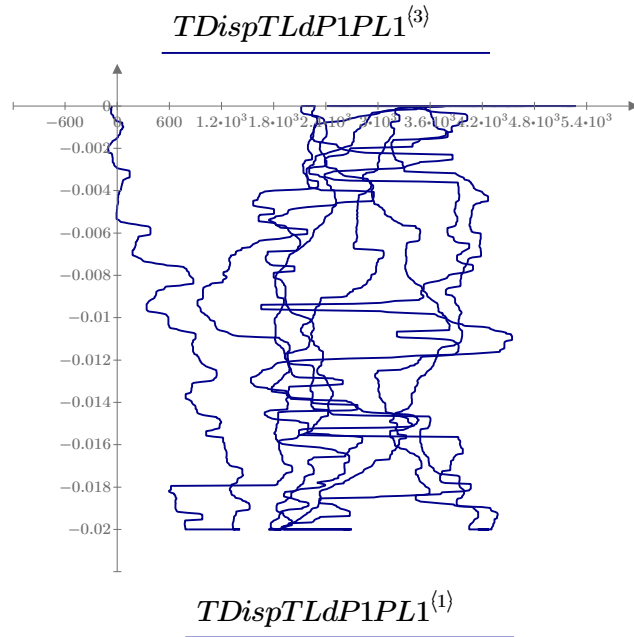


Fig C 13. Load displacement for compression pile P1 PL1 SG1

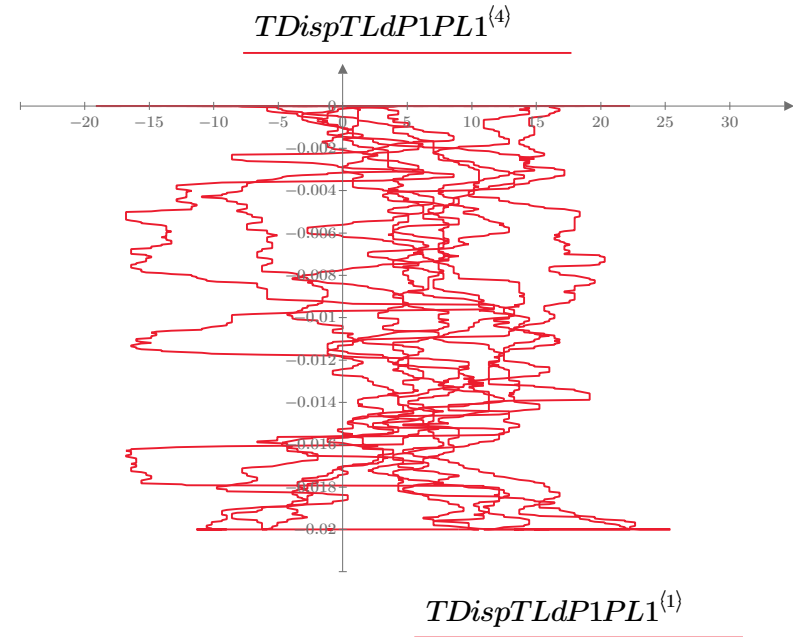


Fig C 14. Load displacement for compression pile P1 PL1 SG2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

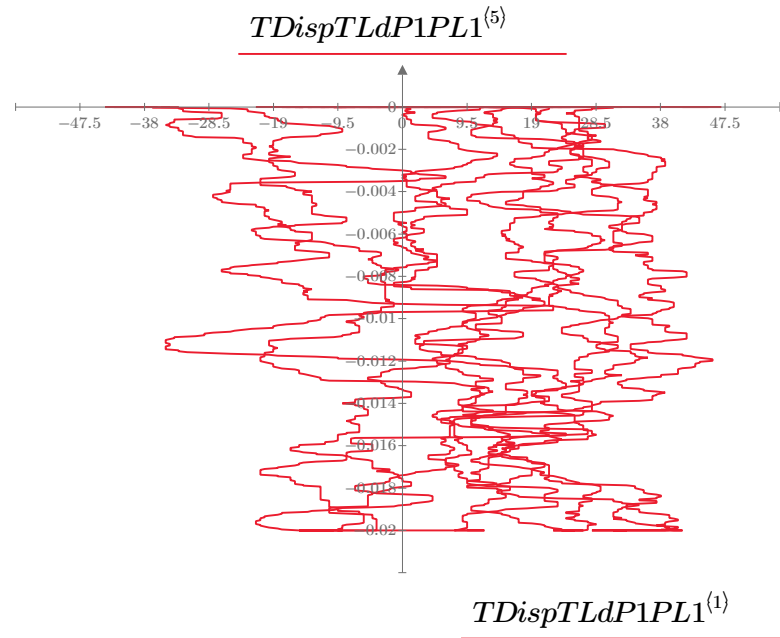


Fig C 15. Load displacement for compression pile P1 PL1 SG3

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for psuedostatic load PL2

$$TDispTLdP1PL2 := TDispTLd(LdTimePL2H, TimeP1, AxLdP1, 2) =$$

0	500.76	0	0	18.866	0	-1.586	0
1	500.86	$-4.374 \cdot 10^{-5}$	0.1	21.67	0	-1.903	0
2	500.96	$-8.749 \cdot 10^{-5}$	0.2	18.866	0	-1.269	0
3	501.06	$-1.312 \cdot 10^{-4}$	0.3	16.061	0	-0.634	0
4	501.16	$-1.75 \cdot 10^{-4}$	0.4	11.217	0	-0.317	0
5	501.26	$-2.187 \cdot 10^{-4}$	0.5	6.374	0	0	0
6	501.36	$-2.625 \cdot 10^{-4}$	0.6	6.374	0.391	1.269	0
7	501.46	$-3.062 \cdot 10^{-4}$	0.7	-364.061	1.562	4.44	0
8	501.56	$-3.5 \cdot 10^{-4}$	0.8	$-1.203 \cdot 10^3$	10.155	24.102	0
9	501.66	$-3.937 \cdot 10^{-4}$	0.9	$-1.33 \cdot 10^3$	12.108	25.37	0
10	501.76	$-4.374 \cdot 10^{-4}$	1	$-1.35 \cdot 10^3$	12.498	26.639	0
11	501.86	$-4.812 \cdot 10^{-4}$	1.1	$-1.407 \cdot 10^3$	12.498	27.907	0
⋮							⋮
8666							

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

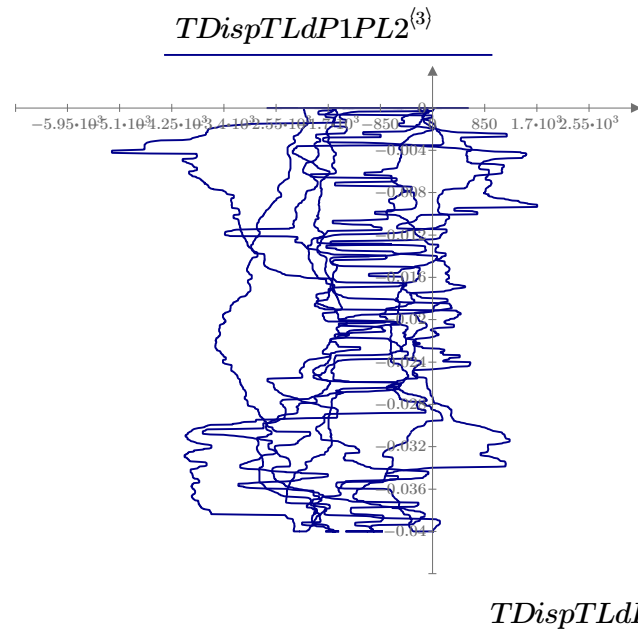


Fig C 16. Load displacement for compression pile P1 PL2 SG1

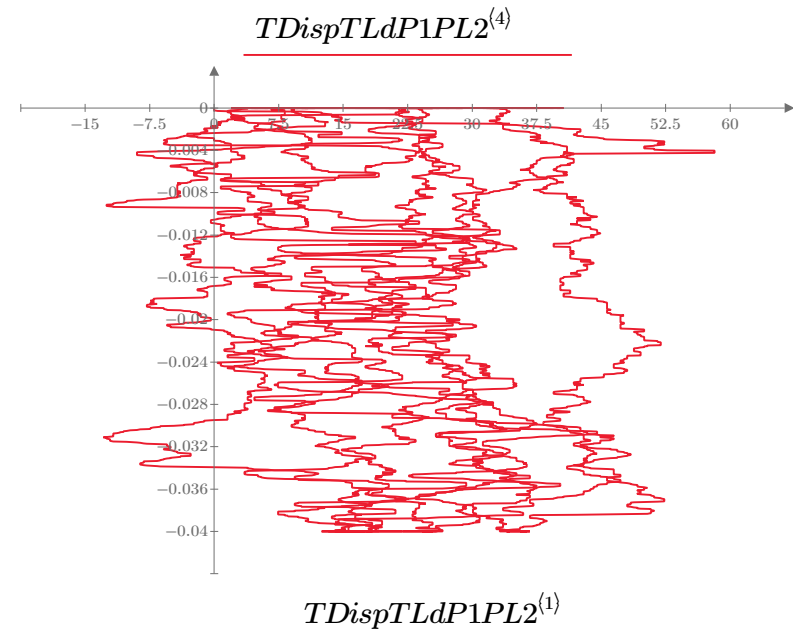


Fig C 17. Load displacement for compression pile P1 PL2 SG2

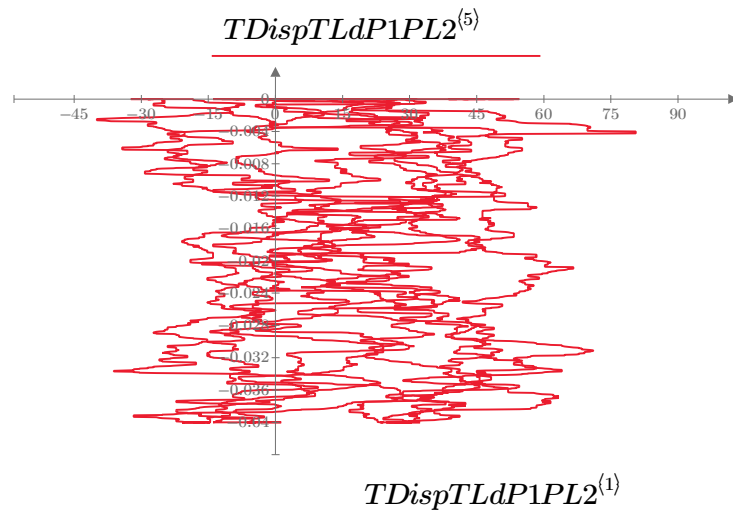


Fig C 18. Load displacement for compression pile P1 PL2 SG3

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for psuedostatic load PL3

$$TDispTLdP1PL3 := TDispTLd(LdTimePL3H, TimeP1, AxLdP1, 3) =$$

0	$1.367 \cdot 10^3$	0	0	46.018	-2.929	-2.537	0
1	$1.367 \cdot 10^3$	$-4.374 \cdot 10^{-5}$	0.1	49.969	-3.125	-1.903	0
2	$1.367 \cdot 10^3$	$-8.749 \cdot 10^{-5}$	0.2	64.756	-3.125	-2.537	0
3	$1.368 \cdot 10^3$	$-1.312 \cdot 10^{-4}$	0.3	79.543	-3.125	-1.903	0
4	$1.368 \cdot 10^3$	$-1.75 \cdot 10^{-4}$	0.4	82.347	-3.71	-2.537	0
5	$1.368 \cdot 10^3$	$-2.187 \cdot 10^{-4}$	0.5	85.151	-4.296	-1.903	0
6	$1.368 \cdot 10^3$	$-2.625 \cdot 10^{-4}$	0.6	87.191	-4.296	-1.903	0
7	$1.368 \cdot 10^3$	$-3.062 \cdot 10^{-4}$	0.7	103.762	-4.296	-1.903	0
8	$1.368 \cdot 10^3$	$-3.5 \cdot 10^{-4}$	0.8	105.292	-4.296	-1.269	0
9	$1.368 \cdot 10^3$	$-3.937 \cdot 10^{-4}$	0.9	107.332	-4.296	-1.269	0
10	$1.368 \cdot 10^3$	$-4.374 \cdot 10^{-4}$	1	107.332	-3.125	0	0
11	$1.368 \cdot 10^3$	$-4.812 \cdot 10^{-4}$	1.1	113.705	-1.953	0	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
10630	⋮	⋮	⋮	⋮	⋮	⋮	⋮

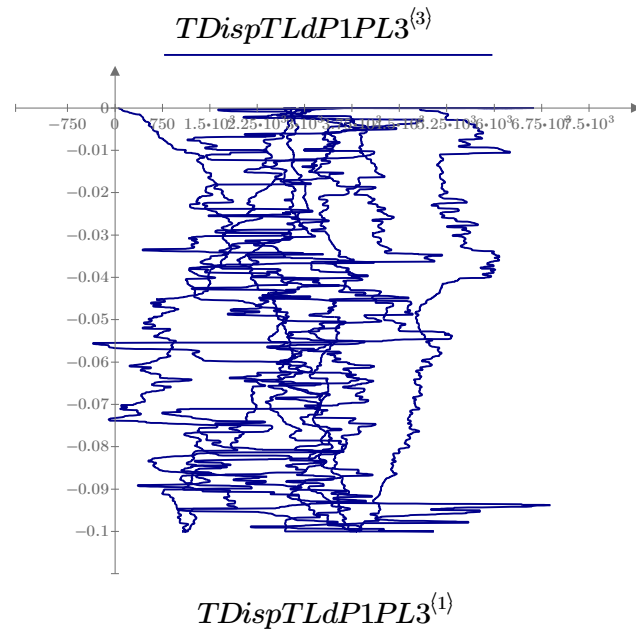


Fig C 19. Load displacement for compression pile P1 PL3 SG1

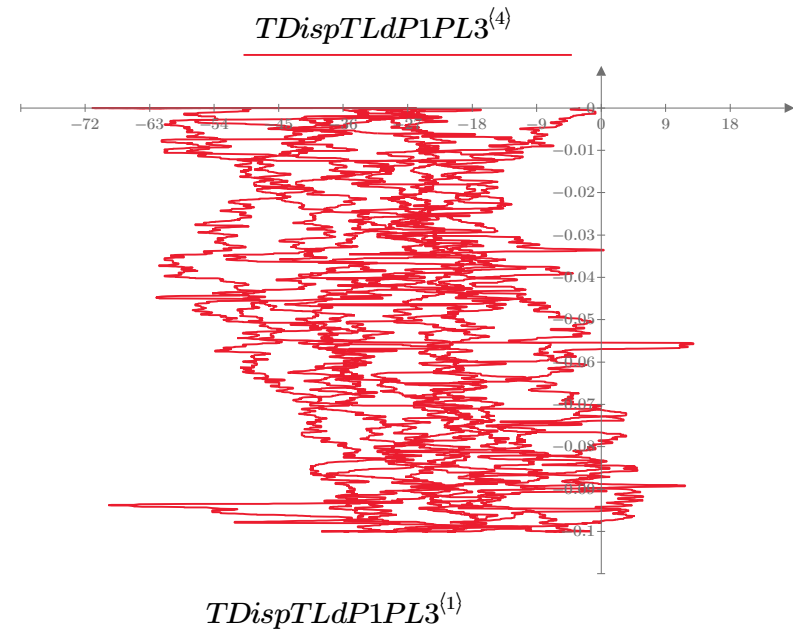


Fig C 20. Load displacement for compression pile P1 PL3 SG2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

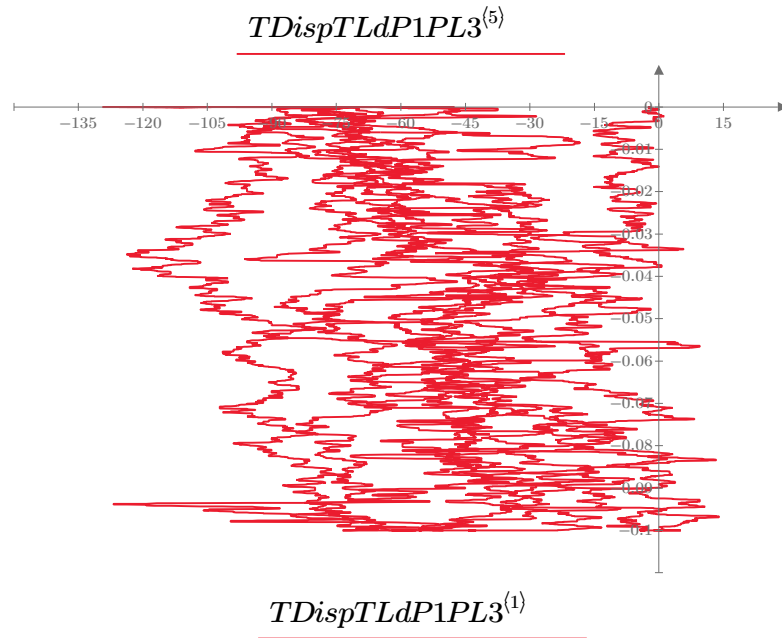


Fig C 21. Load displacement for compression pile P1 PL3 SG3

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for pseudostatic load PL4

$$TDispTLdP1PL4 := TDispTLd(LdTimePL4H, TimeP1, AxLdP1, 4) =$$

0	$3.331 \cdot 10^3$	0	0	-0.382	0.781	0.634	0
1	$3.331 \cdot 10^3$	$-4.374 \cdot 10^{-5}$	0.1	0	0.391	0	0
2	$3.331 \cdot 10^3$	$-8.749 \cdot 10^{-5}$	0.2	0.764	0.195	0	0
3	$3.331 \cdot 10^3$	$-1.312 \cdot 10^{-4}$	0.3	1.529	0.391	0	0
4	$3.331 \cdot 10^3$	$-1.75 \cdot 10^{-4}$	0.4	1.402	0.976	0	0
5	$3.332 \cdot 10^3$	$-2.187 \cdot 10^{-4}$	0.5	1.529	1.562	0	0
6	$3.332 \cdot 10^3$	$-2.625 \cdot 10^{-4}$	0.6	1.529	1.953	0	0
7	$3.332 \cdot 10^3$	$-3.062 \cdot 10^{-4}$	0.7	1.529	1.953	-0.634	0
8	$3.332 \cdot 10^3$	$-3.5 \cdot 10^{-4}$	0.8	1.529	1.953	-1.269	0
9	$3.332 \cdot 10^3$	$-3.937 \cdot 10^{-4}$	0.9	1.787	2.343	-1.269	0
10	$3.332 \cdot 10^3$	$-4.374 \cdot 10^{-4}$	1	2.293	2.343	-3.171	0
11	$3.332 \cdot 10^3$	$-4.812 \cdot 10^{-4}$	1.1	2.293	3.125	-3.171	0
$\vdots$							$\vdots$

37026

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

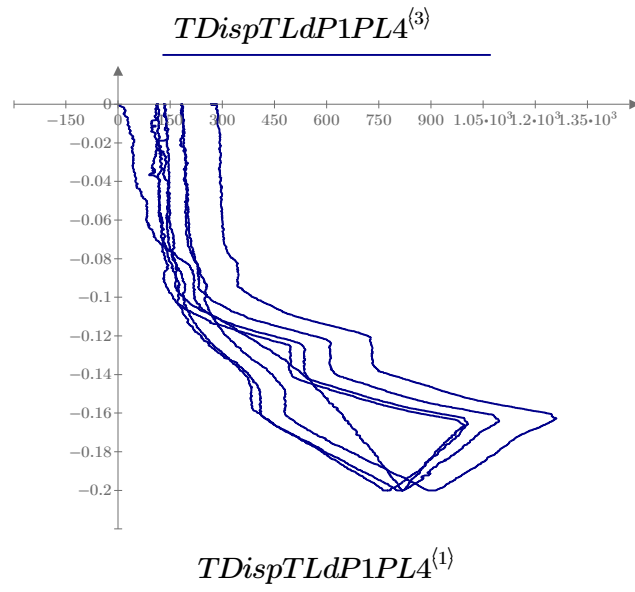


Fig C 22. Load displacement for compression pile P1 PL4 SG1

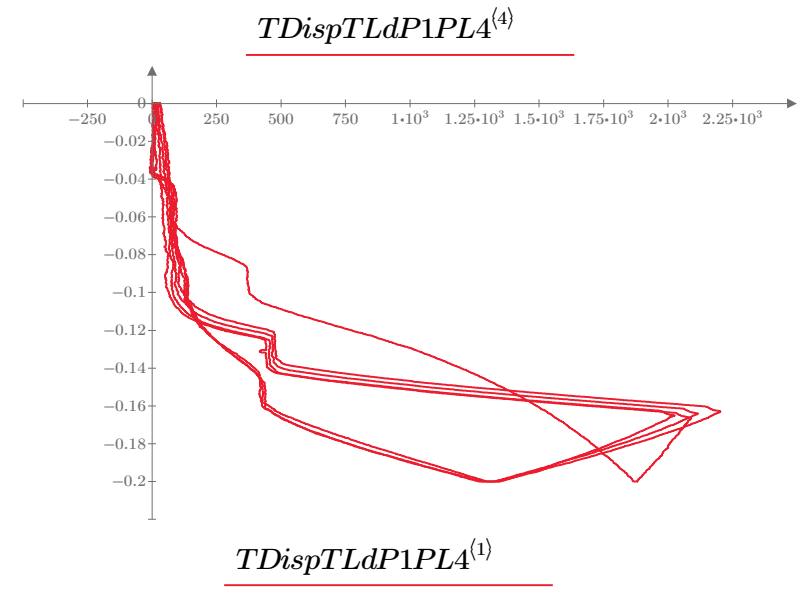


Fig C 23. Load displacement for compression pile P1 PL4 SG2

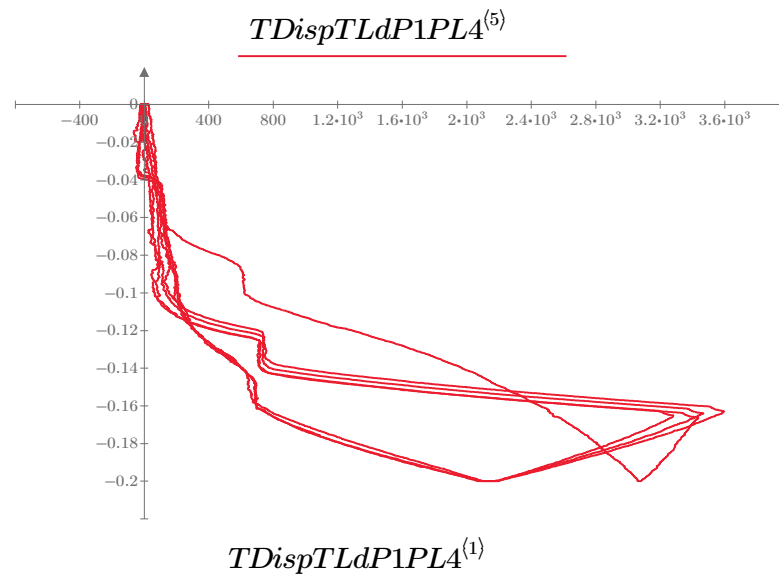


Fig C 24. Load displacement for compression pile P1 PL4 SG3

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for compressive load CL

$$TDispTLdP1CL := TDispTLd(LdTimeCLH, TimeP1, AxLdP1, 5) =$$

0	$7.124 \cdot 10^3$	0	0	0	-0.976	1.586	0
1	$7.124 \cdot 10^3$	$-1.444 \cdot 10^{-5}$	0.1	0	-1.172	3.171	0
2	$7.124 \cdot 10^3$	$-2.887 \cdot 10^{-5}$	0.2	0	-1.367	3.488	0
3	$7.124 \cdot 10^3$	$-4.331 \cdot 10^{-5}$	0.3	0	-1.172	3.806	0
4	$7.124 \cdot 10^3$	$-5.774 \cdot 10^{-5}$	0.4	-0.129	-0.976	3.488	0
5	$7.124 \cdot 10^3$	$-7.218 \cdot 10^{-5}$	0.5	-0.258	-0.781	3.171	0
6	$7.124 \cdot 10^3$	$-8.661 \cdot 10^{-5}$	0.6	-0.511	-0.781	3.806	0
7	$7.124 \cdot 10^3$	$-1.01 \cdot 10^{-4}$	0.7	-1.276	-0.781	3.806	0
8	$7.124 \cdot 10^3$	$-1.155 \cdot 10^{-4}$	0.8	-1.276	0	3.806	0
9	$7.125 \cdot 10^3$	$-1.299 \cdot 10^{-4}$	0.9	-1.276	0	3.806	0
10	$7.125 \cdot 10^3$	$-1.444 \cdot 10^{-4}$	1	-1.276	0.781	3.806	0
11	$7.125 \cdot 10^3$	$-1.588 \cdot 10^{-4}$	1.1	-1.534	1.172	5.074	0
⋮							⋮
12855							

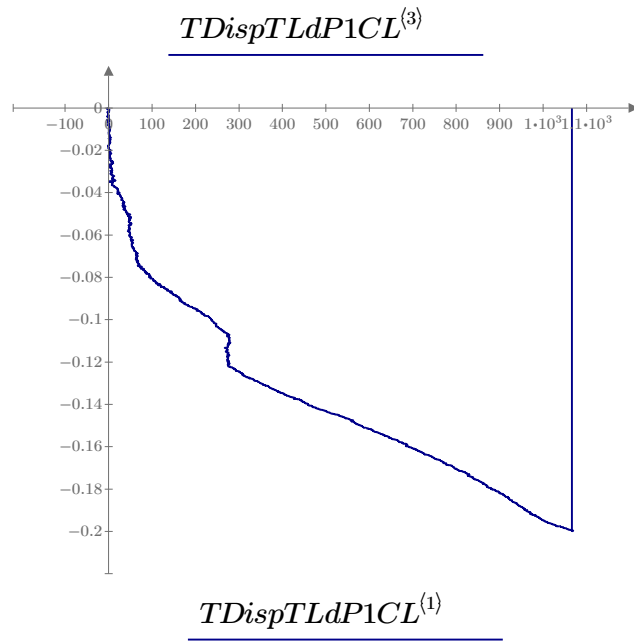


Fig C 25. Load displacement for compression pile P1 CL SG1

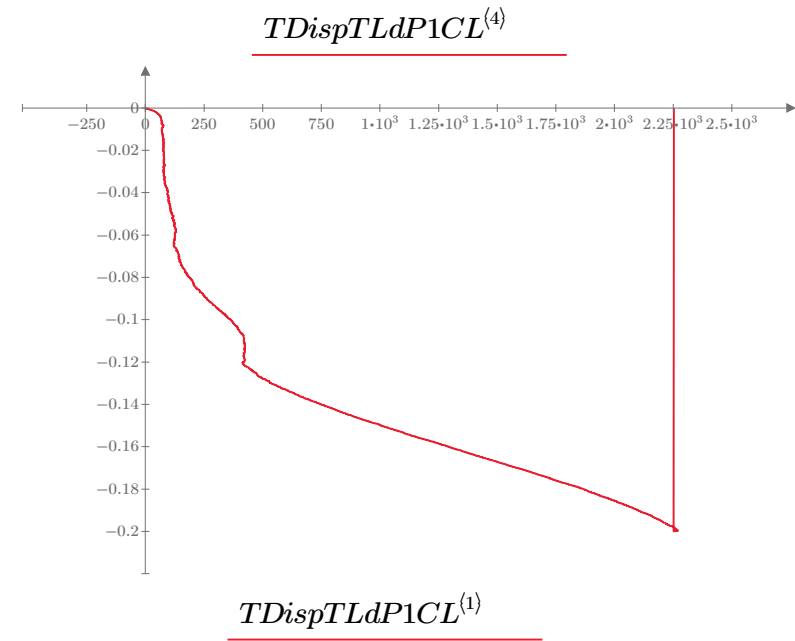


Fig C 26. Load displacement for compression pile P1 CL SG2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

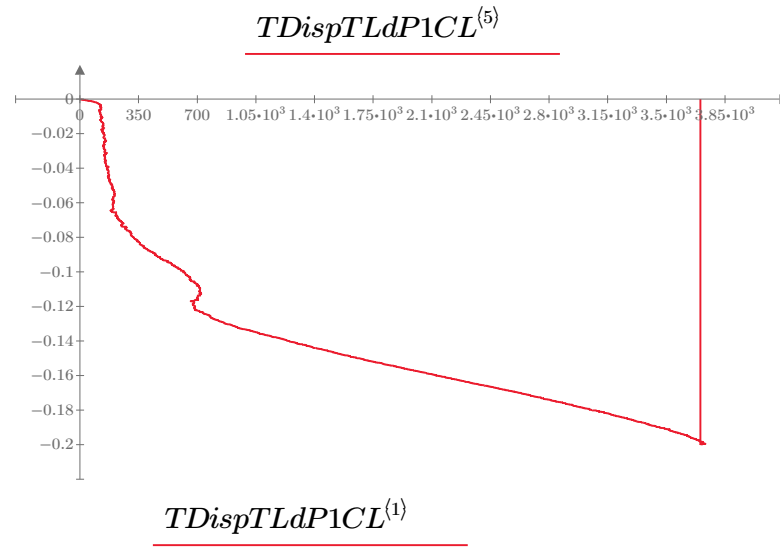


Fig C 27. Load displacement for compression pile P1 CL SG3

Functions for determining the Qult profile from strain gauge location

TOL := 0.00000001

```
SGplotQP(TDispTLdP0CL, PileNum) :=
  QP0 ← if PileNum = 0
    lookup(-0.15, TDispTLdP0CL(1), TDispTLdP0CL(3), "near")
  else
    lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(3), "near")
  QP1 ← if PileNum = 0
    lookup(-0.15, TDispTLdP0CL(1), TDispTLdP0CL(4), "near")
  else
    lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(4), "near")
  QP2 ← lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(5), "near")
  QP3 ← lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(6), "near")
  combined ← if PileNum = 0
    stack(QP0, QP1, QP1, QP1, QP1, QP1)
  else if PileNum = 1
    stack(QP0, QP1, QP1, QP2, QP2, QP2)
  else
    stack(QP0, QP1, QP1, QP2, QP2, QP3)
  combined
```

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

$$SGPlotQP1CL := SGplotQP(TDispTLdP1CL, 1) \text{ } \mathbf{kN} = \begin{bmatrix} 42.321 \\ 112.485 \\ 112.485 \\ 191.545 \\ 191.545 \\ 191.545 \end{bmatrix} \text{ } \mathbf{kN}$$

$$SGEmbDP := - \begin{bmatrix} 0.6 + 3.5 & 0.6 + 3.5 & 0.6 + 3.5 & 0.6 + 3.5 & 0.6 + 3.5 \\ 0.6 & 0.6 + 3 & 0.6 + 3 & 0.6 + 2 & 0.6 + 3 \\ 0 & 0.6 + 3 & 0.6 + 3 & 0.6 + 2 & 0.6 + 3 \\ 0 & 0.6 & 0.6 + 2 & 0.6 + 1 & 0.6 + 1 \\ 0 & 0 & 0.6 + 2 & 0.6 + 1 & 0.6 + 1 \\ 0 & 0 & 0.6 & 0.6 & 0.6 \end{bmatrix} \cdot D \cdot Nscale_{0,0}^{selfac}$$

SG embedment depth in prototype scale. Here, colm 0-4 represents P0 to P4. Row 0 to 5 represents depth to strain SG 1 to 4

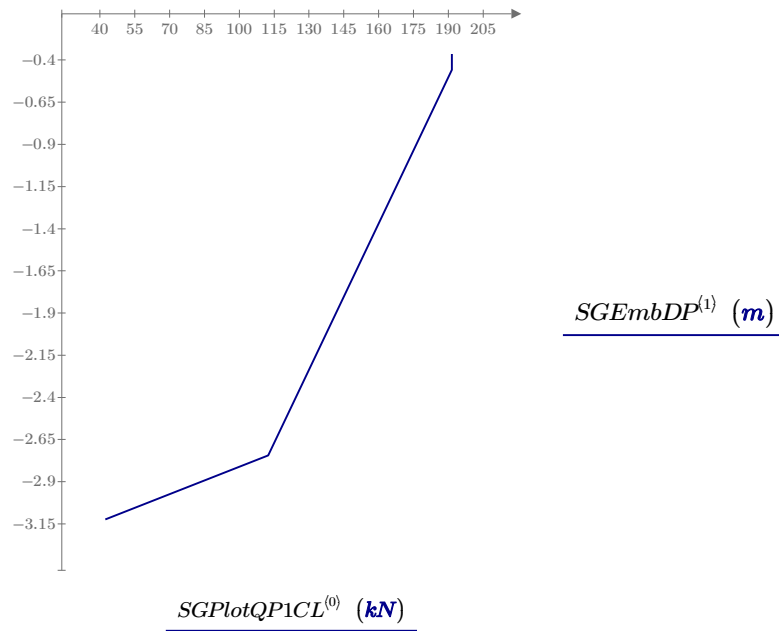


Fig C 28. SG Depth vs Axial Load for P1 pile

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Functions for calculating EDR from the load displacement curve for each cycles and each pseudostatic loads

TOL := 0.00000001

```
EDR(TDispTLdP0PL1, Pseu1perS, IniTime, IniDisp, LoopNo, SGNo) :=
  m ← TDispTLdP0PL1
  o ← TimeCycLoop(Pseu1perS, IniTime, IniDisp) - IniTime
  w ← -m(1)
  wmax ← max(-m(1))
  if SGNo = 1
    q ← m(3)
    qmax ← max(m(3))
  else if SGNo = 2
    q ← m(4)
    qmax ← max(m(4))
  else if SGNo = 3
    q ← m(5)
    qmax ← max(m(5))
  else if SGNo = 4
    q ← m(6)
    qmax ← max(m(6))
  if LoopNo = 1
    t1 ← m1,0 - IniTime
    t2 ← o1
  else if LoopNo = 2
    t1 ← o1
    t2 ← o2
  else if LoopNo = 3
    t1 ← o2
    t2 ← o3
  else if LoopNo = 4
    t1 ← o3
    t2 ← o4
  tstart ← lookup(t1, (m(0) - IniTime), (m(0) - IniTime), "near")
  tend ← lookup(t2, (m(0) - IniTime), (m(0) - IniTime), "near")
  rowstart ← match(t1, (m(0) - IniTime), "near")
  rowend ← match(t2, (m(0) - IniTime), "near")
  for i ∈ rowstart0,0 .. rowend0,0
    r ← (m - w) \ . (qi + qi-1)
```

```

|| 'i' ((wi - wi-1) ( 2 )) ||
area ← ∑ r
EDR ← || if qmax = 0
|| if wmax = 0
|| 0
|| else
|| area
|| -----
|| qmax • wmax
s ← augment ((tstart + IniTime), (tend + IniTime), rowstart, rowend, qmax, wmax, area, EDR)
EDR

```

Functions for combining EDR from the load displacement curve for each cycles and each pseudostatic loads

```

EDRPOPLSG (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, PileNo) := ||
q1 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1)
q2 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1)
q3 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1)
q4 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1)
r1 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2)
r2 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2)
r3 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2)
r4 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2)
w1 ← if PileNo = 0
|| 0
|| else
|| EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 3)
w2 ← if PileNo = 0
|| 0
|| else
|| EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 3)
w3 ← if PileNo = 0
|| 0
|| else
|| EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 3)
w4 ← if PileNo = 0
|| 0
|| else
|| EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3)
s1 ← if PileNo = 0
|| 0
|| else if PileNo = 1
|| 0
|| else
|| EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 4)
s2 ← if PileNo = 0
|| 0
||

```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

$$NoLoop := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

```

0
else if PileNo = 1
0
else
EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 4)
s3 ← if PileNo = 0
0
else if PileNo = 1
0
else
EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 4)
s4 ← if PileNo = 0
0
else if PileNo = 1
0
else
EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 4)
augment(stack(q1, q2, q3, q4), stack(r1, r2, r3, r4), stack(w1, w2, w3, w4), stack(s1, s2, s3, s4))

```

$$EDRP1PL1 := EDRPOPLSG(TDispTLdP1PL1, PseuPL1H, IniTimePL1H, 1) = \begin{bmatrix} -0.212 & -0.045 & 0.124 & 0 \\ 0.148 & -0.491 & -0.504 & 0 \\ -0.064 & 0.199 & -0.024 & 0 \\ -0.047 & 0.17 & 0.131 & 0 \end{bmatrix}$$

$$EDRP1PL2 := EDRPOPLSG(TDispTLdP1PL2, PseuPL2H, IniTimePL2H, 1) = \begin{bmatrix} -1.198 & 0.309 & 0.177 & 0 \\ 0.821 & -0.394 & -0.329 & 0 \\ -0.795 & 0.13 & 0.235 & 0 \\ 1.17 & -0.437 & -0.605 & 0 \end{bmatrix}$$

$$EDRP1PL3 := EDRPOPLSG(TDispTLdP1PL3, PseuPL3H, IniTimePL3H, 1) = \begin{bmatrix} -0.137 & 1.141 & 2.16 & 0 \\ 0.002 & 0.482 & -0.617 & 0 \\ 0.173 & -0.54 & -1.485 & 0 \\ -0.293 & 1.708 & 2.009 & 0 \end{bmatrix}$$

$$EDRP1PL4 := EDRPOPLSG(TDispTLdP1PL4, PseuPL4H, IniTimePL4H, 1) = \begin{bmatrix} -0.045 & 0.055 & 0.062 & 0 \\ -0.113 & -0.113 & -0.108 & 0 \\ -0.15 & -0.132 & -0.13 & 0 \\ -0.196 & -0.148 & -0.147 & 0 \end{bmatrix}$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

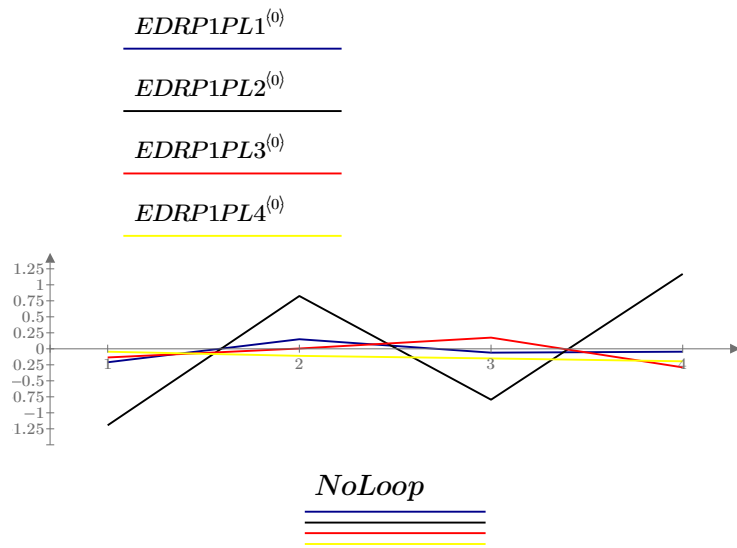


Fig C 29. EDR vs No of loops SG1

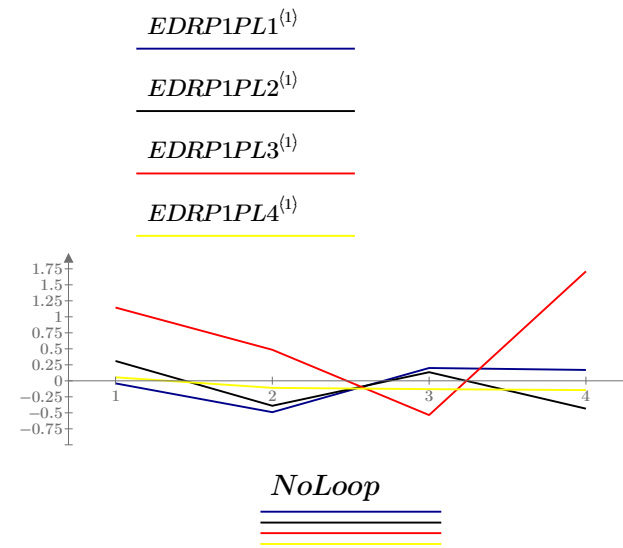


Fig C 30. EDR vs No of loops SG2

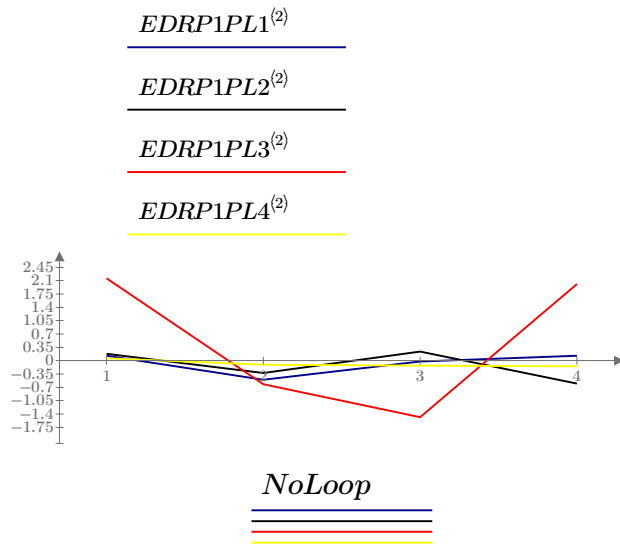


Fig C 31. EDR vs No of loops SG3

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Functions for disintegrating the load-displacement curves into separate cycles

```

DispLd(TDispTLdP0PL1, Pseu1perS, IniTime, IniDisp, LoopNo, SGNo) :=
  m ← TDispTLdP0PL1
  o ← TimeCycLoop(Pseu1perS, IniTime, IniDisp) – IniTime
  w ← m(1)
  if SGNo = 1
    q ← m(3)
  else if SGNo = 2
    q ← m(4)
  else if SGNo = 3
    q ← m(5)
  else if SGNo = 4
    q ← m(6)
  if LoopNo = 1
    t1 ← o0
    t2 ← o1
  else if LoopNo = 2
    t1 ← o1
    t2 ← o2
  else if LoopNo = 3
    t1 ← o2
    t2 ← o3
  else if LoopNo = 4
    t1 ← o3
    t2 ← o4
  tstart ← lookup(t1, (m(0) – IniTime), (m(0) – IniTime), “near”)
  tend ← lookup(t2, (m(0) – IniTime), (m(0) – IniTime), “near”)
  rowstart ← match(t1, (m(0) – IniTime), “near”)
  rowend ← match(t2, (m(0) – IniTime), “near”)
  for i ∈ rowstart0,0 .. rowend0,0
    di ← wi
    ldi ← qi
  augment(d, ld)

```


Appendix C
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

$DispLdP1PL1L1SG1 := DispLd(TDispTLdP1PL1, PseuPL1H, IniTimePL1H, IniDisp, 1, 1)$

$DispLdP1PL1L2SG1 := DispLd(TDispTLdP1PL1, PseuPL1H, IniTimePL1H, IniDisp, 2, 1)$

$DispLdP1PL1L3SG1 := DispLd(TDispTLdP1PL1, PseuPL1H, IniTimePL1H, IniDisp, 3, 1)$

$DispLdP1PL1L4SG1 := DispLd(TDispTLdP1PL1, PseuPL1H, IniTimePL1H, IniDisp, 4, 1)$

$DispLdP1PL2L1SG1 := DispLd(TDispTLdP1PL2, PseuPL2H, IniTimePL2H, IniDisp, 1, 1)$

$DispLdP1PL2L2SG1 := DispLd(TDispTLdP1PL2, PseuPL2H, IniTimePL2H, IniDisp, 2, 1)$

$DispLdP1PL2L3SG1 := DispLd(TDispTLdP1PL2, PseuPL2H, IniTimePL2H, IniDisp, 3, 1)$

$DispLdP1PL2L4SG1 := DispLd(TDispTLdP1PL2, PseuPL2H, IniTimePL2H, IniDisp, 4, 1)$

$DispLdP1PL3L1SG1 := DispLd(TDispTLdP1PL3, PseuPL3H, IniTimePL3H, IniDisp, 1, 1)$

$DispLdP1PL3L2SG1 := DispLd(TDispTLdP1PL3, PseuPL3H, IniTimePL3H, IniDisp, 2, 1)$

$DispLdP1PL3L3SG1 := DispLd(TDispTLdP1PL3, PseuPL3H, IniTimePL3H, IniDisp, 3, 1)$

$DispLdP1PL3L4SG1 := DispLd(TDispTLdP1PL3, PseuPL3H, IniTimePL3H, IniDisp, 4, 1)$

$DispLdP1PL4L1SG1 := DispLd(TDispTLdP1PL4, PseuPL4H, IniTimePL4H, IniDisp, 1, 1)$

$DispLdP1PL4L2SG1 := DispLd(TDispTLdP1PL4, PseuPL4H, IniTimePL4H, IniDisp, 2, 1)$

$DispLdP1PL4L3SG1 := DispLd(TDispTLdP1PL4, PseuPL4H, IniTimePL4H, IniDisp, 3, 1)$

$DispLdP1PL4L4SG1 := DispLd(TDispTLdP1PL4, PseuPL4H, IniTimePL4H, IniDisp, 4, 1)$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

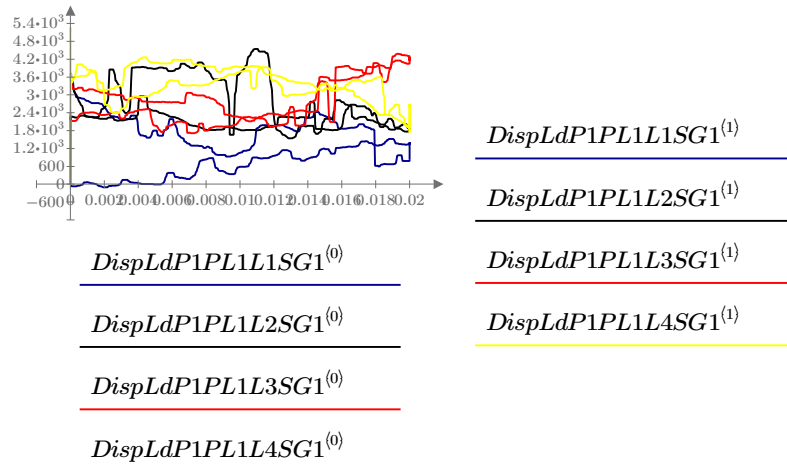


Fig C 32. Load-Displacement for P1 PL1 SG1

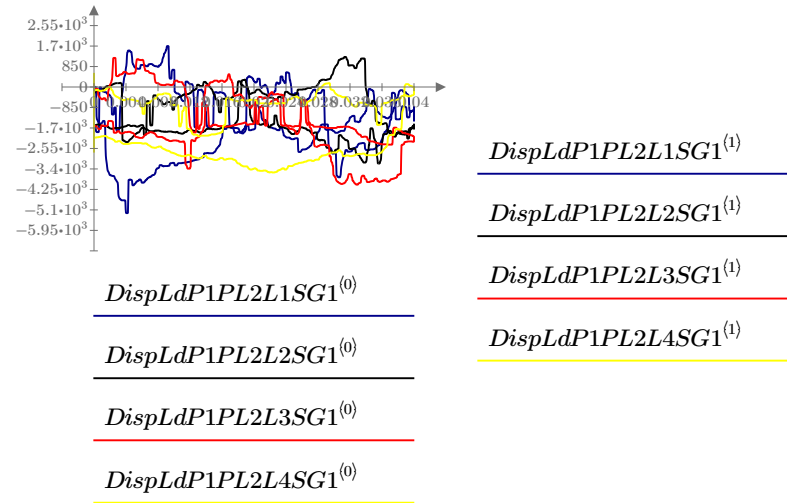


Fig C 33. Load-Displacement for P1 PL1 SG1

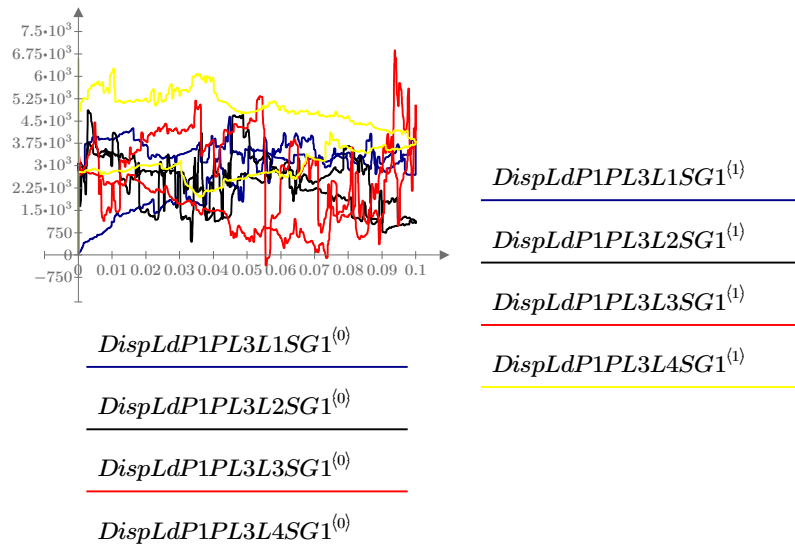


Fig C 34. Load-Displacement for P1 PL1 SG1

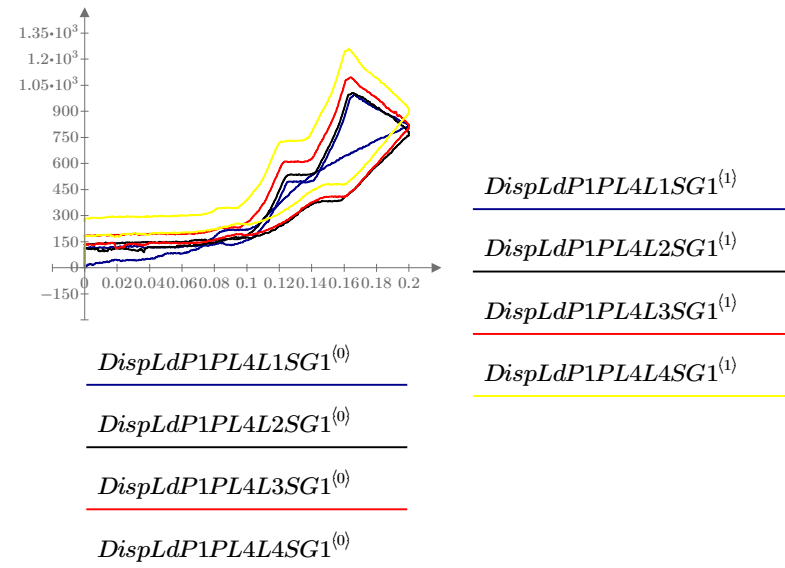


Fig C 35. Load-Displacement for P1 PL1 SG1

Appendix C
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

$DispLdP1PL1L1SG2 := DispLd(TDispTLdP1PL1, PseuPL1H, IniTimePL1H, IniDisp, 1, 2)$

$DispLdP1PL1L2SG2 := DispLd(TDispTLdP1PL1, PseuPL1H, IniTimePL1H, IniDisp, 2, 2)$

$DispLdP1PL1L3SG2 := DispLd(TDispTLdP1PL1, PseuPL1H, IniTimePL1H, IniDisp, 3, 2)$

$DispLdP1PL1L4SG2 := DispLd(TDispTLdP1PL1, PseuPL1H, IniTimePL1H, IniDisp, 4, 2)$

$DispLdP1PL2L1SG2 := DispLd(TDispTLdP1PL2, PseuPL2H, IniTimePL2H, IniDisp, 1, 2)$

$DispLdP1PL2L2SG2 := DispLd(TDispTLdP1PL2, PseuPL2H, IniTimePL2H, IniDisp, 2, 2)$

$DispLdP1PL2L3SG2 := DispLd(TDispTLdP1PL2, PseuPL2H, IniTimePL2H, IniDisp, 3, 2)$

$DispLdP1PL2L4SG2 := DispLd(TDispTLdP1PL2, PseuPL2H, IniTimePL2H, IniDisp, 4, 2)$

$DispLdP1PL3L1SG2 := DispLd(TDispTLdP1PL3, PseuPL3H, IniTimePL3H, IniDisp, 1, 2)$

$DispLdP1PL3L2SG2 := DispLd(TDispTLdP1PL3, PseuPL3H, IniTimePL3H, IniDisp, 2, 2)$

$DispLdP1PL3L3SG2 := DispLd(TDispTLdP1PL3, PseuPL3H, IniTimePL3H, IniDisp, 3, 2)$

$DispLdP1PL3L4SG2 := DispLd(TDispTLdP1PL3, PseuPL3H, IniTimePL3H, IniDisp, 4, 2)$

$DispLdP1PL4L1SG2 := DispLd(TDispTLdP1PL4, PseuPL4H, IniTimePL4H, IniDisp, 1, 2)$

$DispLdP1PL4L2SG2 := DispLd(TDispTLdP1PL4, PseuPL4H, IniTimePL4H, IniDisp, 2, 2)$

$DispLdP1PL4L3SG2 := DispLd(TDispTLdP1PL4, PseuPL4H, IniTimePL4H, IniDisp, 3, 2)$

$DispLdP1PL4L4SG2 := DispLd(TDispTLdP1PL4, PseuPL4H, IniTimePL4H, IniDisp, 4, 2)$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

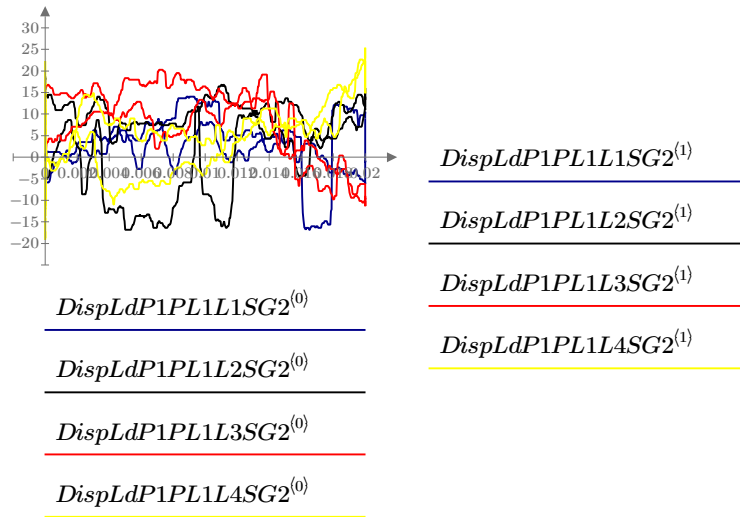


Fig C 36. Load-Displacement for P1 PL1 SG2

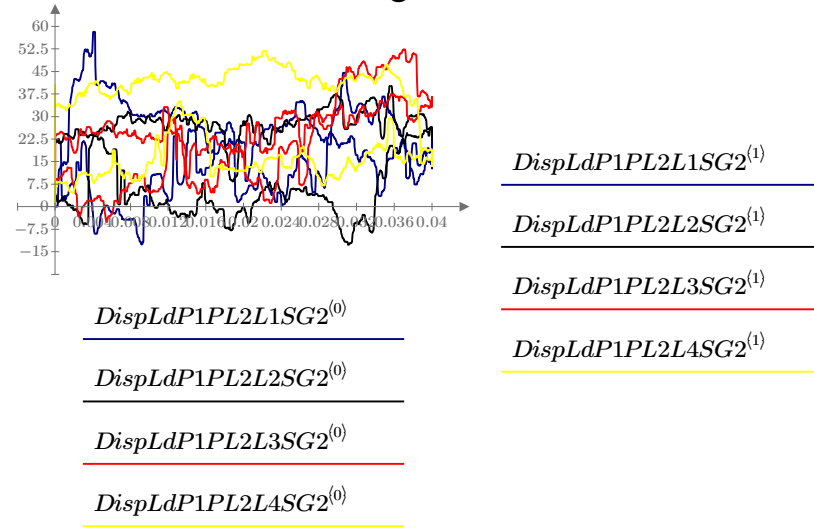


Fig C 37. Load-Displacement for P1 PL1 SG2

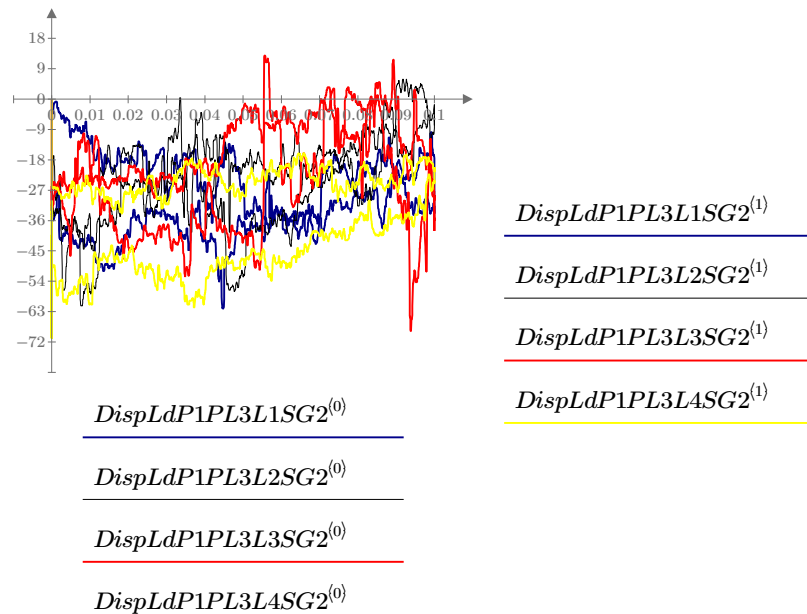


Fig C 38. Load-Displacement for P1 PL1 SG2

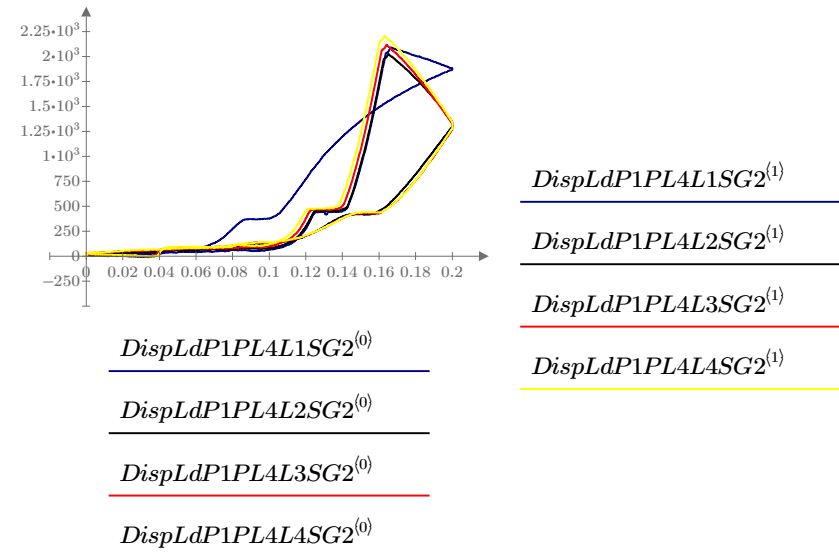


Fig C 39. Load-Displacement for P1 PL1 SG2

Appendix C
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

$DispLdP1PL1L1SG3 := DispLd(TDispTLdP1PL1, PseuPL1H, IniTimePL1H, IniDisp, 1, 3)$

$DispLdP1PL1L2SG3 := DispLd(TDispTLdP1PL1, PseuPL1H, IniTimePL1H, IniDisp, 2, 3)$

$DispLdP1PL1L3SG3 := DispLd(TDispTLdP1PL1, PseuPL1H, IniTimePL1H, IniDisp, 3, 3)$

$DispLdP1PL1L4SG3 := DispLd(TDispTLdP1PL1, PseuPL1H, IniTimePL1H, IniDisp, 4, 3)$

$DispLdP1PL2L1SG3 := DispLd(TDispTLdP1PL2, PseuPL2H, IniTimePL2H, IniDisp, 1, 3)$

$DispLdP1PL2L2SG3 := DispLd(TDispTLdP1PL2, PseuPL2H, IniTimePL2H, IniDisp, 2, 3)$

$DispLdP1PL2L3SG3 := DispLd(TDispTLdP1PL2, PseuPL2H, IniTimePL2H, IniDisp, 3, 3)$

$DispLdP1PL2L4SG3 := DispLd(TDispTLdP1PL2, PseuPL2H, IniTimePL2H, IniDisp, 4, 3)$

$DispLdP1PL3L1SG3 := DispLd(TDispTLdP1PL3, PseuPL3H, IniTimePL3H, IniDisp, 1, 3)$

$DispLdP1PL3L2SG3 := DispLd(TDispTLdP1PL3, PseuPL3H, IniTimePL3H, IniDisp, 2, 3)$

$DispLdP1PL3L3SG3 := DispLd(TDispTLdP1PL3, PseuPL3H, IniTimePL3H, IniDisp, 3, 3)$

$DispLdP1PL3L4SG3 := DispLd(TDispTLdP1PL3, PseuPL3H, IniTimePL3H, IniDisp, 4, 3)$

$DispLdP1PL4L1SG3 := DispLd(TDispTLdP1PL4, PseuPL4H, IniTimePL4H, IniDisp, 1, 3)$

$DispLdP1PL4L2SG3 := DispLd(TDispTLdP1PL4, PseuPL4H, IniTimePL4H, IniDisp, 2, 3)$

$DispLdP1PL4L3SG3 := DispLd(TDispTLdP1PL4, PseuPL4H, IniTimePL4H, IniDisp, 3, 3)$

$DispLdP1PL4L4SG3 := DispLd(TDispTLdP1PL4, PseuPL4H, IniTimePL4H, IniDisp, 4, 3)$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

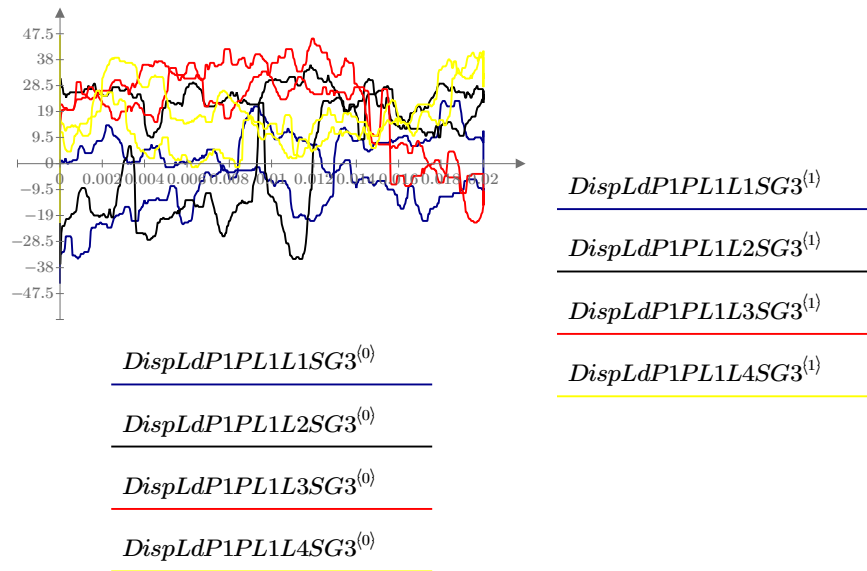


Fig C 40. Load-Displacement for P1 PL1 SG3

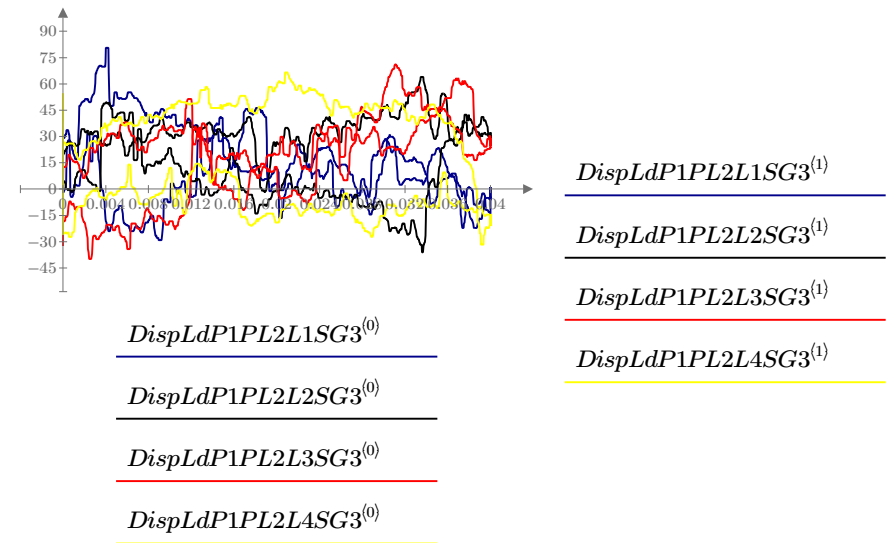


Fig C 41. Load-Displacement for P1 PL1 SG3

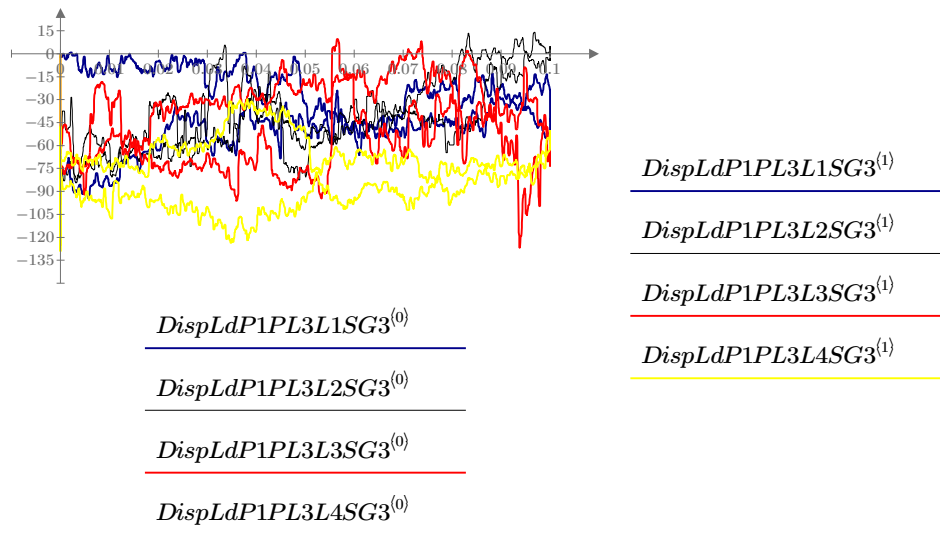


Fig C 42. Load-Displacement for P1 PL1 SG3

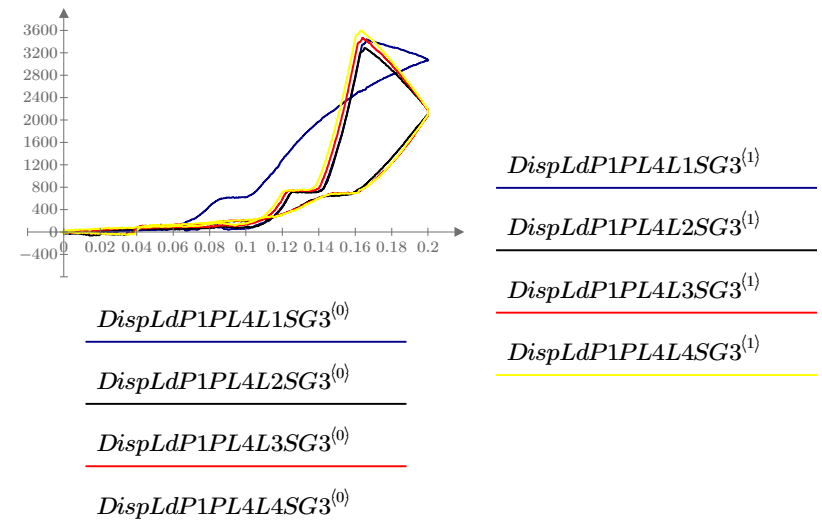


Fig C 43. Load-Displacement for P1 PL1 SG3

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Functions for determining the Qmax profile from each loads

TOL := 0.00000001

$$Q_{maxSG}(TDispTLdP2PL1, PileNum) := \begin{cases} QP0 \leftarrow \max(TDispTLdP2PL1^{(3)}) \\ QP1 \leftarrow \max(TDispTLdP2PL1^{(4)}) \\ QP2 \leftarrow \max(TDispTLdP2PL1^{(5)}) \\ QP3 \leftarrow \max(TDispTLdP2PL1^{(6)}) \\ combined \leftarrow \text{if } PileNum = 0 \\ \quad \text{stack}(QP0, QP1, QP1, QP1, QP1, QP1) \\ \text{else if } PileNum = 1 \\ \quad \text{stack}(QP0, QP1, QP1, QP2, QP2, QP2) \\ \text{else} \\ \quad \text{stack}(QP0, QP1, QP1, QP2, QP2, QP3) \\ combined \end{cases}$$

$Q_{maxP1PL1} := Q_{maxSG}(TDispTLdP1PL1, 1) \cdot \text{kN}$

$Q_{maxP1PL2} := Q_{maxSG}(TDispTLdP1PL2, 1) \text{ kN}$

$Q_{maxP1PL3} := Q_{maxSG}(TDispTLdP1PL3, 1) \text{ kN}$

$Q_{maxP1PL4} := Q_{maxSG}(TDispTLdP1PL4, 1) \text{ kN}$

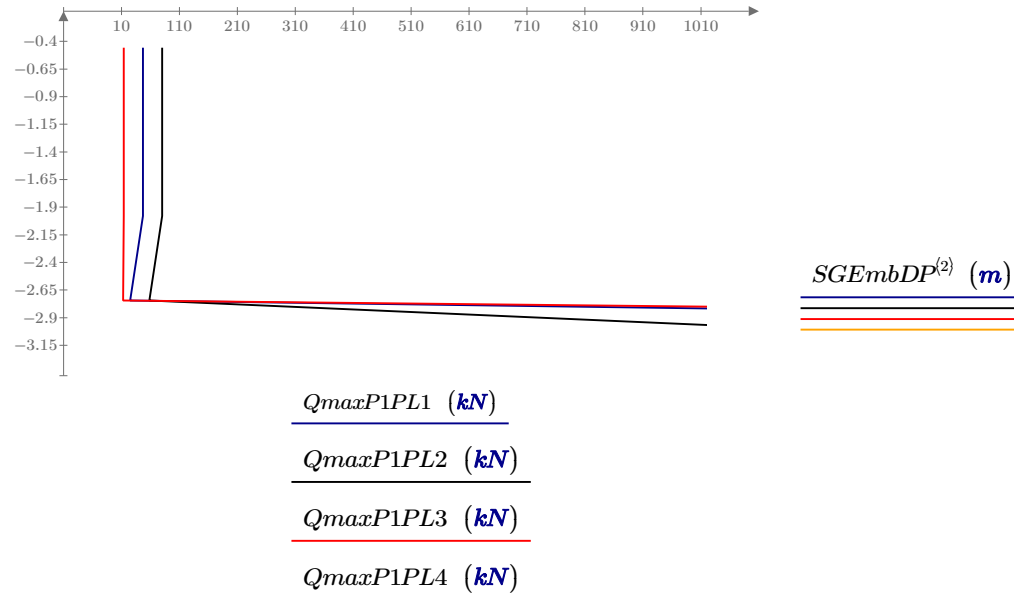
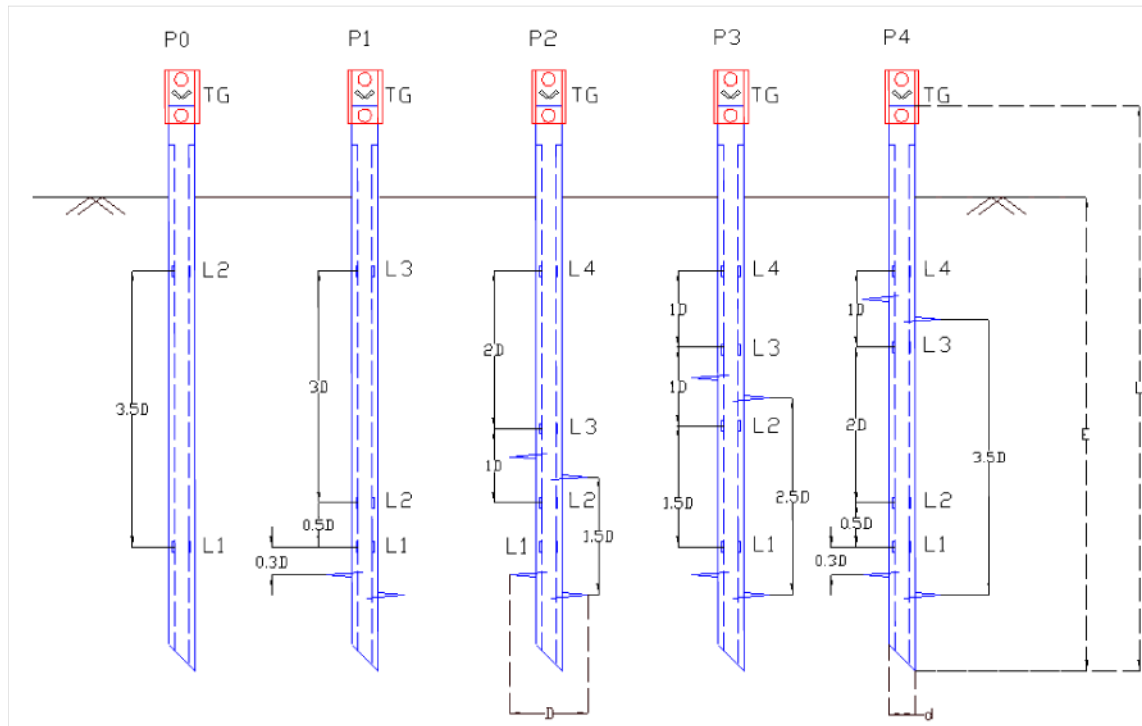


Fig C 44. SG Depth vs Q max from each load amplitude for P1 pile

2.3.3 Skin Friction vs Depth



Strain gauge locations in model piles.

$$HgtShaft := \begin{bmatrix} 3.5 & 0.5 & 0.5 & 1.5 & 0.5 \\ 0 & 3 & 1 & 1 & 2 \\ 0 & 0 & 2 & 1 & 1 \end{bmatrix} \cdot D \cdot Nscale^{sclfac_{0,0}} = \begin{bmatrix} 2.667 & 0.381 & 0.381 & 1.143 & 0.381 \\ 0 & 2.286 & 0.762 & 0.762 & 1.524 \\ 0 & 0 & 1.524 & 0.762 & 0.762 \end{bmatrix} \text{ m}$$

Height in the shaft segment between two stations in prototype scale. Here, colm 0-4 represents P0 to P4. Row 0 to 2 represents height between SG 1-2, 2-3 & 3-4

$$SurfArea := HgtShaft \cdot \pi \cdot d \cdot Nscale^{sclfac_{0,0}} = \begin{bmatrix} 2.128 & 0.304 & 0.304 & 0.912 & 0.304 \\ 0 & 1.824 & 0.608 & 0.608 & 1.216 \\ 0 & 0 & 1.216 & 0.608 & 0.608 \end{bmatrix} \text{ m}^2$$

Surface Area of the shaft segment between two stations in prototype scale. Here, colm 0-4 represents P0 to P4. Row 0 to 2 represents surface area between SG 1-2, 2-3 & 3-4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Function for determining the Unit Shaft Resistance within the shaft segment

$$\begin{aligned}
 \text{UntShtRes}(LdP, PileNum) := & \text{for } i \in 0, 1 \dots \text{rows}(LdP) - 1 \\
 & \text{for } j \in 0, 1 \dots \text{cols}(LdP) - 1 \\
 & \quad \text{shaft12}_{i,0} \leftarrow \frac{(LdP_{i,4} - LdP_{i,3}) \text{ kN}}{\text{submatrix}(\text{SurfArea}, 0, 2, PileNum, PileNum)_{0,0}} \\
 & \quad \text{shaft23}_{i,1} \leftarrow \text{if submatrix}(\text{SurfArea}, 0, 2, PileNum, PileNum)_1 = 0 \\
 & \quad \quad \quad 0 \\
 & \quad \quad \quad \text{else} \\
 & \quad \quad \quad \frac{(LdP_{i,5} - LdP_{i,4}) \text{ kN}}{\text{submatrix}(\text{SurfArea}, 0, 2, PileNum, PileNum)_1} \\
 & \quad \text{shaft34}_{i,2} \leftarrow \text{if submatrix}(\text{SurfArea}, 0, 2, PileNum, PileNum)_2 = 0 \\
 & \quad \quad \quad 0 \\
 & \quad \quad \quad \text{else} \\
 & \quad \quad \quad \frac{(LdP_{i,6} - LdP_{i,5}) \text{ kN}}{\text{submatrix}(\text{SurfArea}, 0, 2, PileNum, PileNum)_2} \\
 & \text{augment}(\text{shaft12}^{(0)}, \text{shaft23}^{(1)}, \text{shaft34}^{(2)})
 \end{aligned}$$

$$ShftResP1PL1 := \text{UntShtRes}(TDispTLdP1PL1, 1)$$

$$ShftResP1PL2 := \text{UntShtRes}(TDispTLdP1PL2, 1)$$

$$ShftResP1PL3 := \text{UntShtRes}(TDispTLdP1PL3, 1)$$

$$ShftResP1PL4 := \text{UntShtRes}(TDispTLdP1PL4, 1)$$

$$ShftResP1CL := \text{UntShtRes}(TDispTLdP1CL, 1)$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

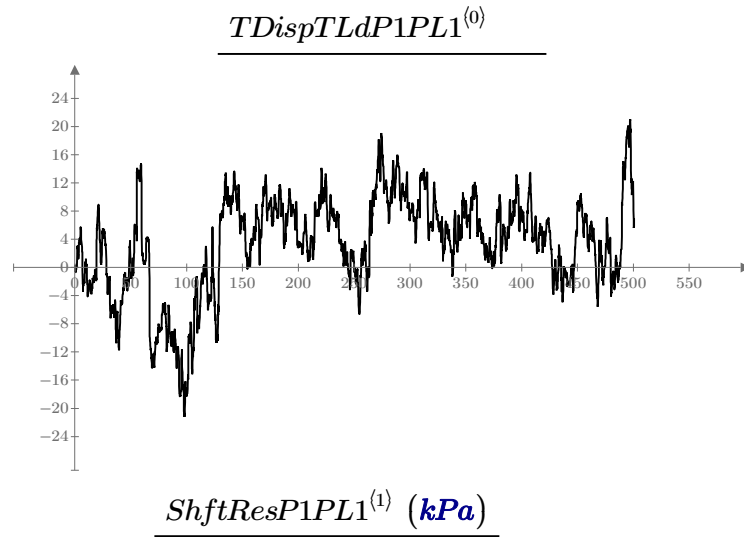


Fig C 45. Shaft Resistances vs Time, P1 PL1

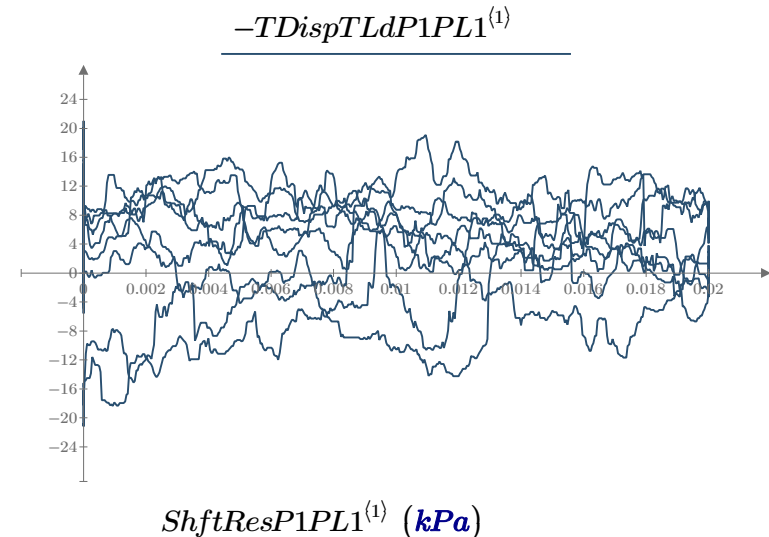


Fig C 46. Shaft Resistances vs Displacement, P1 PL1

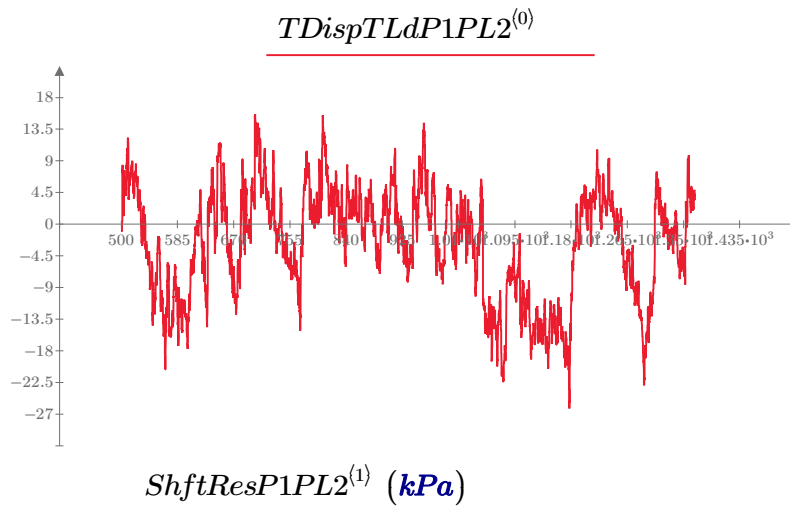


Fig C 47. Shaft Resistances vs Time, P1 PL2

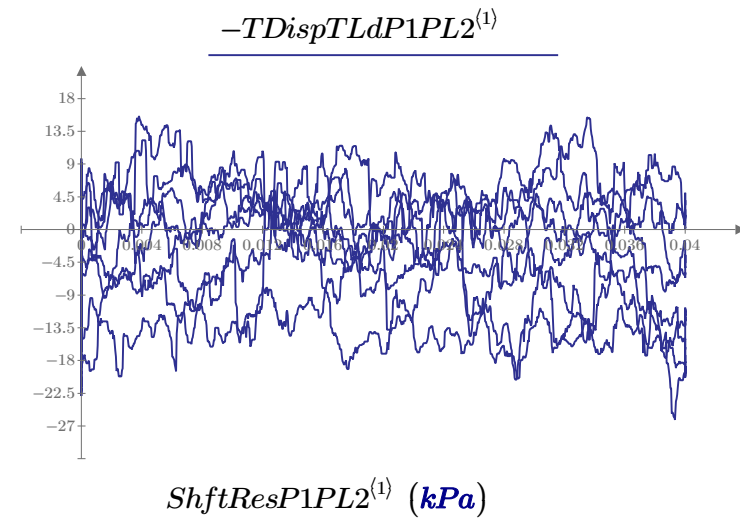
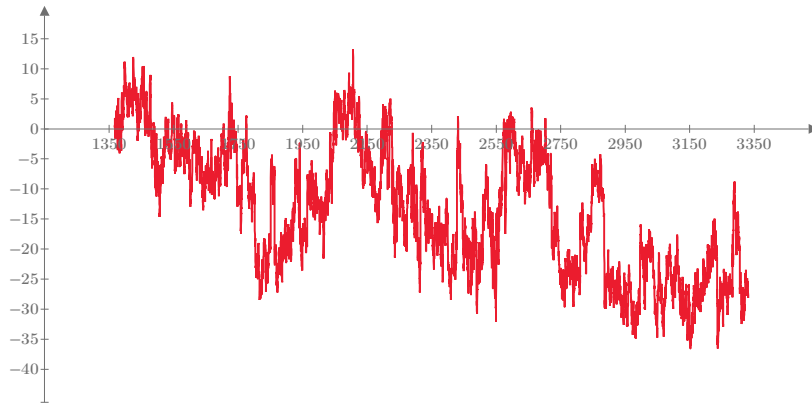


Fig C 48. Shaft Resistances vs Displacement, P1 PL2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

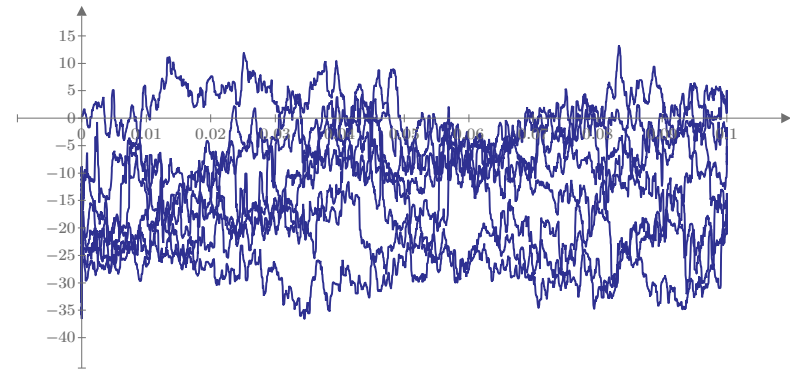
$TDispTLdP1PL3^{(0)}$



$ShftResP1PL3^{(1)} \text{ (kPa)}$

Fig C 49. Shaft Resistances vs Time, P1 PL3

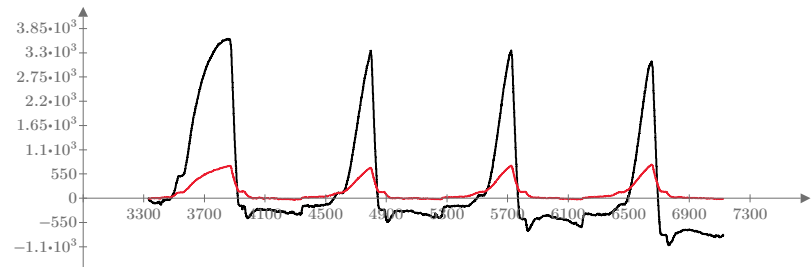
$-TDispTLdP1PL3^{(1)}$



$ShftResP1PL3^{(1)} \text{ (kPa)}$

Fig C 50. Shaft Resistances vs Displacement, P1 PL3

$TDispTLdP1PL4^{(0)}$

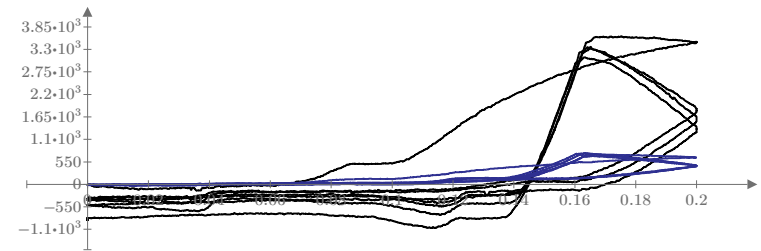


$ShftResP1PL4^{(0)} \text{ (kPa)}$

$ShftResP1PL4^{(1)} \text{ (kPa)}$

Fig C 51. Shaft Resistances vs Time, P1 PL4

$-TDispTLdP1PL4^{(1)}$



$ShftResP1PL4^{(0)} \text{ (kPa)}$

$ShftResP1PL4^{(1)} \text{ (kPa)}$

Fig C 52. Shaft Resistances vs Displacement, P1 PL4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

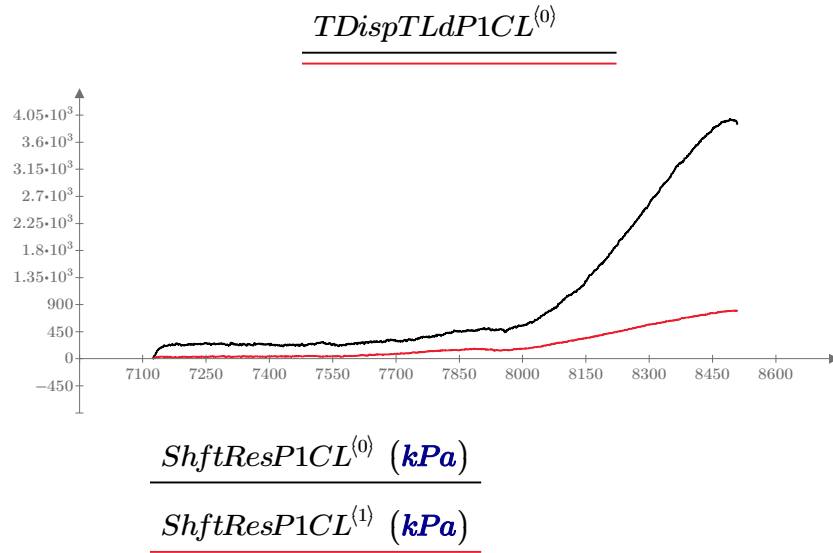


Fig C 53. Shaft Resistances vs Time, P1 CL

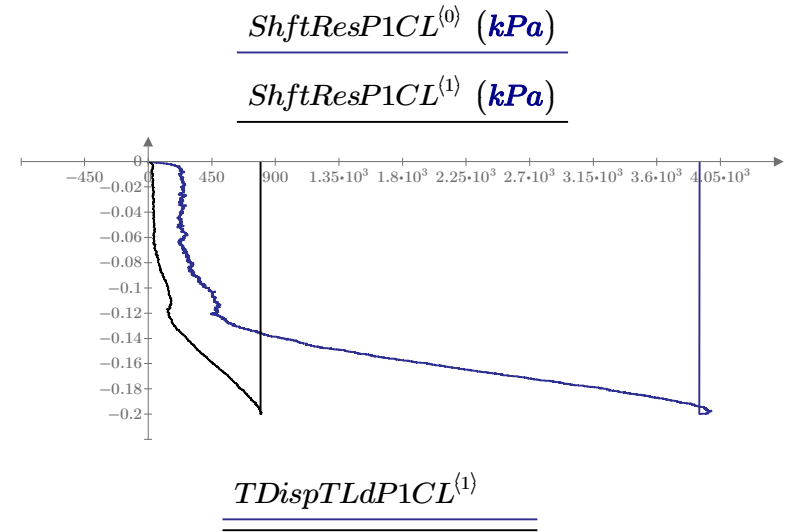


Fig C 54. Shaft Resistances vs Displacement, P1 CL

$$ShftP1CL := \text{augment} \left(TDispTLdP1CL^{(1)}, \frac{ShftResP1CL^{(0)}}{\mathbf{kPa}}, \frac{ShftResP1CL^{(1)}}{\mathbf{kPa}} \right)$$

$$UltShReP1_1 := \text{lookup} (-0.05, ShftP1CL^{(0)}, ShftP1CL^{(2)}, \text{"near"}) = [43.341]$$

$$UltShReP1_0 := \text{lookup} (-0.05, ShftP1CL^{(0)}, ShftP1CL^{(1)}, \text{"near"}) = [230.786]$$

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Functions for calculating the ultimate unit shaft resistance along the depth

```

ShftResplot (ShftP0CL, PileNum) := for i ∈ 0, 1 .. cols (ShftP0CL) - 1
    ||
    || UltShReP0 ← if PileNum = 0
    ||     || lookup (-0.15, ShftP0CL(0), ShftP0CL(1), "near")
    ||     || else
    ||     || lookup (-0.05, ShftP0CL(0), ShftP0CL(1), "near")
    ||
    || UltShReP1 ← if PileNum = 0
    ||     || 0
    ||     || else
    ||     || lookup (-0.05, ShftP0CL(0), ShftP0CL(2), "near")
    ||
    || UltShReP2 ← if PileNum = 0
    ||     || 0
    ||     || else if PileNum = 1
    ||     || 0
    ||     || else
    ||     || lookup (-0.05, ShftP0CL(0), ShftP0CL(3), "near")
    ||
    || combined ← if PileNum = 0
    ||     || stack (UltShReP0, UltShReP0, UltShReP0, UltShReP0, UltShReP0, UltShReP0)
    ||     || else if PileNum = 1
    ||     || stack (UltShReP0, UltShReP0, UltShReP1, UltShReP1, UltShReP1, UltShReP1)
    ||     || else
    ||     || stack (UltShReP0, UltShReP0, UltShReP1, UltShReP1, UltShReP2, UltShReP2)

```

$$ShftResPlotP1CL := ShftResplot (ShftP1CL, 1) \text{ kPa} = \begin{bmatrix} 230.786 \\ 230.786 \\ 43.341 \\ 43.341 \\ 43.341 \\ 43.341 \end{bmatrix} \text{ kPa}$$

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

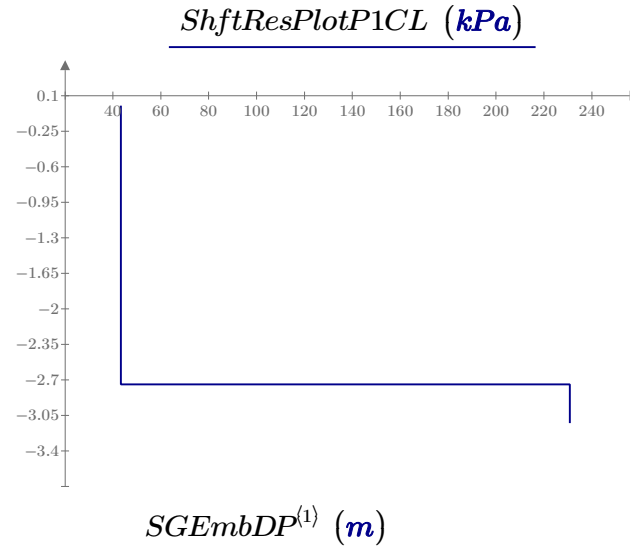


Fig C 55. Strain Gauge Depth vs Unit Shaft Resistance for post cyclic pile P1.

ShftResplotP_C := augment(*ShftResPlotP1CL*, *ShftResPlotP1CL*, *ShftResPlotP1CL*, *ShftResPlotP1CL*, *ShftResPlotP1CL*)
Ultimate Shaft resistance on the five compression piles between SGS

Function for estimating Mid depth of SGs on each piles

```

MidDSGsgmt(PileNum) :=
    shaft12 ← mean(submatrix(SGEmbDP, 0, 1, PileNum, PileNum))
    shaft23 ← if mean(submatrix(SGEmbDP, 2, 3, PileNum, PileNum)) = 0
                0
            else
                mean(submatrix(SGEmbDP, 2, 3, PileNum, PileNum))
    shaft34 ← if mean(submatrix(SGEmbDP, 4, 5, PileNum, PileNum)) = 0
                0
            else
                mean(submatrix(SGEmbDP, 4, 5, PileNum, PileNum))
    stack(shaft12, shaft23, shaft34)

```

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Function for estimating Ks of each piles

```

Ks(ShftResplotP, PileNum) :=
  shaft12 ←  $\frac{\text{mean}(\text{submatrix}(ShftResplotP, 0, 1, PileNum, PileNum))}{\text{mean}(\text{submatrix}(SGEbDP, 0, 1, PileNum, PileNum)) \cdot \gamma \cdot \tan(\delta)}$ 
  shaft23 ← if PileNum = 2
              0
            else if PileNum = 3
              0
            else
              if mean(submatrix(SGEbDP, 2, 3, PileNum, PileNum)) = 0
                0
              else
                 $\frac{\text{mean}(\text{submatrix}(ShftResplotP, 2, 3, PileNum, PileNum))}{\text{mean}(\text{submatrix}(SGEbDP, 2, 3, PileNum, PileNum)) \cdot \gamma \cdot \tan(\delta)}$ 
  shaft34 ← if PileNum = 4
              0
            else
              if mean(submatrix(SGEbDP, 4, 5, PileNum, PileNum)) = 0
                0
              else
                 $\frac{\text{mean}(\text{submatrix}(ShftResplotP, 4, 5, PileNum, PileNum))}{\text{mean}(\text{submatrix}(SGEbDP, 4, 5, PileNum, PileNum)) \cdot \gamma \cdot \tan(\delta)}$ 
  stack(-shaft12, -shaft23, -shaft34)

```

$KsP_C := Ks(ShftResplotP_C, 1)$

$MidDSGsgmtP := \text{augment}(MidDSGsgmt(0), MidDSGsgmt(1), MidDSGsgmt(2), MidDSGsgmt(3), MidDSGsgmt(4))$

$Ko := \begin{bmatrix} 1 - \sin(\varphi) & 1 - \sin(\varphi) \end{bmatrix}$
 $Kp := \begin{bmatrix} \frac{1 + \sin(\varphi)}{1 - \sin(\varphi)} & \frac{1 + \sin(\varphi)}{1 - \sin(\varphi)} \end{bmatrix}$
 $Ka := \begin{bmatrix} \frac{1 - \sin(\varphi)}{1 + \sin(\varphi)} & \frac{1 - \sin(\varphi)}{1 + \sin(\varphi)} \end{bmatrix} = \begin{bmatrix} 0.317 & 0.317 \end{bmatrix}$
 $K := \begin{bmatrix} 0.09 \cdot e^{0.08 \cdot \left(\varphi \cdot \frac{180}{\pi}\right)} & 0.09 \cdot e^{0.08 \cdot \left(\varphi \cdot \frac{180}{\pi}\right)} \end{bmatrix}$
Mitsch and Clemence 1985

$ProtEmbed := \begin{bmatrix} 0 & -E \cdot Nscale^{scifac_{0,0}} \end{bmatrix} = \begin{bmatrix} 0 & -3.382 \end{bmatrix} \mathbf{m}$ Pile Embedment in prototype scale unit

$KsP_C = \begin{bmatrix} 11.291 \\ 3.887 \\ 0 \end{bmatrix}$
 $MidDSGsgmtP = \begin{bmatrix} -1.791 & -2.934 & -2.934 & -2.553 & -2.934 \\ 0 & -1.6 & -2.362 & -1.6 & -1.981 \\ 0 & 0 & -1.219 & -0.838 & -0.838 \end{bmatrix} \mathbf{m}$

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

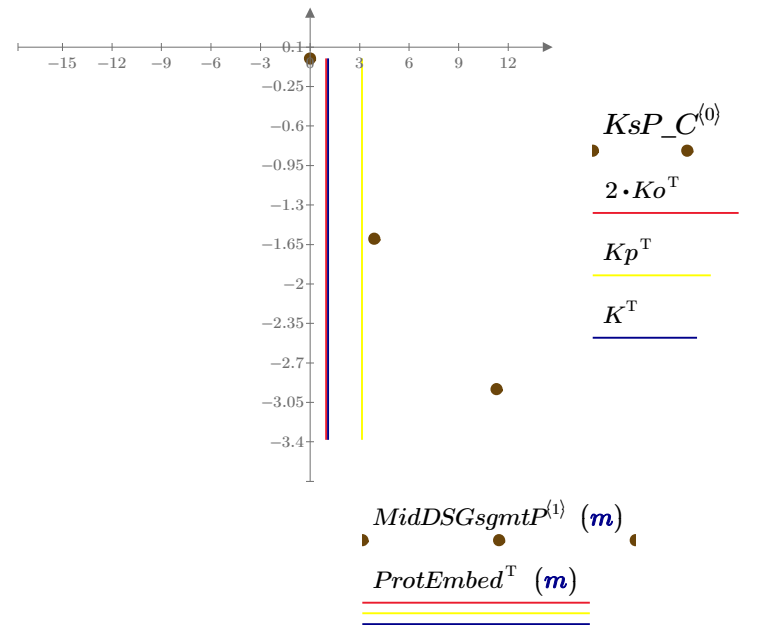


Fig C 56. Ks vs depth for P1

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Function for estimating the shaft resistance EDR

```

ShftEDR (TDispTLdP0PL1 , ShftResP2PL1 , Pseu1perS , IniTime , IniDisp , LoopNo , ShftNo) :=
    m ← TDispTLdP0PL1
    n ←  $\frac{ShftResP2PL1}{kPa}$ 
    o ← TimeCycLoop (Pseu1perS , IniTime , IniDisp) − IniTime
    w ← −m(1)
    wmax ← max (−m(1))
    if ShftNo = 1
        q ← n(0)
        qmax ← max (n(0))
    else if ShftNo = 2
        q ← n(1)
        qmax ← max (n(1))
    else if ShftNo = 3
        q ← n(2)
        qmax ← max (n(2))

    if LoopNo = 1
        t1 ← m1,0 − IniTime
        t2 ← o1
    else if LoopNo = 2
        t1 ← o1
        t2 ← o2
    else if LoopNo = 3
        t1 ← o2
        t2 ← o3
    else if LoopNo = 4
        t1 ← o3
        t2 ← o4

    tstart ← lookup (t1 , (m(0) − IniTime) , (m(0) − IniTime) , "near")
    tend ← lookup (t2 , (m(0) − IniTime) , (m(0) − IniTime) , "near")
    rowstart ← match (t1 , (m(0) − IniTime) , "near")
    rowend ← match (t2 , (m(0) − IniTime) , "near")
    for i ∈ rowstart0,0 .. rowend0,0
        ri ←  $\left( (w - w_{i-1}) \cdot \left( \frac{(q_i + q_{i-1})}{2} \right) \right)$ 

    area ← ∑ r

    EDR ← if qmax = 0
        0
        else if wmax = 0
        0
        else if area = 0
        0
        else
         $\frac{area}{qmax \cdot wmax}$ 

    s ← augment ((tstart + IniTime) , (tend + IniTime) , rowstart , rowend , qmax , wmax , area , EDR)
    EDR

```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Function for combining the shaft resistance EDR

$$ShftEDRPOPLSG(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, PileNo) := \begin{array}{l} q1 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1) \\ q2 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1) \\ q3 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1) \\ q4 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1) \\ r1 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2) \\ r2 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2) \\ r3 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2) \\ r4 \leftarrow ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2) \\ w1 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 3) \\ w2 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 3) \\ w3 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 3) \\ w4 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3) \\ \text{augment}(\text{stack}(q1, q2, q3, q4), \text{stack}(r1, r2, r3, r4), \text{stack}(w1, w2, w3, w4)) \end{array}$$

$$NoLoop := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

$$ShftEDRP1PL1 := ShftEDRPOPLSG(TDispTLdP1PL1, ShftResP1PL1, PseuPL1H, IniTimePL1H, 1) = \begin{bmatrix} 10.264 & 0.181 & 0 \\ -7.291 & -0.291 & 0 \\ 3.135 & -0.162 & 0 \\ 2.311 & 0.047 & 0 \end{bmatrix}$$

$$ShftEDRP1PL2 := ShftEDRPOPLSG(TDispTLdP1PL2, ShftResP1PL2, PseuPL2H, IniTimePL2H, 1) = \begin{bmatrix} 0.39 & -0.13 & 0 \\ -0.269 & -0.126 & 0 \\ 0.258 & 0.399 & 0 \\ -0.382 & -0.815 & 0 \end{bmatrix}$$

$$ShftEDRP1PL3 := ShftEDRPOPLSG(TDispTLdP1PL3, ShftResP1PL3, PseuPL3H, IniTimePL3H, 1) = \begin{bmatrix} 2.672 & 0.637 & 0 \\ -0.015 & -0.611 & 0 \\ -3.332 & -0.567 & 0 \\ 5.68 & 0.248 & 0 \end{bmatrix}$$

$$ShftEDRP1PL4 := ShftEDRPOPLSG(TDispTLdP1PL4, ShftResP1PL4, PseuPL4H, IniTimePL4H, 1) = \begin{bmatrix} 0.162 & 0.072 & 0 \\ -0.098 & -0.101 & 0 \\ -0.091 & -0.127 & 0 \\ -0.071 & -0.146 & 0 \end{bmatrix}$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

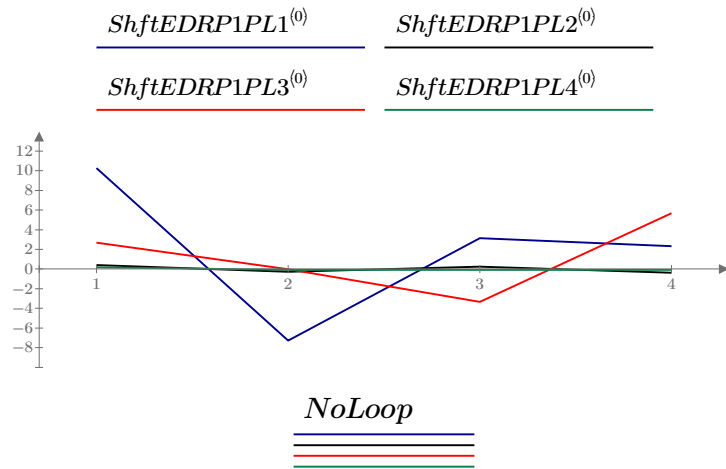


Fig C 57. Shaft EDR vs No of loops Seg1

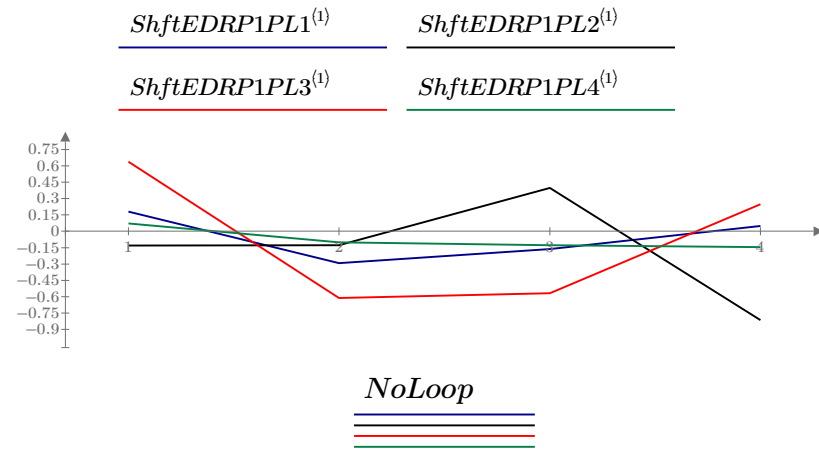


Fig C 58. Shaft EDR vs No of loops Seg 2

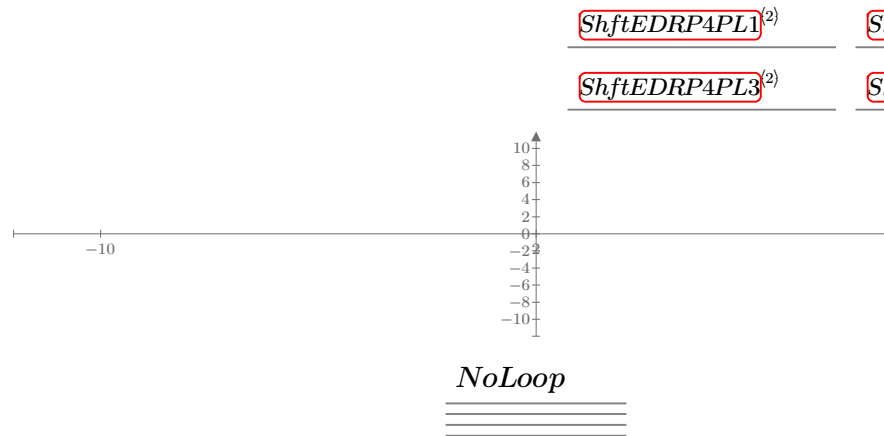
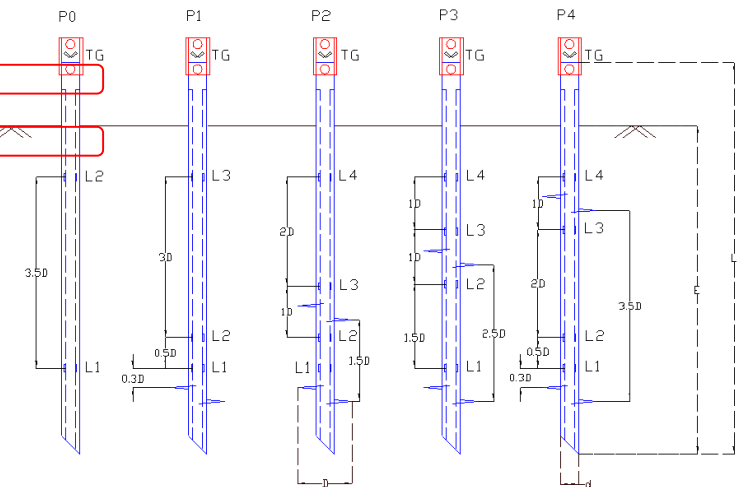


Fig C 59. EDR vs No of loops Seg 3



2.3.4 End Bearing vs Depth

$$A_b := \pi \cdot \frac{\left(D \cdot Nscale^{sclfac_{0,0}}\right)^2}{4} = 0.456 \text{ m}^2$$

Total area at the helix in prototype scale

$$A_d := \pi \cdot \frac{\left(d \cdot Nscale^{sclfac_{0,0}}\right)^2}{4} = 0.051 \text{ m}^2$$

Total area at the shaft in prototype scale

Function for determining the end bearing

```

EndBrng (TDispTLdP0CL, PileNum) :=
  for i ∈ 0, 1..rows (TDispTLdP0CL) - 1
    for j ∈ 0, 1..cols (TDispTLdP0CL) - 1
      qb1i,0 ← if PileNum = 0
                (TDispTLdP0CLi,3) kN
                Ad
            else
                (TDispTLdP0CLi,3) kN
                Ab - Ad
      qb23i,1 ← if PileNum = 2
                  (TDispTLdP0CLi,5 - TDispTLdP0CLi,4) kN
                  Ab - Ad
                else if PileNum = 3
                  (TDispTLdP0CLi,5 - TDispTLdP0CLi,4) kN
                  Ab - Ad
                else
                  0
      qb34i,2 ← if PileNum = 4
                  (TDispTLdP0CLi,6 - TDispTLdP0CLi,5) kN
                  Ab - Ad
                else
                  0
    augment (qb1(0), qb23(1), qb34(2))
  
```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

$$EndBrng(TDispTLdP1CL, 1)^{(0)} = \begin{matrix} 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ \vdots \\ 13855 \end{matrix} \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ -318.653 \\ -637.306 \\ -1.262 \cdot 10^3 \\ -3.148 \cdot 10^3 \\ -3.148 \cdot 10^3 \\ -3.148 \cdot 10^3 \\ -3.148 \cdot 10^3 \\ -3.785 \cdot 10^3 \\ \vdots \end{bmatrix} \text{ Pa}$$

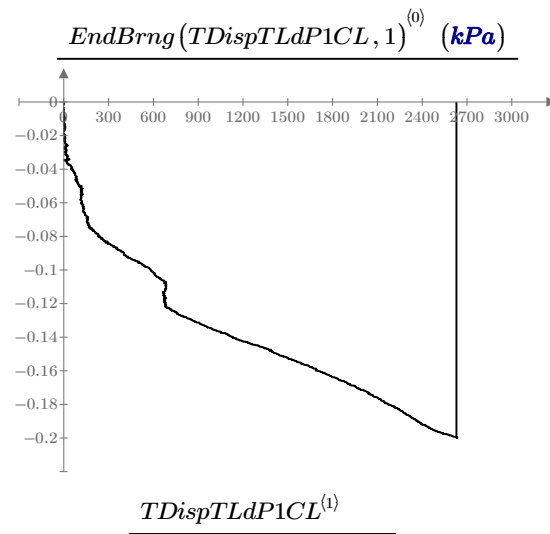


Fig C 60. Depth vs End Bearing for compression pile P1

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

$$UltEndBrngP1_0 := \text{lookup} \left(-0.05, TDispTLdP1CL^{(1)}, EndBrng(TDispTLdP1CL, 0)^{(0)}, \text{"near"} \right) = [835.209] \text{ } \mathbf{kPa}$$

$$HelixLoc := - \begin{bmatrix} 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 \\ 0 & 0 & 0.6 + 2 + 0.3 + 0.17 & 0.6 + 1 + 0.3 + 0.17 & 0.6 + 0.3 + 0.17 \end{bmatrix} \cdot D \cdot Nscale^{scifac}_{0,0}$$

$$\text{stack} \left(\frac{UltEndBrngP1_0}{-HelixLoc_{0,1} \cdot \gamma}, 0 \right) = \begin{bmatrix} 14.897 \\ 0 \end{bmatrix}$$

$$HelixLoc = \begin{bmatrix} -3.482 & -3.482 & -3.482 & -3.482 & -3.482 \\ 0 & 0 & -2.339 & -1.577 & -0.815 \end{bmatrix} \text{ } \mathbf{m}$$

$$BrngP1PL1 := EndBrng(TDispTLdP1PL1, 1)$$

$$BrngP1PL2 := EndBrng(TDispTLdP1PL2, 1)$$

$$BrngP1PL3 := EndBrng(TDispTLdP1PL3, 1)$$

$$BrngP1PL4 := EndBrng(TDispTLdP1PL4, 1)$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

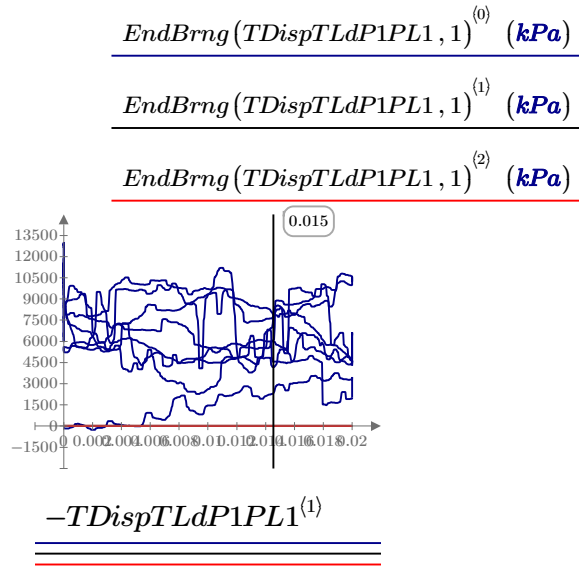


Fig C 61. End Bearing vs Depth for P1 PL1

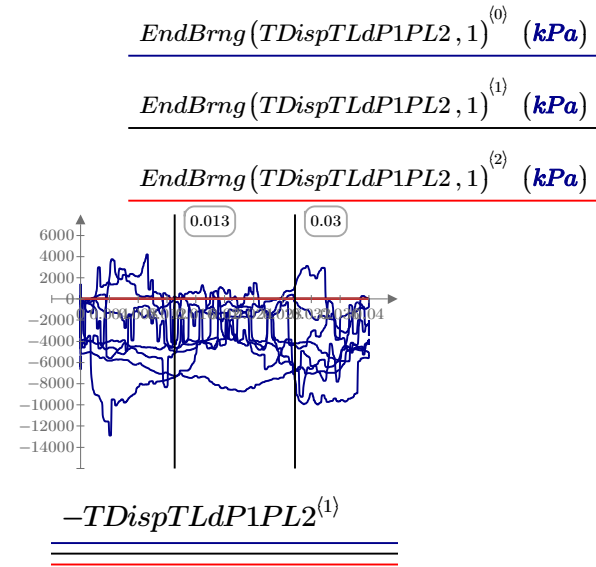


Fig C 62. End Bearing vs Depth for P1 PL2

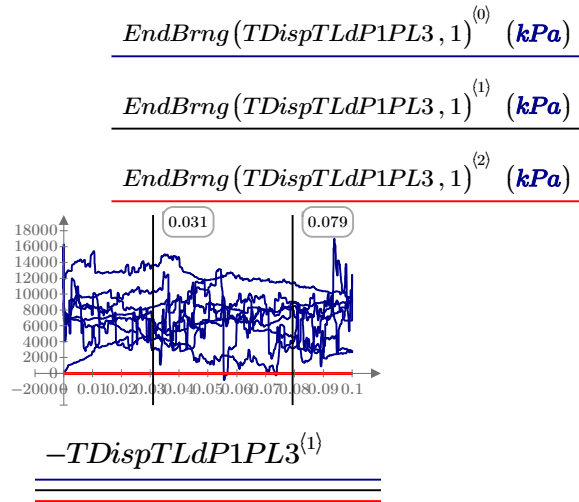


Fig C 63. End Bearing vs Depth for P4 PL3

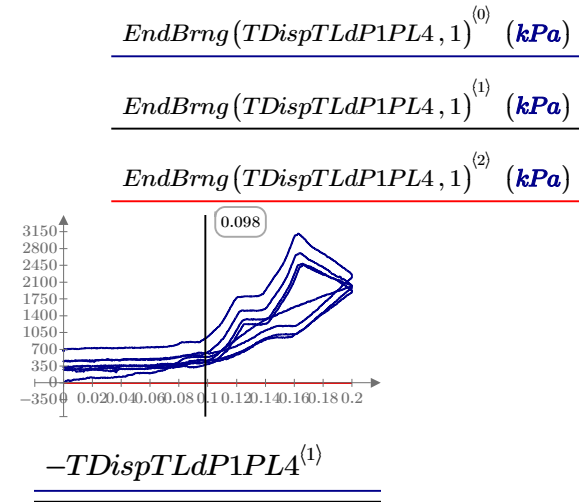


Fig C 64. End Bearing vs Depth for P1 PL4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Functions for calculating the EDR from the bearing resistances

```

BrngEDR (TDispTLdP0PL1 , BrngP2PL1 , Pseu1perS , IniTime , IniDisp , LoopNo , ShftNo) :=
  m ← TDispTLdP0PL1
  n ←  $\frac{BrngP2PL1}{kPa}$ 
  o ← TimeCycLoop (Pseu1perS , IniTime , IniDisp) - IniTime
  w ← -m(1)
  umax ← max (-m(1))
  if ShftNo = 1
    q ← n(0)
    qmax ← max (n(0))
  else if ShftNo = 2
    q ← n(1)
    qmax ← max (n(1))
  else if ShftNo = 3
    q ← n(2)
    qmax ← max (n(2))

  if LoopNo = 1
    t1 ← m1,0 - IniTime
    t2 ← o1
  else if LoopNo = 2
    t1 ← o1
    t2 ← o2
  else if LoopNo = 3
    t1 ← o2
    t2 ← o3
  else if LoopNo = 4
    t1 ← o3
    t2 ← o4

  tstart ← lookup (t1 , (m(0) - IniTime) , (m(0) - IniTime) , "near")
  tend ← lookup (t2 , (m(0) - IniTime) , (m(0) - IniTime) , "near")
  rowstart ← match (t1 , (m(0) - IniTime) , "near")
  rowend ← match (t2 , (m(0) - IniTime) , "near")
  for i ∈ rowstart0,0 .. rowend0,0
    ri ←  $\left( (w - w_{i-1}) \cdot \left( \frac{q_i + q_{i-1}}{2} \right) \right)$ 

  area ← ∑ r

  EDR ← if qmax = 0
    0
  else if umax = 0
    0
  else if area = 0
    0
  else
     $\frac{area}{qmax \cdot umax}$ 

  s ← augment ((tstart + IniTime) , (tend + IniTime) , rowstart , rowend , qmax , umax , area , EDR)
  EDR

```


Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

Function for compiling EDR for the end bearing in loading cycles

$$BrngEDRPOPLSG(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, PileNo) := \begin{array}{l} q1 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1) \\ q2 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1) \\ q3 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1) \\ q4 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1) \\ r1 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2) \\ r2 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2) \\ r3 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2) \\ r4 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2) \\ w1 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 3) \\ w2 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 3) \\ w3 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 3) \\ w4 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3) \\ \text{augment}(\text{stack}(q1, q2, q3, q4), \text{stack}(r1, r2, r3, r4), \text{stack}(w1, w2, w3, w4)) \end{array}$$

$$NoLoop := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

$$BrngEDRP1PL1 := BrngEDRPOPLSG(TDispTLdP1PL1, BrngP1PL1, PseuPL1H, IniTimePL1H, 1) = \begin{bmatrix} -0.212 & 0 & 0 \\ 0.148 & 0 & 0 \\ -0.064 & 0 & 0 \\ -0.047 & 0 & 0 \end{bmatrix}$$

$$BrngEDRP1PL2 := BrngEDRPOPLSG(TDispTLdP1PL2, BrngP1PL2, PseuPL2H, IniTimePL2H, 1) = \begin{bmatrix} -1.198 & 0 & 0 \\ 0.821 & 0 & 0 \\ -0.795 & 0 & 0 \\ 1.17 & 0 & 0 \end{bmatrix}$$

$$BrngEDRP1PL3 := BrngEDRPOPLSG(TDispTLdP1PL3, BrngP1PL3, PseuPL3H, IniTimePL3H, 1) = \begin{bmatrix} -0.137 & 0 & 0 \\ 0.002 & 0 & 0 \\ 0.173 & 0 & 0 \\ -0.293 & 0 & 0 \end{bmatrix}$$

$$BrngEDRP1PL4 := BrngEDRPOPLSG(TDispTLdP1PL4, BrngP1PL4, PseuPL4H, IniTimePL4H, 1) = \begin{bmatrix} -0.045 & 0 & 0 \\ -0.113 & 0 & 0 \\ -0.15 & 0 & 0 \\ -0.196 & 0 & 0 \end{bmatrix}$$

Appendix C

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P1 Helix Pile

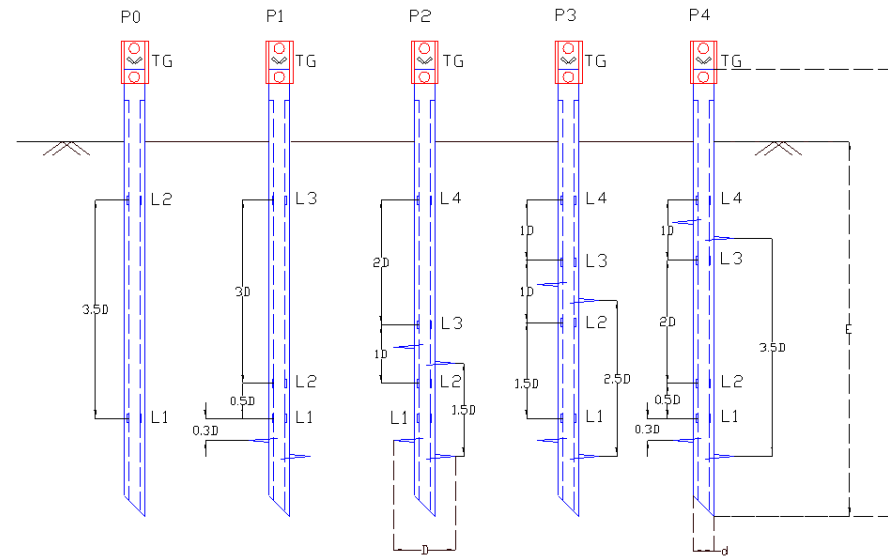
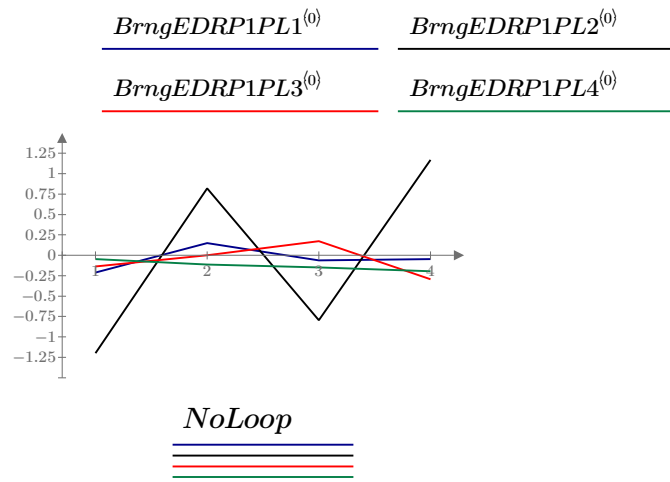


Fig C 65. Shaft EDR vs No of loops Helix Location 1 SG 1

1. Introduction

The series of sheets in Appendix D contains the data conversion and processing procedures specifically for the NI02 centrifuge test series on P2 pile type. For the data conversion procedures, the raw data files were first corrected by subtracting the initial value of pre spin data depending on file index. The data were then converted into engineering units through recalibrations of the strain gauges in the centrifuge data logger.

2. HBM Data Conversion

HBM data were recorded by the HBM Data Logger connected to the main computer unit of the GeoCerf centrifuge.

2.1 General Information

2.1.1 Model Pile Dimensions

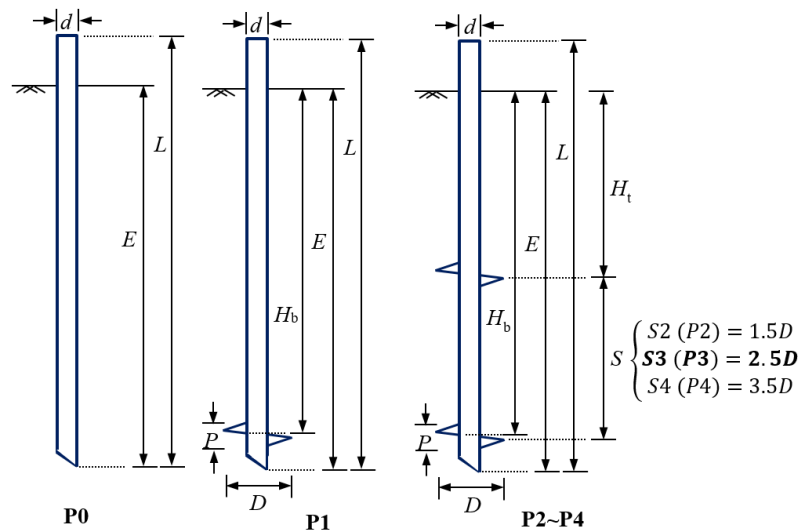
$L := 271.8 \text{ mm}$	Length of the Pile
$d := 12.7 \text{ mm}$	Diameter of the shaft
$D := 38.1 \text{ mm}$	Diameter of the helix
$E := 169.1 \text{ mm}$	Embedment depth of pile
$H_b := 150 \text{ mm}$	Depth to bottom helix
$H_t := [150] \text{ mm}$	Depth to top helix
$P_s := \pi \cdot D = 0.12 \text{ m}$	Perimeter of the Helical Pile Shaft
$H_{eff} := (H_b - D)$	Effective Shaft Length
$P := 12.7 \text{ mm}$	Pitch of the helix

2.1.2 Properties of Sand

$\gamma := 16.1 \frac{\text{kN}}{\text{m}^3}$	Unit Weight
$\varphi := 31.2 \text{ deg}$	CV Friction Angle
$\delta := \left(\frac{3}{4} \cdot \varphi\right) = 23.4 \text{ deg}$	CV Dilation Angle

2.1.3 Centrifuge Scale

$NoSGages := 4$	1 refers to the Strain Gage at the bottom and 4 the Strain Gage at the top of the pile; Total No of Strain Gages: P0=2, P1=3, P2 to P4= 4
$Nscale := 20$	Centrifuge g-level



Schematic of the model piles

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

$sclfac := [1 \ 2 \ 3]$ Centrifuge scale factor $N^{\wedge}scale$, 1 for displacement, 2 for force, 3 for Torque

2.1.4 Pseudostatic Loading Stages

2.1.4.1 Actuator Scale Factors

$$RateScale := \frac{8}{\frac{mm}{sec}} \quad <= 1V8 = 1mm/sec \quad DistanScale := \frac{64000}{mm} \quad <= 1D64000 = 1mm$$

2.1.4.2 Pseudostatic Loading Stages for Helix Piles (P1 to P4)

$$LDisp := \begin{bmatrix} 0.01 \\ 0.02 \\ 0.05 \\ 0.10 \\ 0.10 \end{bmatrix} \quad LNoLoop := \begin{bmatrix} 8 \\ 8 \\ 8 \\ 8 \\ 1 \end{bmatrix} \quad PsdoTLag := 5 \text{ s} \quad LRate := \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 0.33 \end{bmatrix} \frac{mm}{min}$$

$$LTime(Dia) := \left\| \begin{array}{l} \text{for } i \in 0, 1 \dots \text{rows}(LDisp) - 1 \\ \left\| \begin{array}{l} 2 \cdot LDisp_i \cdot Dia \cdot LNoLoop_i \\ k_i \leftarrow \frac{\quad}{LRate_i} + (PsdoTLag \cdot (LNoLoop_i - 1)) \end{array} \right\| \\ k \end{array} \right\|$$

$$LTime(D) = \begin{bmatrix} 400.76 \\ 766.52 \\ 1863.8 \\ 3692.6 \\ 1385.455 \end{bmatrix} \text{ s} \quad LTime(d) = \begin{bmatrix} 156.92 \\ 278.84 \\ 644.6 \\ 1254.2 \\ 461.818 \end{bmatrix} \text{ s}$$

2.2 Calibration of the Strain Gages in HBM Data Logger

2.2.1 Calibration of Axial Strain Gages

RawDataCalib := READEXCEL (“..\Finalized NI01\Calibration SGages HBM Centrifuge Corrected.xlsx”, “Sheet1!A1:G12”)

$$\text{RawDataCalib} = \begin{bmatrix} 4.427 & 1 & 0.076 & 0.104 & 0.149 & 0.098 & 0.132 \\ 7.97 & 1 & 0.152 & 0.171 & 0.23 & 0.195 & 0.244 \\ 13.606 & 1 & 0.391 & 0.295 & 0.343 & 0.287 & 0.336 \\ 4.427 & 2 & 0.048 & 0.06 & 0.078 & 0.091 & 0.1 \\ 7.97 & 2 & 0.053 & 0.114 & 0.114 & 0.136 & 0.194 \\ 13.606 & 2 & 0.088 & 0.214 & 0.161 & 0.225 & 0.231 \\ 4.427 & 3 & 0 & 0.043 & 0.028 & 0.052 & 0.037 \\ 7.97 & 3 & 0 & 0.063 & 0.151 & 0.087 & 0.078 \\ 13.606 & 3 & 0 & 0.127 & 0.199 & 0.149 & 0.112 \\ 4.427 & 4 & 0 & 0 & 0.089 & 0.035 & 0.028 \\ 7.97 & 4 & 0 & 0 & 0.109 & 0.067 & 0.055 \\ 13.606 & 4 & 0 & 0 & 0.145 & 0.127 & 0.141 \end{bmatrix}$$

Colm 0 represents calibration loads in kg, Colm 1 represents Strain Gage Number, Colm 2-6 represents Strain Gage HBM readings for piles P0,P1,P2,P3 and P4 respectively

CmbLdAx := RawDataCalib⁽⁰⁾ **kg · g** Load Combinations

CalibdataPile := submatrix(RawDataCalib, 0, rows(RawDataCalib) - 1, 2, 6) · 10⁻³ · $\frac{mV}{V}$ HBM Strain Gage Data

Function for Calibration factor for all axial load on strain gages in each pile

$$CF := \begin{matrix} \text{for } i \in 0, 1 \dots \text{rows}(\text{CalibdataPile}) - 1 \\ \text{for } j \in 0, 1 \dots \text{cols}(\text{CalibdataPile}) - 1 \\ k_{i,j} \leftarrow \text{CmbLdAx}_{i,0} \\ q_{i,j} \leftarrow \text{CalibdataPile}_{i,j} \\ m_{i,j} \leftarrow \text{if } q_{i,j} = 0 \\ \quad 0 \\ \text{else} \\ \quad \frac{k_{i,j}}{q_{i,j}} \end{matrix} = \begin{bmatrix} 571.237 & 417.443 & 291.369 & 443 & 328.894 \\ 514.204 & 457.07 & 339.822 & 400.815 & 320.324 \\ 341.251 & 452.303 & 389.007 & 464.91 & 397.111 \\ 904.459 & 723.567 & 556.59 & 477.077 & 434.14 \\ 1474.698 & 685.605 & 685.605 & 574.699 & 402.881 \\ 1516.242 & 623.501 & 828.753 & 593.019 & 577.616 \\ 0 & 1009.629 & 1550.501 & 834.885 & 1173.352 \\ 0 & 1240.619 & 517.609 & 898.379 & 1002.038 \\ 0 & 1050.624 & 670.499 & 895.499 & 1191.333 \\ 0 & 0 & 487.798 & 1240.401 & 1550.501 \\ 0 & 0 & 717.055 & 1166.552 & 1421.073 \\ 0 & 0 & 920.202 & 1050.624 & 946.307 \end{bmatrix} \frac{kN}{mV}$$

Calibration Factor. Here, the columns represents the Piles from P0 to P4 (left to right) and the rows represents the Strain Gage readings SG1 to SG4 (top to bottom) for three load combinations

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

2.2.1 Calibration of Torque Strain Gages

RawDataTorque := READEXCEL (“..\Finalized NI01\Calibration Torque S Gages HBM Centrifuge .xlsx”, “Sheet1!J34:K36”)

$$\text{RawDataTorque} = \begin{bmatrix} 0.144 & 0.022 \\ 0.206 & 0.03 \\ 0.35 & 0.052 \end{bmatrix} \quad \text{CmbLdTr} := \text{RawDataTorque}^{(0)} \cdot \mathbf{N} \cdot \mathbf{m} \quad \text{CalibdataTr} := \text{RawDataTorque}^{(1)} \cdot 10^{-3} \cdot \frac{\mathbf{mV}}{\mathbf{V}}$$

Function for Calibration factor for all torsional load on strain gages in each pile

$$\text{CFTr} := \left\| \begin{array}{l} \text{for } i \in 0, 1 \dots \text{rows}(\text{CalibdataTr}) - 1 \\ \quad \left\| \begin{array}{l} \text{for } j \in 0, 1 \dots \text{cols}(\text{CalibdataTr}) - 1 \\ \quad \left\| \begin{array}{l} k_{i,j} \leftarrow \text{CmbLdTr}_{i,0} \\ q_{i,j} \leftarrow \text{CalibdataTr}_{i,j} \\ m_{i,j} \leftarrow \text{if } q_{i,j} = 0 \\ \quad \left\| \begin{array}{l} 0 \\ \text{else} \\ \frac{k_{i,j}}{q_{i,j}} \end{array} \end{array} \right. \\ m \end{array} \right. \end{array} \right\| = \begin{bmatrix} 6.674 \\ 6.813 \\ 6.763 \end{bmatrix} \cdot \mathbf{m} \cdot \frac{\mathbf{kN}}{\frac{\mathbf{mV}}{\mathbf{V}}}$$

2.3 Pseudostatic Cyclic Centrifuge Test on Piles

Five piles were tested in compression and four piles were tested in tension in two separate model boxes two ascertain the axial load transfer mechanism within the pile.

2.3.1 Pseudostatic Cyclic Displacement Time History

$$\text{Lag} := 5 \quad \text{LagCyc} := 100 \quad \text{LoadCycRate} := 1 \frac{\mathbf{mm}}{\mathbf{min}} = 0.017 \frac{\mathbf{mm}}{\mathbf{s}} \quad \text{LoadCompRate} := 0.33 \frac{\mathbf{mm}}{\mathbf{min}} = 0.006 \frac{\mathbf{mm}}{\mathbf{s}}$$

Actuator Loading rate in cyclic Actuator Loading rate in compression

$$\text{NormDisp} := \begin{bmatrix} 0.01 \\ 0.02 \\ 0.05 \\ 0.1 \\ 0.2 \end{bmatrix} \quad \text{NormDispPeakCycles} := 2 \cdot \begin{bmatrix} \text{NormDisp}_0 \\ \text{NormDisp}_1 \\ \text{NormDisp}_2 \\ \text{NormDisp}_3 \end{bmatrix} = \begin{bmatrix} 0.02 \\ 0.04 \\ 0.1 \\ 0.2 \end{bmatrix}$$

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

Function for calculating time required for each pseudostatic load

$$\begin{aligned}
 &Time(Dia) := \text{for } j \in 0, 1 \dots 3 \\
 &\quad \text{for } i \in 0, 1 \dots 4 \\
 &\quad \quad k \leftarrow NormDisp \\
 &\quad \quad p \leftarrow \frac{Dia}{m} \\
 &\quad \quad z \leftarrow \frac{LoadCycRate}{\frac{m}{s}} \\
 &\quad \quad x \leftarrow \frac{LoadCompRate}{\frac{m}{s}} \\
 &\quad \quad q_{0,0} \leftarrow k_{0,0} \cdot \frac{p}{z} \\
 &\quad \quad q_{1,0} \leftarrow k_{1,0} \cdot \frac{p}{z} \\
 &\quad \quad q_{2,0} \leftarrow k_{2,0} \cdot \frac{p}{z} \\
 &\quad \quad q_{3,0} \leftarrow k_{3,0} \cdot \frac{p}{z} \\
 &\quad \quad q_{4,0} \leftarrow k_{4,0} \cdot \frac{p}{x} \\
 &\quad q
 \end{aligned}$$

$$TimeHelix := Time(D) = \begin{bmatrix} 22.86 \\ 45.72 \\ 114.3 \\ 228.6 \\ 1385.455 \end{bmatrix}$$

$$TimeShaft := Time(d) = \begin{bmatrix} 7.62 \\ 15.24 \\ 38.1 \\ 76.2 \\ 461.818 \end{bmatrix}$$

Function for calculating initial time required for each pseudostatic load

$$\begin{aligned}
 &DispIniTime(DispHelixShaft) := \text{for } j \in 0, 1 \dots 3 \\
 &\quad \text{for } i \in 0, 1 \dots 5 \\
 &\quad \quad q_{0,0} \leftarrow 0 \\
 &\quad \quad q_{1,0} \leftarrow \left((16 \cdot DispHelixShaft_{0,0}) + (7 \cdot Lag) + LagCyc \right) \\
 &\quad \quad q_{2,0} \leftarrow q_{1,0} + \left((16 \cdot DispHelixShaft_{1,0}) + (7 \cdot Lag) + (LagCyc) \right) \\
 &\quad \quad q_{3,0} \leftarrow q_{2,0} + \left((16 \cdot DispHelixShaft_{2,0}) + (7 \cdot Lag) + (LagCyc) \right) \\
 &\quad \quad q_{4,0} \leftarrow q_{3,0} + \left((16 \cdot DispHelixShaft_{3,0}) + (7 \cdot Lag) + (LagCyc) \right) \\
 &\quad q
 \end{aligned}$$

$$IniTimeHelix := DispIniTime(TimeHelix) = \begin{bmatrix} 0 \\ 500.76 \\ 1367.28 \\ 3331.08 \\ 7123.68 \end{bmatrix}$$

$$IniTimeShaft := DispIniTime(TimeShaft) = \begin{bmatrix} 0 \\ 256.92 \\ 635.76 \\ 1380.36 \\ 2734.56 \end{bmatrix}$$

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

$PseuPL1H := \begin{bmatrix} TimeHelix_{0,0} & NormDisp_{0,0} \end{bmatrix}$	$IniTimePL1H := DispIniTime(TimeHelix)_{0,0} = 0$	$IniDisp := 0$
$PseuPL2H := \begin{bmatrix} TimeHelix_{1,0} & NormDisp_{1,0} \end{bmatrix}$	$IniTimePL2H := DispIniTime(TimeHelix)_{1,0} = 500.76$	
$PseuPL3H := \begin{bmatrix} TimeHelix_{2,0} & NormDisp_{2,0} \end{bmatrix}$	$IniTimePL3H := DispIniTime(TimeHelix)_{2,0} = 1.367 \cdot 10^3$	
$PseuPL4H := \begin{bmatrix} TimeHelix_{3,0} & NormDisp_{3,0} \end{bmatrix}$	$IniTimePL4H := DispIniTime(TimeHelix)_{3,0} = 3.331 \cdot 10^3$	
$PseuCLH := \begin{bmatrix} TimeHelix_{4,0} & NormDisp_{4,0} \end{bmatrix}$	$IniTimeCLH := DispIniTime(TimeHelix)_{4,0} = 7.124 \cdot 10^3$	
$PseuPL1S := \begin{bmatrix} TimeShaft_{0,0} & NormDisp_{0,0} \end{bmatrix}$	$IniTimePL1S := DispIniTime(TimeShaft)_{0,0} = 0$	$IniDisp := 0$
$PseuPL2S := \begin{bmatrix} TimeShaft_{1,0} & NormDisp_{1,0} \end{bmatrix}$	$IniTimePL2S := DispIniTime(TimeShaft)_{1,0} = 256.92$	
$PseuPL3S := \begin{bmatrix} TimeShaft_{2,0} & NormDisp_{2,0} \end{bmatrix}$	$IniTimePL3S := DispIniTime(TimeShaft)_{2,0} = 635.76$	
$PseuPL4S := \begin{bmatrix} TimeShaft_{3,0} & NormDisp_{3,0} \end{bmatrix}$	$IniTimePL4S := DispIniTime(TimeShaft)_{3,0} = 1.38 \cdot 10^3$	
$PseuCLS := \begin{bmatrix} TimeShaft_{4,0} & NormDisp_{4,0} \end{bmatrix}$	$IniTimeCLS := DispIniTime(TimeShaft)_{4,0} = 2.735 \cdot 10^3$	

Function for calculating time required for each cycle of the pseudostatic loads

```

TimeCycLoop(Pseu1per, IniTimeHelix, IniDisp) :=
  for j ∈ 0, 1..3
    for i ∈ 0, 1..40000
      q0,0 ← IniTimeHelix
      diff ← 0.1
      qi+1,0 ← qi,0 + diff
      q0,1 ← IniDisp
      Lag ← 5
      LagCyc ← 100
      k0,0 ← q0,0
      k1,0 ← ((q0,0 + 4 • Pseu1per0,0) + (2 • Lag))
      k2,0 ← ((q0,0 + 8 • Pseu1per0,0) + (4 • Lag))
      k3,0 ← ((q0,0 + 12 • Pseu1per0,0) + (6 • Lag))
      k4,0 ← ((q0,0 + 16 • Pseu1per0,0) + (7 • Lag) + LagCyc)
    k
  
```


Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

Function for calculating displacement increments for each cycles of the pseudostatic loads

```

DispCyc(Pseu1per, IniTimeHelix, IniDisp) :=
  for j ∈ 0, 1..3
  for i ∈ 0, 1..40000
    q0,0 ← IniTimeHelix
    diff ← 0.1
    qi+1,0 ← qi,0 + diff
    q0,1 ← IniDisp
    Lag ← 5
    LagCyc ← 100
    qi+1,0 ← if qi+1,0 ≤ ((q0,0 + 16 • Pseu1per0,0) + (7 • Lag) + LagCyc)
      || qi+1,0
    else if qi+1,0 > ((q0,0 + 16 • Pseu1per0,0) + (7 • Lag) + LagCyc)
      || break
    qi+1,1 ← if (qi+1,0) ≤ (q0,0 + 2 • Pseu1per0,0)
      ||  $\frac{(q_{i+1,0} - q_{0,0})}{((q_{0,0} + 2 \cdot Pseu1per_{0,0}) - q_{0,0})} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if (q0,0 + 2 • Pseu1per0,0) < qi+1,0 ≤ ((q0,0 + 2 • Pseu1per0,0) + Lag)
      || 2 • Pseu1per0,1
    else if ((q0,0 + 2 • Pseu1per0,0) + Lag) < qi+1,0 ≤ ((q0,0 + 4 • Pseu1per0,0) + Lag)
      ||  $\frac{(((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + Lag) - q_{i+1,0})}{(((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + Lag) - ((q_{0,0} + 2 \cdot Pseu1per_{0,0}) + Lag))} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if ((q0,0 + 4 • Pseu1per0,0) + Lag) < qi+1,0 ≤ ((q0,0 + 4 • Pseu1per0,0) + (2 • Lag))
      || q0,1
    else if ((q0,0 + 4 • Pseu1per0,0) + (2 • Lag)) < qi+1,0 ≤ ((q0,0 + 6 • Pseu1per0,0) + (2 • Lag))
      ||  $\frac{(q_{i+1,0} - ((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + (2 \cdot Lag)))}{(((q_{0,0} + 6 \cdot Pseu1per_{0,0}) + 2 \cdot Lag) - ((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + (2 \cdot Lag)))} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if ((q0,0 + 6 • Pseu1per0,0) + (2 • Lag)) < qi+1,0 ≤ ((q0,0 + 6 • Pseu1per0,0) + (3 • Lag))
      || 2 • Pseu1per0,1
    else if ((q0,0 + 6 • Pseu1per0,0) + (3 • Lag)) < qi+1,0 ≤ ((q0,0 + 8 • Pseu1per0,0) + (3 • Lag))
      ||  $\frac{(((q_{0,0} + 8 \cdot Pseu1per_{0,0}) + (3 \cdot Lag)) - q_{i+1,0})}{(((q_{0,0} + 8 \cdot Pseu1per_{0,0}) + (3 \cdot Lag)) - ((q_{0,0} + 6 \cdot Pseu1per_{0,0}) + (3 \cdot Lag)))} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if ((q0,0 + 8 • Pseu1per0,0) + (3 • Lag)) < qi+1,0 ≤ ((q0,0 + 8 • Pseu1per0,0) + (4 • Lag))
      || q0,1
    else if ((q0,0 + 8 • Pseu1per0,0) + (4 • Lag)) < qi+1,0 ≤ ((q0,0 + 10 • Pseu1per0,0) + (4 • Lag))

```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

 q

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

Function for calculating displacement for the monotonic loads

```

DispComp(Pseu1per, IniTime, IniDisp) :=
  for j ∈ 0, 1..3
    for i ∈ 0, 1..40000
      q0,0 ← IniTime
      diff ← 0.1
      qi+1,0 ← qi,0 + diff
      qi+1,0 ← if (qi+1,0) ≤ (q0,0 + Pseu1per0,0)
                qi+1,0
                else if qi+1,0 > (q0,0 + Pseu1per0,0)
                break
      q0,1 ← IniDisp
      qi+1,1 ← if (qi+1,0) ≤ (q0,0 + Pseu1per0,0)
                (qi+1,0 - q0,0) / ((q0,0 + Pseu1per0,0) - q0,0) · (Pseu1per0,1)
                else
                qi+1,1
  q

```

$LdTimePL1H := DispCyc(PseuPL1H, IniTimePL1H, IniDisp)$

$LdTimePL2H := DispCyc(PseuPL2H, IniTimePL2H, IniDisp)$

$LdTimePL3H := DispCyc(PseuPL3H, IniTimePL3H, IniDisp)$

$LdTimePL4H := DispCyc(PseuPL4H, IniTimePL4H, IniDisp)$

$LdTimeCLH := DispComp(PseuCLH, IniTimeCLH, IniDisp)$

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

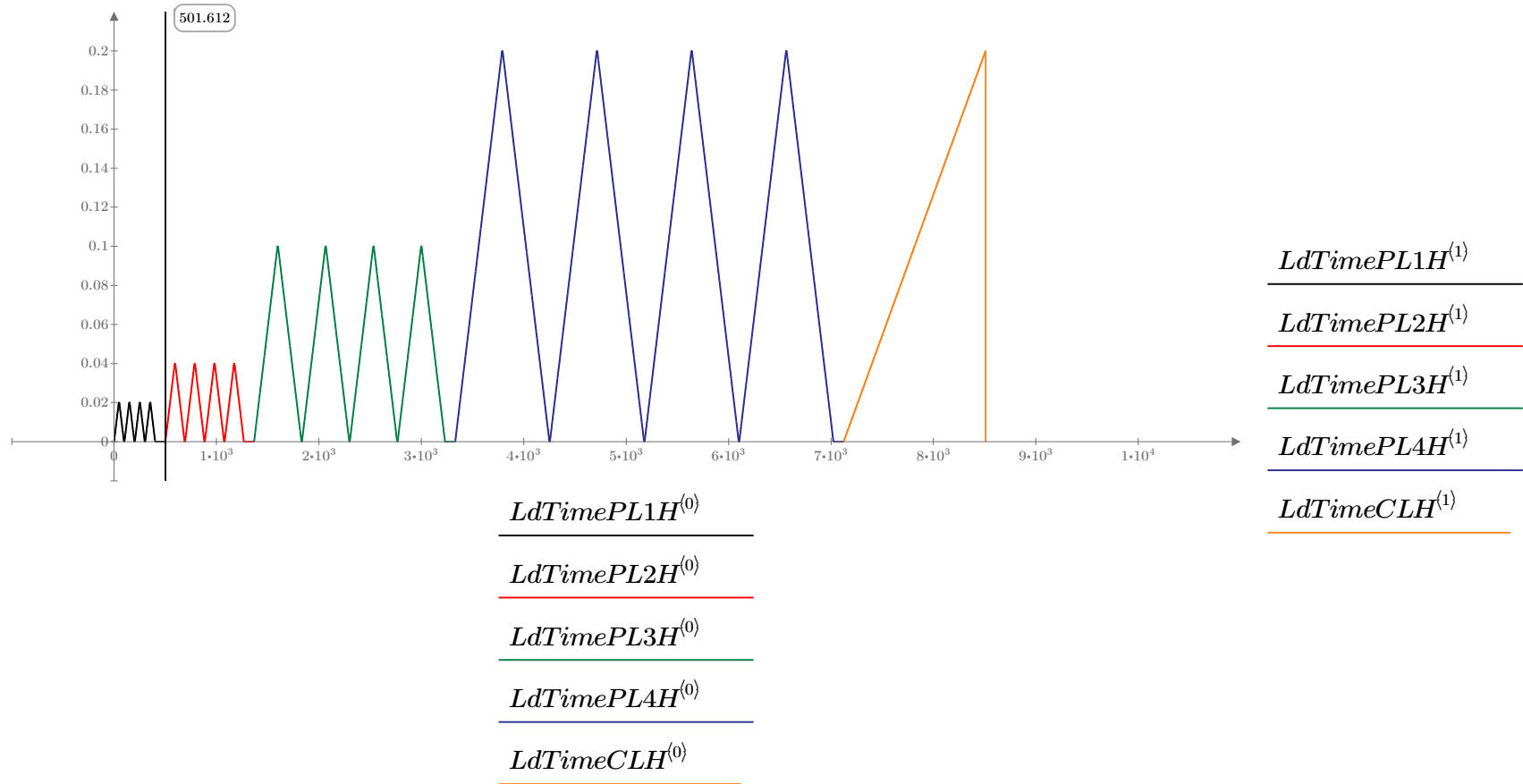


Fig D 1. DisplacementTime History for the Helix Piles

$$LdTimePL1S := DispCyc(PseuPL1S, IniTimePL1S, IniDisp)$$

$$LdTimePL2S := DispCyc(PseuPL2S, IniTimePL2S, IniDisp)$$

$$LdTimePL3S := DispCyc(PseuPL3S, IniTimePL3S, IniDisp)$$

$$LdTimePL4S := DispCyc(PseuPL4S, IniTimePL4S, IniDisp)$$

$$LdTimeCLS := DispComp(PseuCLS, IniTimeCLS, IniDisp)$$

Appendix D Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

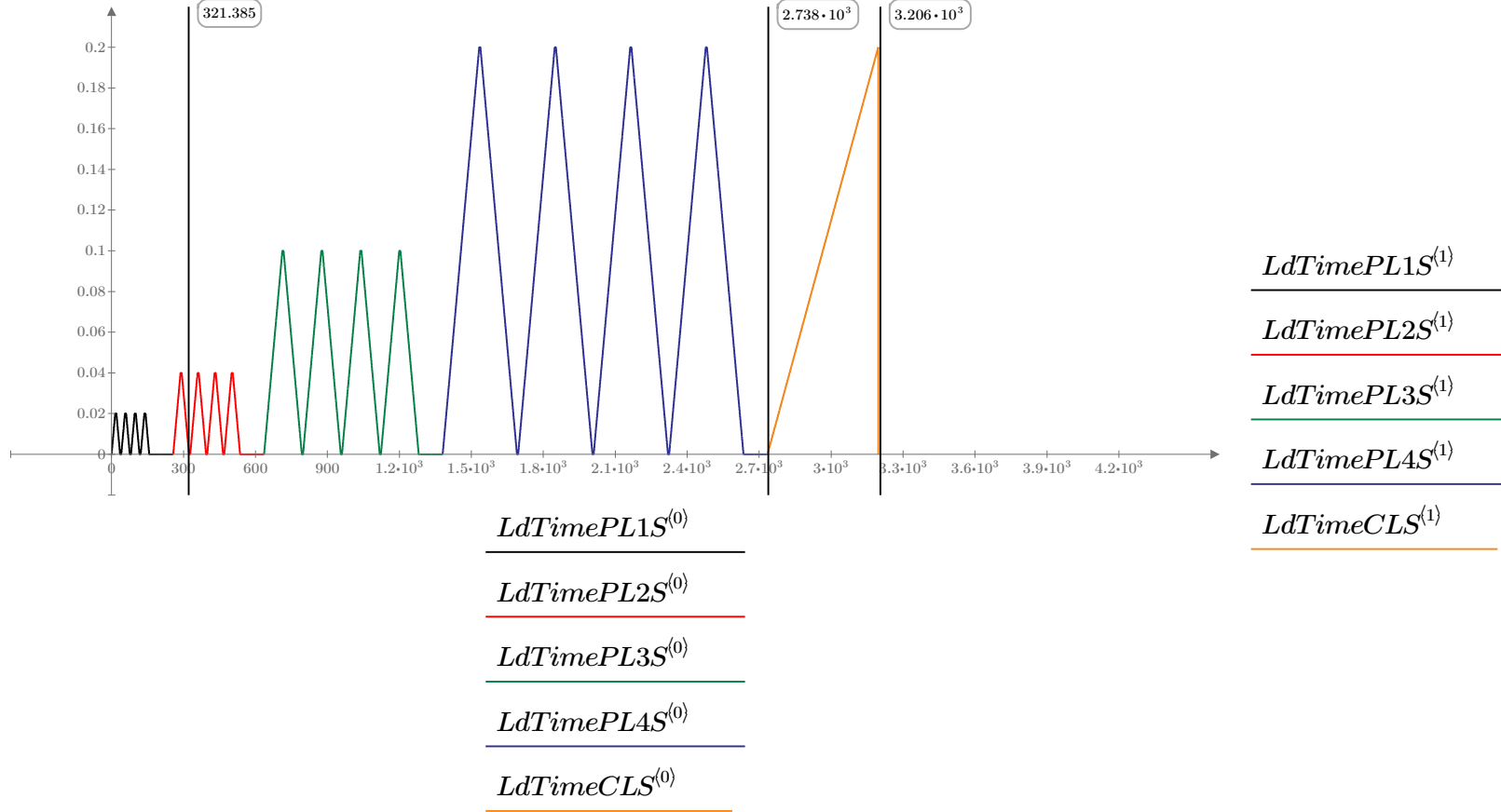


Fig D 2. DisplacementTime History for the smooth pile.

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

2.3.2 Axial Load vs Time

Function for determining the Axial Load Distribution in each pile

```

AxLd (Rawdata , PileNum) :=
  for i ∈ 0, 1 .. rows (Rawdata) - 1
  for j ∈ 0, 1 .. cols (Rawdata) - 1
    qi,j ← Rawdatai,j - Rawdata0,j
    SG1i,0 ← qi,0 • mean (submatrix (CF, 0, 2, PileNum, PileNum)) • Nscalesclfac0,1
    SG2i,1 ← qi,1 • mean (submatrix (CF, 3, 5, PileNum, PileNum)) • Nscalesclfac0,1
    SG3i,2 ← qi,2 • mean (submatrix (CF, 6, 8, PileNum, PileNum)) • Nscalesclfac0,1
    SG4i,3 ← qi,3 • mean (submatrix (CF, 9, 11, PileNum, PileNum)) • Nscalesclfac0,1
  augment (SG1(0), SG2(1), SG3(2), SG4(3))

```

Function for determining the Time, Displacement Input to Time Axial Load Distribution output in each pile

```

TDispTLd (LdTime1perS, TimeP0, AxLdP0, LdNo) :=
  m ← TimeP0
  n ← AxLdP0
  p ← LdTime1perS
  q ← if LdNo = 1
    m0
  else if LdNo = 2
    m1
  else if LdNo = 3
    m2
  else if LdNo = 4
    m3
  else if LdNo = 5
    m4
  k ← if LdNo = 1
    n0
  else if LdNo = 2
    n1
  else if LdNo = 3
    n2
  else if LdNo = 4
    n3
  else if LdNo = 5
    n4

```

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

```

else if  $Ld_{avo} = 3$ 
     $n_4$ 
 $o \leftarrow$  if rows( $p$ ) > rows( $q$ )
         $q$ 
    else if rows( $p$ ) < rows( $q$ )
         $p$ 
 $tdisp \leftarrow$  submatrix( $LdTime1perS^{(0)}$ , 0, rows( $o$ ) - 1, 0, 0)
 $disp \leftarrow$  submatrix( $-LdTime1perS^{(1)}$ , 0, rows( $o$ ) - 1, 0, 0)
 $tld \leftarrow$  submatrix( $\frac{q}{s}$ , 0, rows( $o$ ) - 1, 0, 0)
 $ld1 \leftarrow$  medsmooth(submatrix( $\frac{k^{(0)}}{kN}$ , 0, rows( $o$ ) - 1, 0, 0), 11)
 $ld2 \leftarrow$  medsmooth(submatrix( $\frac{k^{(1)}}{kN}$ , 0, rows( $o$ ) - 1, 0, 0), 11)
 $ld3 \leftarrow$  medsmooth(submatrix( $\frac{k^{(2)}}{kN}$ , 0, rows( $o$ ) - 1, 0, 0), 11)
 $ld4 \leftarrow$  medsmooth(submatrix( $\frac{k^{(3)}}{kN}$ , 0, rows( $o$ ) - 1, 0, 0), 11)
augment( $tdisp$ ,  $disp$ ,  $tld$ ,  $ld1$ ,  $ld2$ ,  $ld3$ ,  $ld4$ )

```

There were four strain gages placed within the P2 pile. The following sub sections provides the details on the load distributions:

$$P2HBM := \begin{bmatrix} \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P2_PL1!A1:E5146"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P2_PL2!A1:E10418"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P2_PL3!A1:E19566"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P2_PL4!A1:E38096"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P2_CL!A1:E14961"}) \end{bmatrix}$$

$$TimeP2 := \begin{bmatrix} \text{for } i \in 0, 1..4 \\ \quad q_i \leftarrow \text{submatrix}(P2HBM_i, 0, \text{rows}(P2HBM_i) - 1, 0, 0) \quad s \\ q \end{bmatrix} = \begin{bmatrix} [5146 \times 1] \quad s \\ [10418 \times 1] \quad s \\ [19566 \times 1] \quad s \\ [38096 \times 1] \quad s \\ [14961 \times 1] \quad s \end{bmatrix} s$$

$$RawdataP2 := \begin{bmatrix} \text{for } i \in 0, 1..4 \\ \quad q_i \leftarrow \text{submatrix}(P2HBM_i, 0, \text{rows}(P2HBM_i) - 1, 1, 4) \quad \frac{mV}{V} \\ q \end{bmatrix} = \begin{bmatrix} [5146 \times 4] \\ [10418 \times 4] \\ [19566 \times 4] \\ [38096 \times 4] \\ [14961 \times 4] \end{bmatrix}$$

$$AxLdP2 := \left\| \begin{array}{l} \text{for } i \in 0, 1 \dots 4 \\ q_i \leftarrow AxLd(RawdataP2_i, 2) \\ q \end{array} \right\| = \begin{bmatrix} [5146 \times 4] \\ [10418 \times 4] \\ [19566 \times 4] \\ [38096 \times 4] \\ [14961 \times 4] \end{bmatrix} \text{ kN}$$

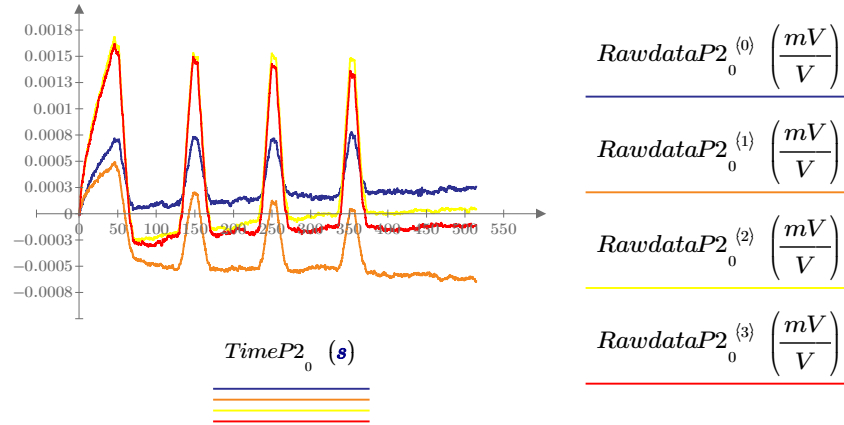


Fig D 3. Rawdata time history for compression pile P2 PL1

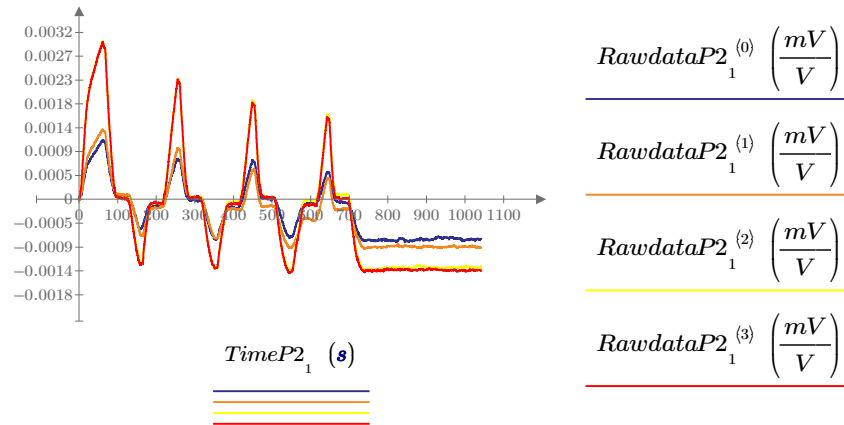


Fig D 5. Rawdata time history for compression pile P2 PL2

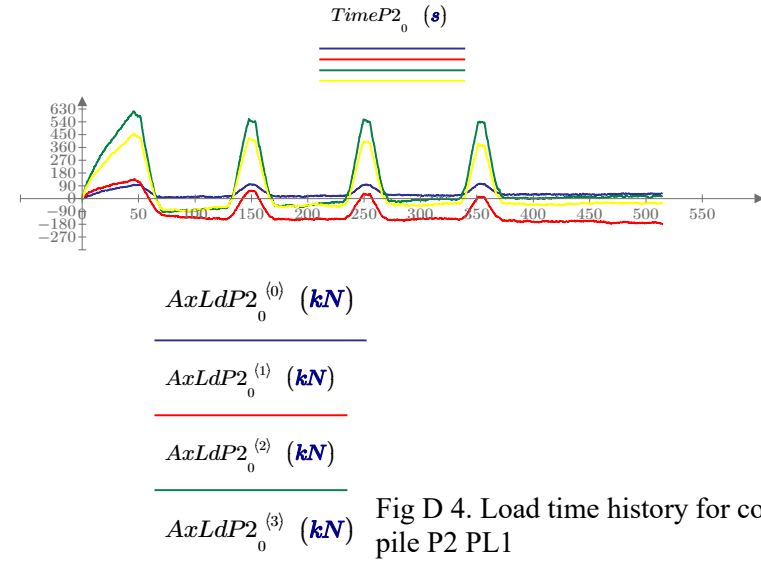


Fig D 4. Load time history for compression pile P2 PL1

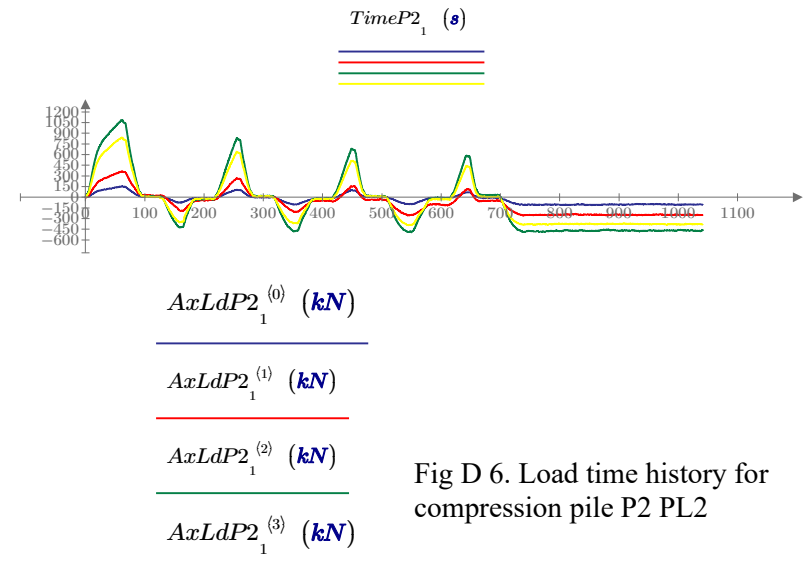


Fig D 6. Load time history for compression pile P2 PL2

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

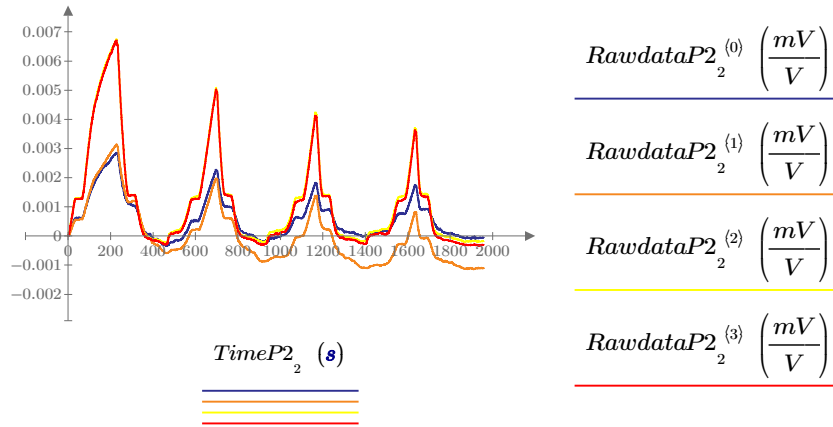


Fig D 7. Rawdata time history for compression pile P2 PL3

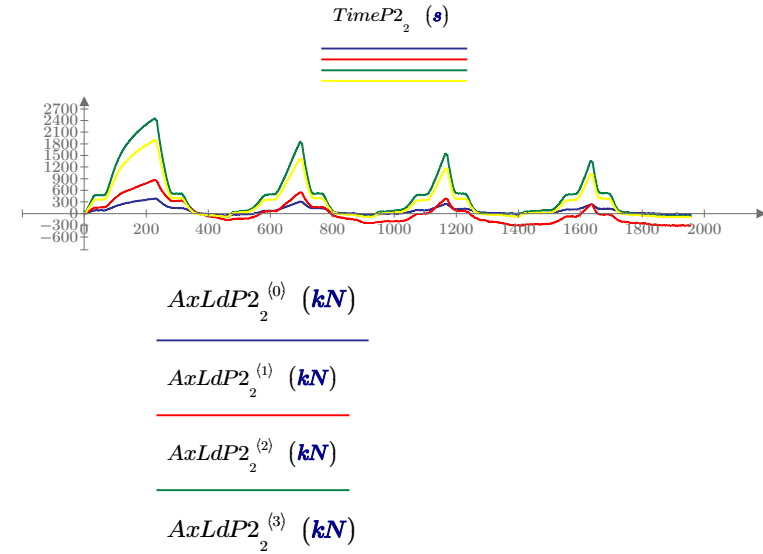


Fig D 8. Load time history for compression pile P2 PL3

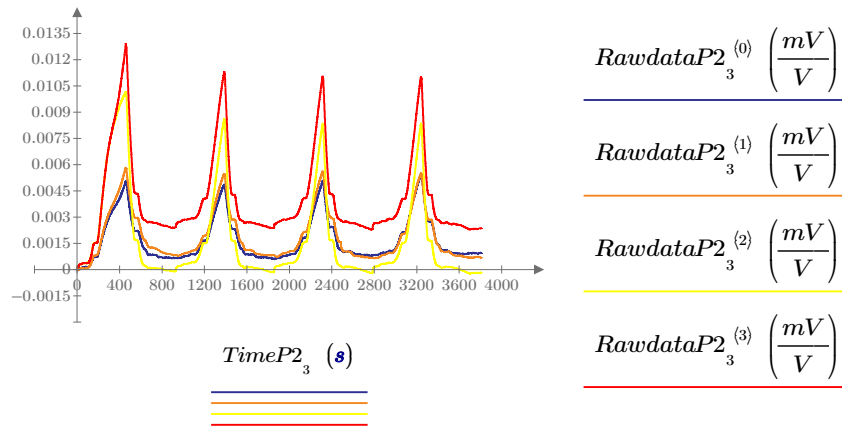


Fig D 9. Rawdata time history for compression pile P2 PL4

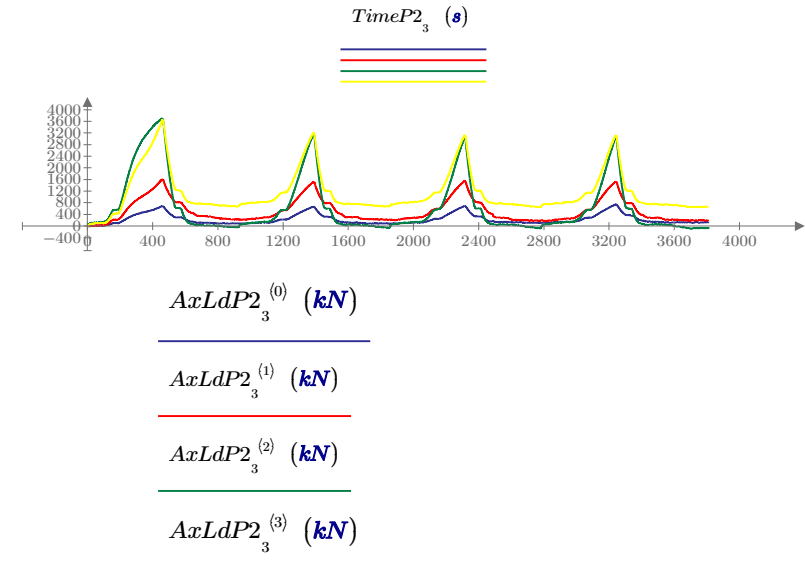


Fig D 10. Load time history for compression pile P2 PL4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

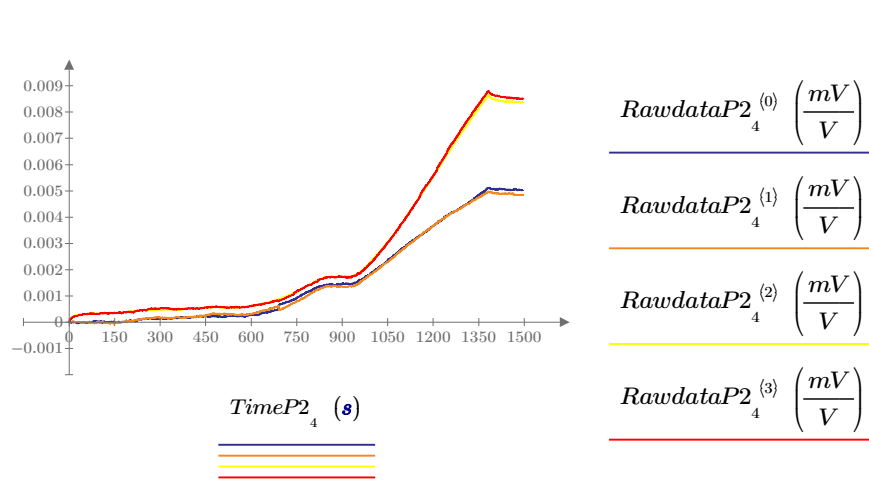


Fig D 11. Rawdata time history for compression pile P2 CL

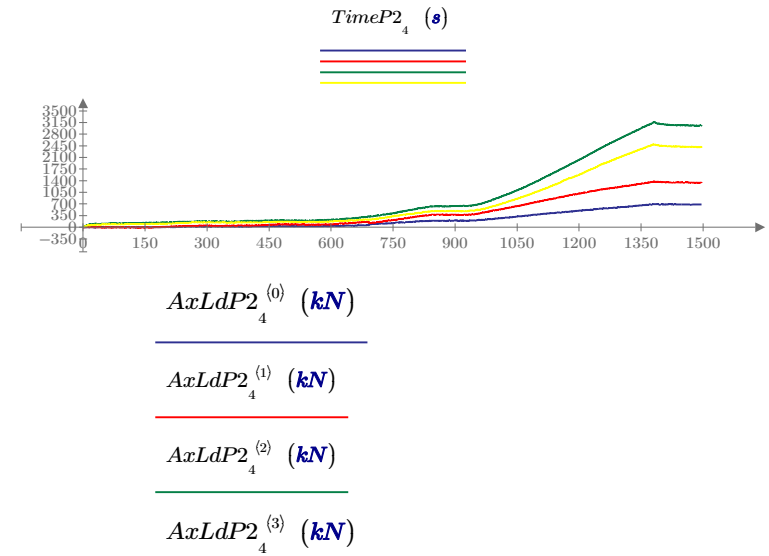


Fig D 12. Load time history for compression pile P2 CL

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for pseudostatic load PL1

$$TDispTLdP2PL1 := TDispTLd(LdTimePL1H, TimeP2, AxLdP2, 1) =$$

0	0	0	-0.098	-0.796	0.526	-1.633
1	0.1	$-4.374 \cdot 10^{-5}$	0.1	-0.196	-0.796	1.052
2	0.2	$-8.749 \cdot 10^{-5}$	0.2	-0.49	-0.398	1.052
3	0.3	$-1.312 \cdot 10^{-4}$	0.3	-0.196	0	1.052
4	0.4	$-1.75 \cdot 10^{-4}$	0.4	-0.49	0.199	1.579
5	0.5	$-2.187 \cdot 10^{-4}$	0.5	-0.196	0.398	2.105
6	0.6	$-2.625 \cdot 10^{-4}$	0.6	-0.196	3.581	11.577
7	0.7	$-3.062 \cdot 10^{-4}$	0.7	-0.196	7.163	17.365
8	0.8	$-3.5 \cdot 10^{-4}$	0.8	-0.196	7.163	17.891
9	0.9	$-3.937 \cdot 10^{-4}$	0.9	-0.196	8.356	18.944
10	1	$-4.374 \cdot 10^{-4}$	1	-0.196	11.938	25.785
11	1.1	$-4.812 \cdot 10^{-4}$	1.1	1.372	13.53	26.311
⋮	⋮	⋮	⋮	⋮	⋮	⋮
5008						

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

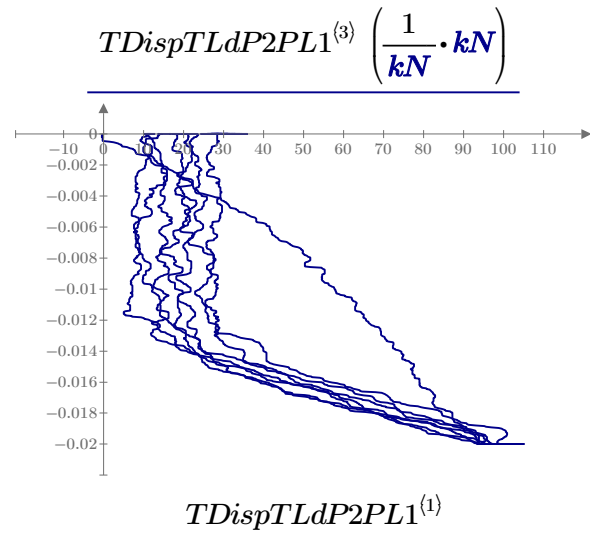


Fig D 13. Load displacement for compression pile P2 PL1 SG1

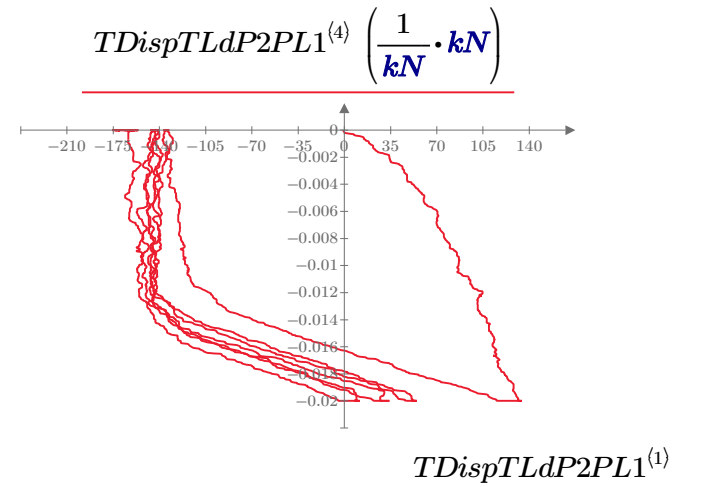


Fig D 14. Load displacement for compression pile P2 PL1 SG2

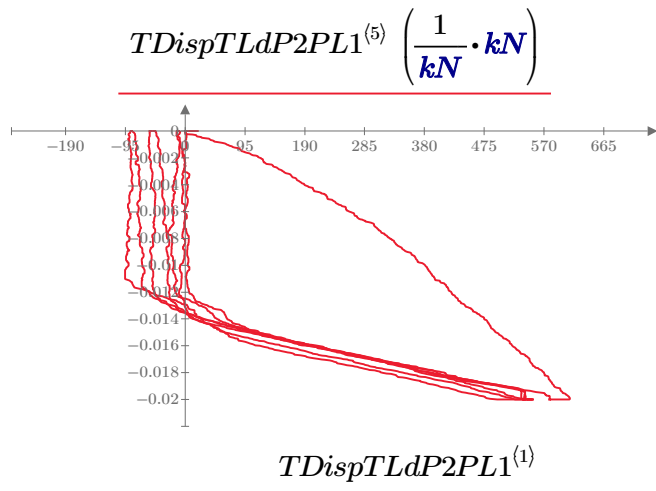


Fig D 15. Load displacement for compression pile P2 PL1 SG3

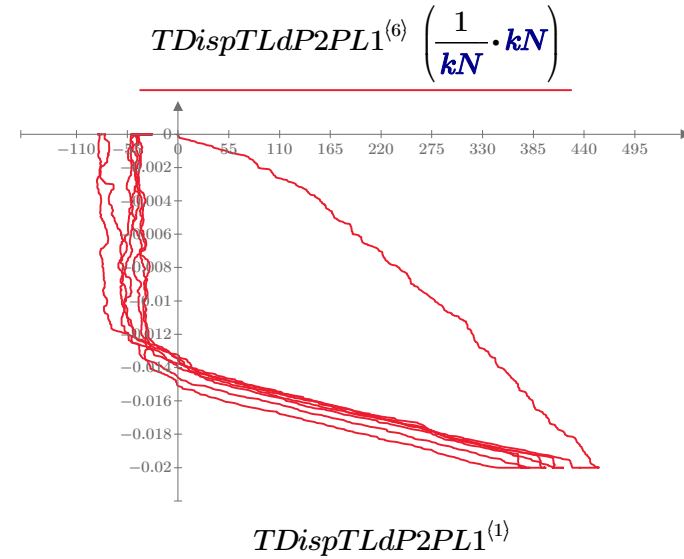


Fig D 16. Load displacement for compression pile P2 PL1 SG4

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for psuedostatic load PL2

$$TDispTLdP2PL2 := TDispTLd(LdTimePL2H, TimeP2, AxLdP2, 2) =$$

0	500.76	0	0	0	-2.587	7.367	4.083
1	500.86	$-4.374 \cdot 10^{-5}$	0.1	0	-2.785	9.472	4.9
2	500.96	$-8.749 \cdot 10^{-5}$	0.2	0.098	-3.382	9.735	6.329
3	501.06	$-1.312 \cdot 10^{-4}$	0.3	0.196	-2.785	9.998	7.758
4	501.16	$-1.75 \cdot 10^{-4}$	0.4	0.392	-2.587	9.735	7.758
5	501.26	$-2.187 \cdot 10^{-4}$	0.5	0.588	-2.388	9.998	7.758
6	501.36	$-2.625 \cdot 10^{-4}$	0.6	1.176	-2.785	10.524	8.166
7	501.46	$-3.062 \cdot 10^{-4}$	0.7	1.176	-3.979	10.524	8.575
8	501.56	$-3.5 \cdot 10^{-4}$	0.8	1.372	-4.377	10.524	12.25
9	501.66	$-3.937 \cdot 10^{-4}$	0.9	2.548	-4.377	10.524	12.25
10	501.76	$-4.374 \cdot 10^{-4}$	1	2.548	-4.775	11.051	12.25
11	501.86	$-4.812 \cdot 10^{-4}$	1.1	2.548	-4.377	11.577	12.25
⋮							⋮
8666							

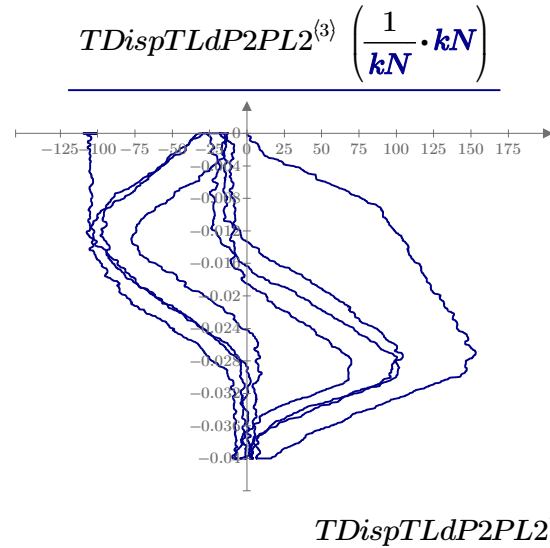


Fig D 17. Load displacement for compression pile P2 PL2 SG1

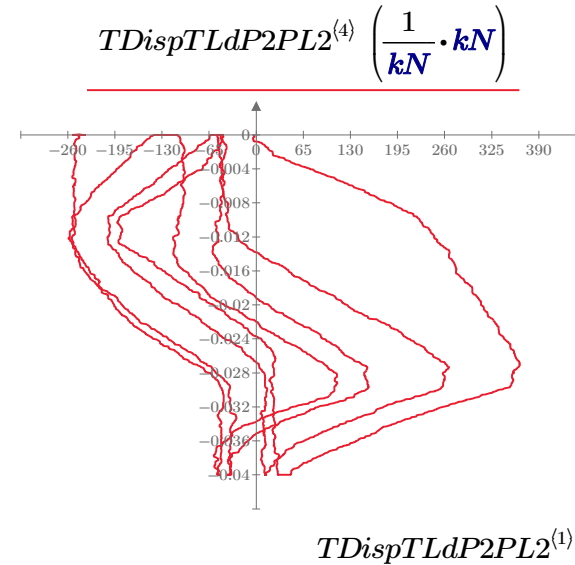


Fig D 18. Load displacement for compression pile P2 PL2 SG2

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

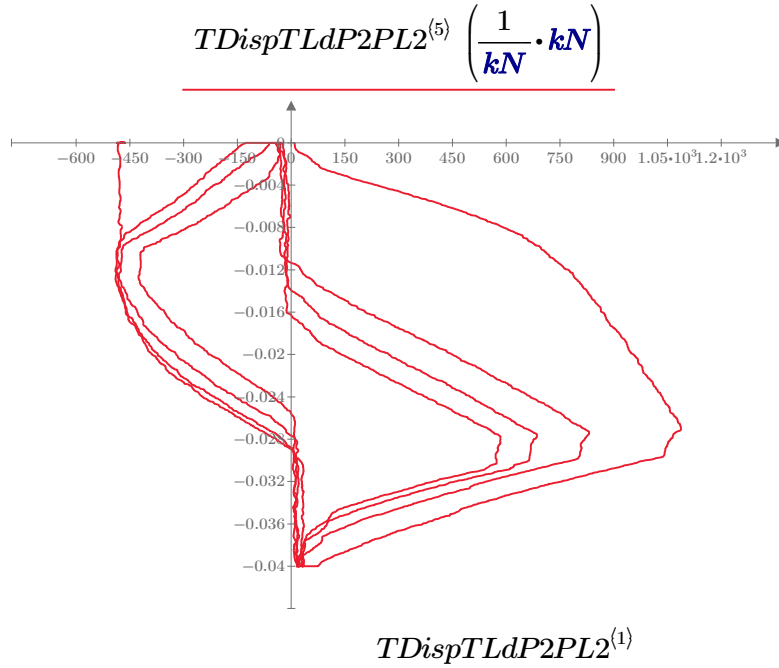


Fig D 19. Load displacement for compression pile P2 PL2 SG3

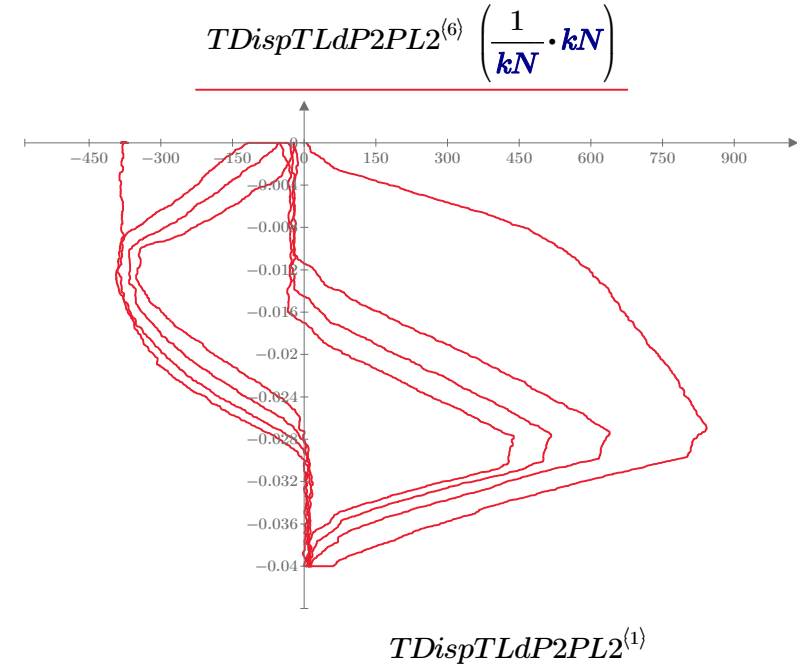


Fig D 20. Load displacement for compression pile P2 PL2 SG4

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for psuedostatic load PL3

$$TDispTLdP2PL3 := TDispTLd(LdTimePL3H, TimeP2, AxLdP2, 3) =$$

0	$1.367 \cdot 10^3$	0	0	-0.098	-0.199	2.631	0.817
1	$1.367 \cdot 10^3$	$-4.374 \cdot 10^{-5}$	0.1	0	0	2.631	0.817
2	$1.367 \cdot 10^3$	$-8.749 \cdot 10^{-5}$	0.2	0.196	0.398	4.999	1.225
3	$1.368 \cdot 10^3$	$-1.312 \cdot 10^{-4}$	0.3	0.392	0.796	7.367	1.633
4	$1.368 \cdot 10^3$	$-1.75 \cdot 10^{-4}$	0.4	0.686	1.393	7.63	2.042
5	$1.368 \cdot 10^3$	$-2.187 \cdot 10^{-4}$	0.5	0.392	1.99	7.367	2.042
6	$1.368 \cdot 10^3$	$-2.625 \cdot 10^{-4}$	0.6	0.392	2.785	7.367	2.042
7	$1.368 \cdot 10^3$	$-3.062 \cdot 10^{-4}$	0.7	0.392	3.979	7.367	1.633
8	$1.368 \cdot 10^3$	$-3.5 \cdot 10^{-4}$	0.8	0	5.173	7.367	1.633
9	$1.368 \cdot 10^3$	$-3.937 \cdot 10^{-4}$	0.9	0	5.173	7.893	1.633
10	$1.368 \cdot 10^3$	$-4.374 \cdot 10^{-4}$	1	0	5.571	8.419	2.042
11	$1.368 \cdot 10^3$	$-4.812 \cdot 10^{-4}$	1.1	0	5.571	8.419	2.042
⋮							
10565							

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

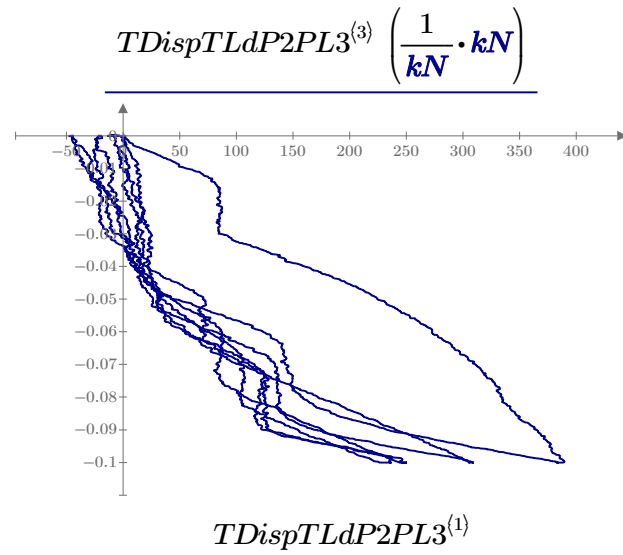


Fig D 21. Load displacement for compression pile P2 PL3 SG1

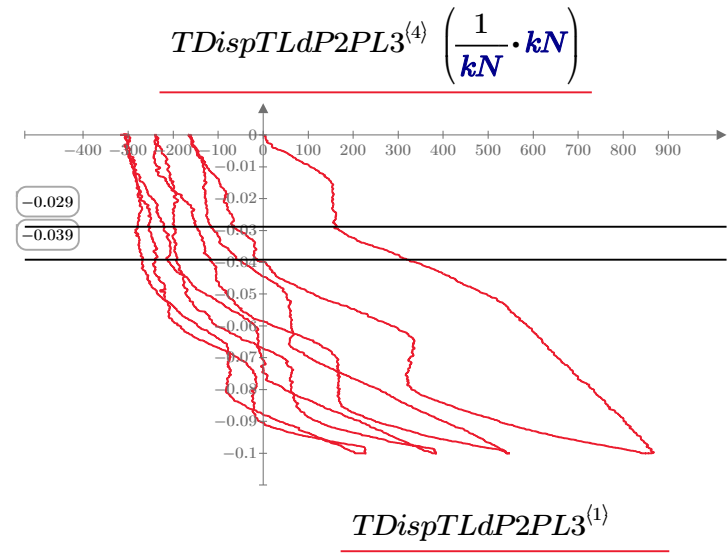


Fig D 22. Load displacement for compression pile P2 PL3 SG2

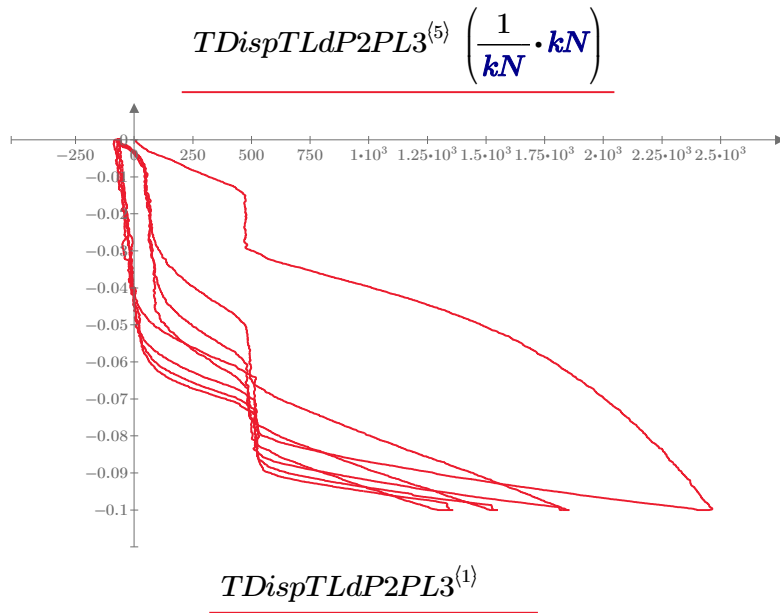


Fig D 23. Load displacement for compression pile P2 PL3 SG3

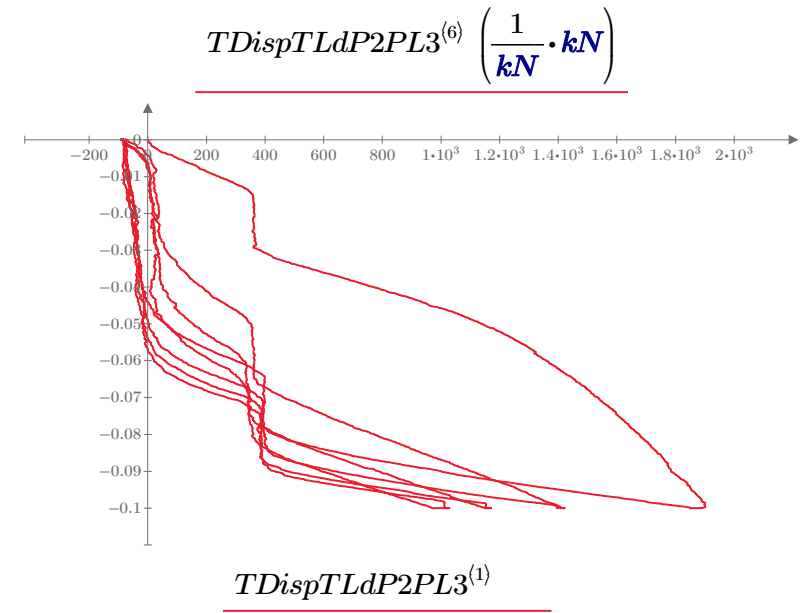


Fig D 24. Load displacement for compression pile P2 PL3 SG4

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for pseudostatic load PL4

$$TDispTLdP2PL4 := TDispTLd(LdTimePL4H, TimeP2, AxLdP2, 4) =$$

0	$3.331 \cdot 10^3$	0	0	1.372	-1.99	0	-4.083
1	$3.331 \cdot 10^3$	$-4.374 \cdot 10^{-5}$	0.1	1.176	0	0	-4.083
2	$3.331 \cdot 10^3$	$-8.749 \cdot 10^{-5}$	0.2	1.372	0.199	-0.526	-3.471
3	$3.331 \cdot 10^3$	$-1.312 \cdot 10^{-4}$	0.3	1.176	0.398	0	-2.858
4	$3.331 \cdot 10^3$	$-1.75 \cdot 10^{-4}$	0.4	1.176	0.398	-0.526	-3.471
5	$3.332 \cdot 10^3$	$-2.187 \cdot 10^{-4}$	0.5	1.176	0.398	-0.526	-4.083
6	$3.332 \cdot 10^3$	$-2.625 \cdot 10^{-4}$	0.6	1.176	0.398	-1.052	-4.083
7	$3.332 \cdot 10^3$	$-3.062 \cdot 10^{-4}$	0.7	1.176	-2.785	-1.052	-4.083
8	$3.332 \cdot 10^3$	$-3.5 \cdot 10^{-4}$	0.8	0.98	-2.785	-1.052	-3.675
9	$3.332 \cdot 10^3$	$-3.937 \cdot 10^{-4}$	0.9	-1.372	-1.592	-1.052	-2.858
10	$3.332 \cdot 10^3$	$-4.374 \cdot 10^{-4}$	1	-2.548	0	-1.052	-2.858
11	$3.332 \cdot 10^3$	$-4.812 \cdot 10^{-4}$	1.1	-2.94	0	-0.526	-3.675
⋮							⋮

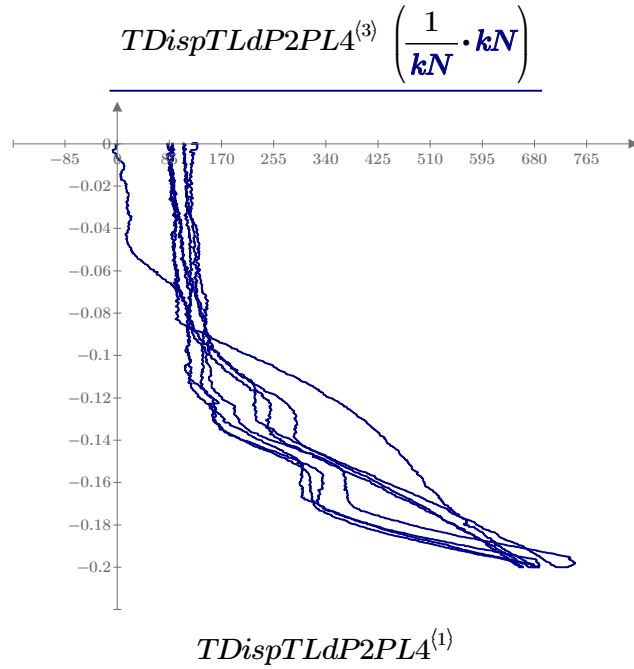


Fig D 25. Load displacement for compression pile P2 PL4 SG1

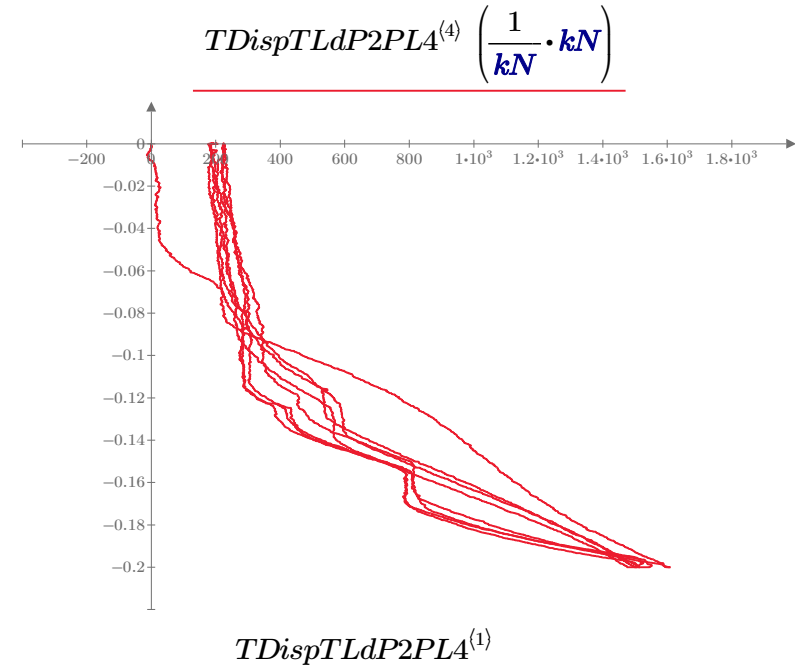


Fig D 26. Load displacement for compression pile P2 PL4 SG2

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

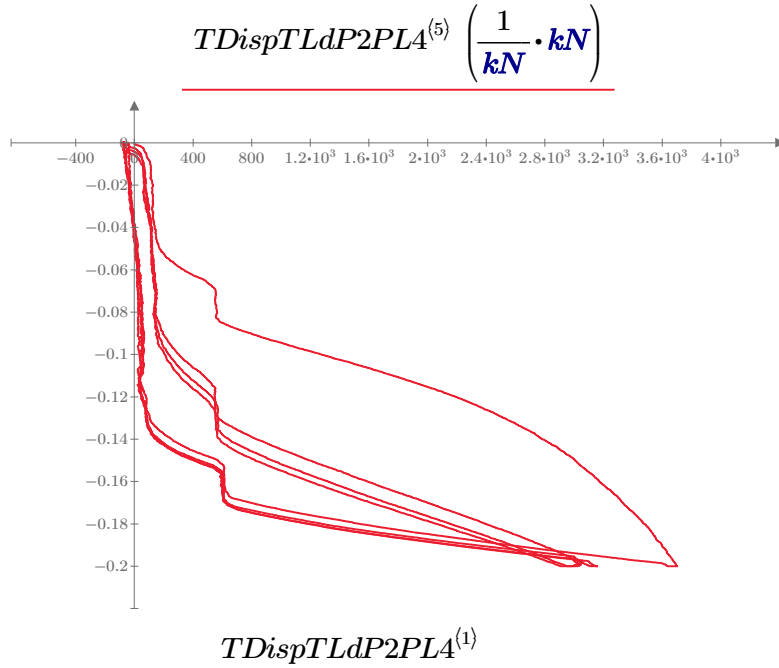


Fig D 27. Load displacement for compression pile P2 PL4 SG3

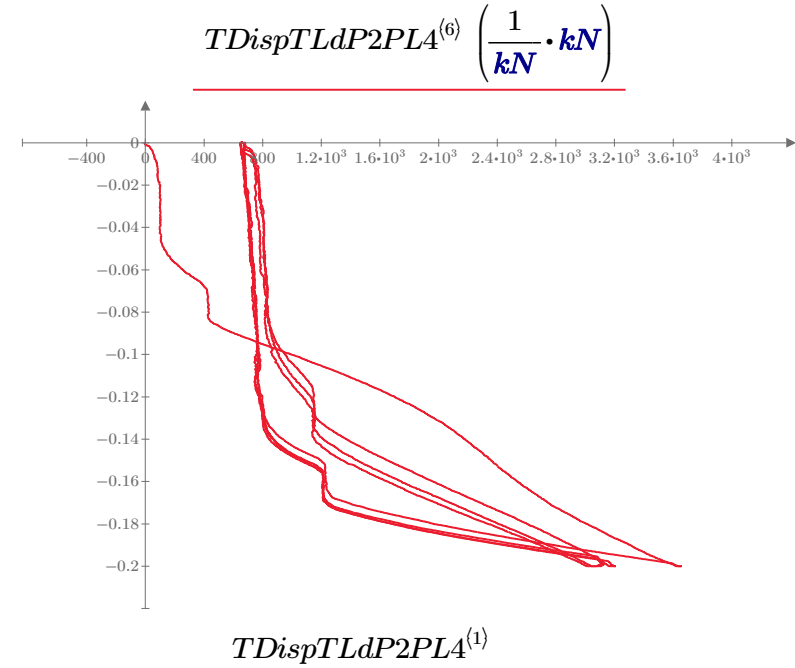


Fig D 28. Load displacement for compression pile P2 PL4 SG4

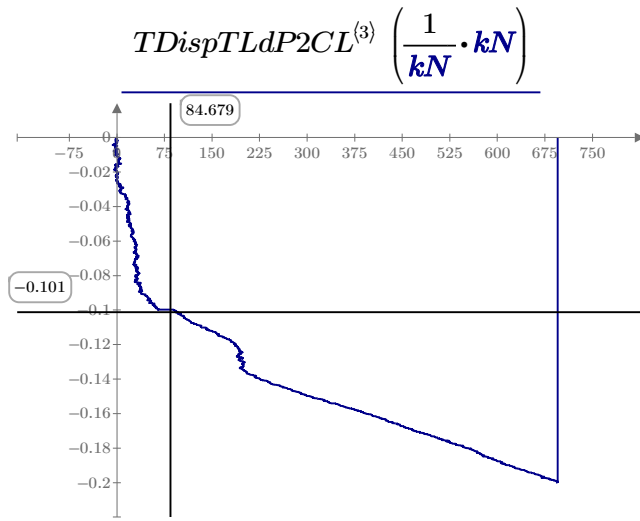
Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for post cyclic compressive load CL

$$TDispTLdP2CL := TDispTLd(LdTimeCLH, TimeP2, AxLdP2, 5) =$$

0	$7.124 \cdot 10^3$	0	0	-0.784	0.796	2.105	1.225
1	$7.124 \cdot 10^3$	$-1.444 \cdot 10^{-5}$	0.1	-0.784	0.796	2.105	1.633
2	$7.124 \cdot 10^3$	$-2.887 \cdot 10^{-5}$	0.2	-0.784	0.995	1.842	1.633
3	$7.124 \cdot 10^3$	$-4.331 \cdot 10^{-5}$	0.3	-0.784	1.194	2.105	1.633
4	$7.124 \cdot 10^3$	$-5.774 \cdot 10^{-5}$	0.4	-0.98	0.995	2.368	2.45
5	$7.124 \cdot 10^3$	$-7.218 \cdot 10^{-5}$	0.5	-0.98	0.796	2.631	3.267
6	$7.124 \cdot 10^3$	$-8.661 \cdot 10^{-5}$	0.6	-0.98	0.796	2.631	5.308
7	$7.124 \cdot 10^3$	$-1.01 \cdot 10^{-4}$	0.7	-0.98	0.796	4.21	5.717
8	$7.124 \cdot 10^3$	$-1.155 \cdot 10^{-4}$	0.8	-1.176	0.796	4.21	6.533
9	$7.125 \cdot 10^3$	$-1.299 \cdot 10^{-4}$	0.9	-0.98	0.796	6.841	7.35
10	$7.125 \cdot 10^3$	$-1.444 \cdot 10^{-4}$	1	-0.98	0.796	6.841	7.35
11	$7.125 \cdot 10^3$	$-1.588 \cdot 10^{-4}$	1.1	-0.196	-0.796	8.419	8.166
⋮							⋮

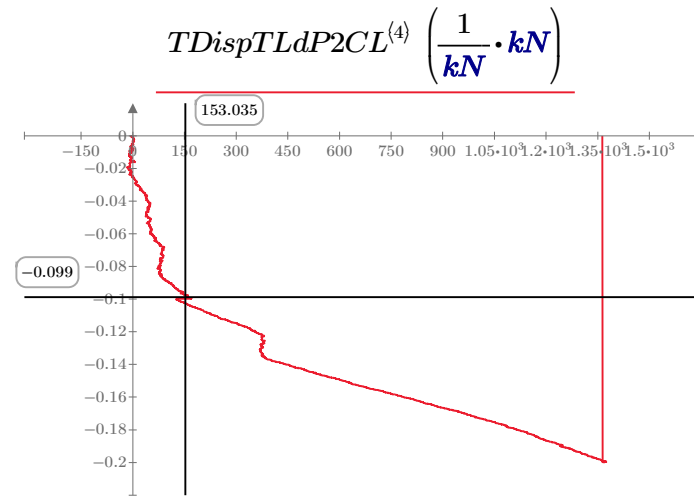
1 2 3 4 5

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile



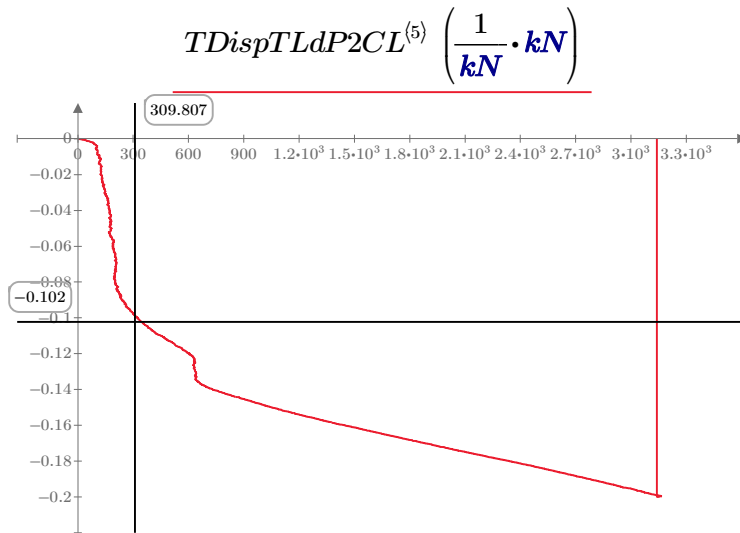
$$TDispTLdP2CL^{(1)}$$

Fig D 29. Load displacement for compression pile P2 CL SG1



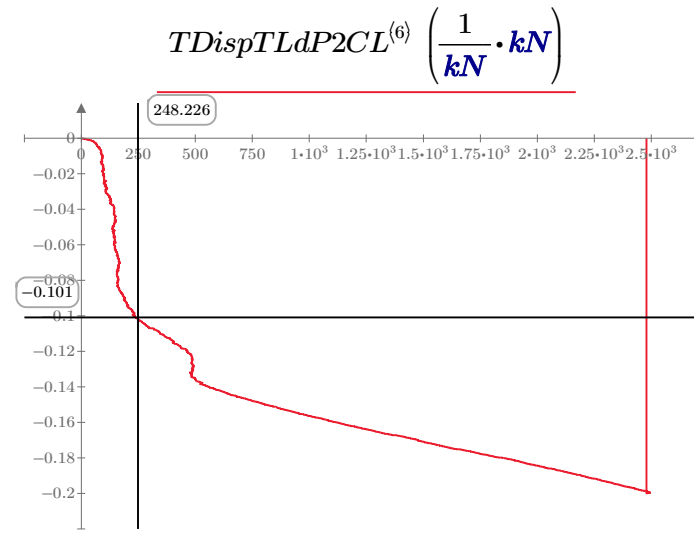
$$TDispTLdP2CL^{(1)}$$

Fig D 30. Load displacement for compression pile P2 CL SG2



$$TDispTLdP2CL^{(1)}$$

Fig D 31. Load displacement for compression pile P2 CL SG3



$$TDispTLdP2CL^{(1)}$$

Fig D 32. Load displacement for compression pile P2 CL SG4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

Functions for determining the Qult profile from strain gauge location

TOL := 0.00000001

```
SGplotQP(TDispTLdP0CL, PileNum) :=
  QP0 ← if PileNum = 0
    lookup(-0.15, TDispTLdP0CL(1), TDispTLdP0CL(3), "near")
  else
    lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(3), "near")
  QP1 ← if PileNum = 0
    lookup(-0.15, TDispTLdP0CL(1), TDispTLdP0CL(4), "near")
  else
    lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(4), "near")
  QP2 ← lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(5), "near")
  QP3 ← lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(6), "near")
  combined ← if PileNum = 0
    stack(QP0, QP1, QP1, QP1, QP1, QP1)
  else if PileNum = 1
    stack(QP0, QP1, QP1, QP2, QP2, QP2)
  else
    stack(QP0, QP1, QP1, QP2, QP2, QP3)
  combined
```

$$SGPlotQP2CL := SGplotQP(TDispTLdP2CL, 2) \text{ } \mathbf{kN} = \begin{bmatrix} 20.387 \\ 45.364 \\ 45.364 \\ 183.124 \\ 183.124 \\ 137.605 \end{bmatrix} \text{ } \mathbf{kN}$$

$$SGEmbDP := \begin{bmatrix} 0.6 + 3.5 & 0.6 + 3.5 & 0.6 + 3.5 & 0.6 + 3.5 & 0.6 + 3.5 \\ 0.6 & 0.6 + 3 & 0.6 + 3 & 0.6 + 2 & 0.6 + 3 \\ 0 & 0.6 + 3 & 0.6 + 3 & 0.6 + 2 & 0.6 + 3 \\ 0 & 0.6 & 0.6 + 2 & 0.6 + 1 & 0.6 + 1 \\ 0 & 0 & 0.6 + 2 & 0.6 + 1 & 0.6 + 1 \\ 0 & 0 & 0.6 & 0.6 & 0.6 \end{bmatrix} \cdot D \cdot Nscale_{0,0}^{sclfac}$$

SG embedment depth in prototype scale. Here, colm 0-4 represents P0 to P4. Row 0 to 5 represents depth to strain SG 1 to 4

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

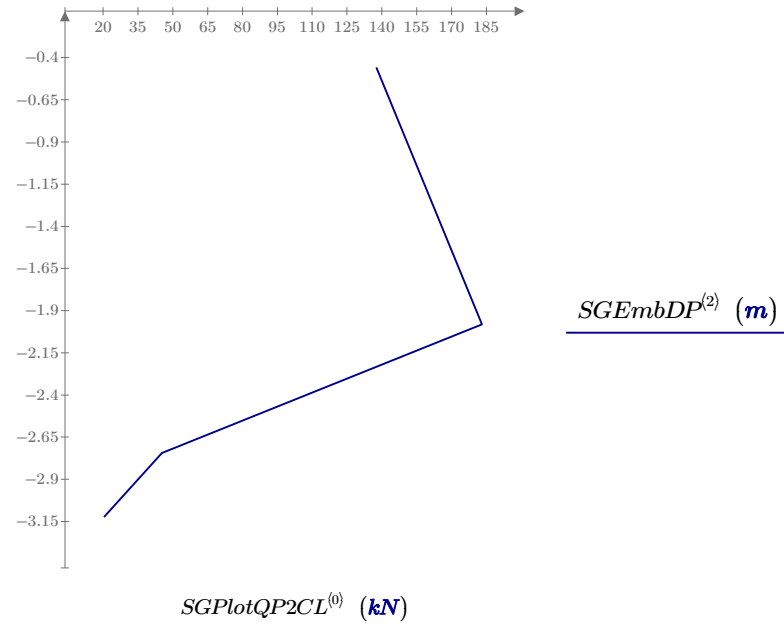


Fig D 33. SG Depth vs Axial Load for P1 pile

Functions for calculating EDR from the load displacement curve for each cycles and each pseudostatic loads

TOL := 0.00000001

```
EDR(TDispTLdP0PL1, Pseu1perS, IniTime, IniDisp, LoopNo, SGNo) :=
    m ← TDispTLdP0PL1
    o ← TimeCycLoop(Pseu1perS, IniTime, IniDisp) - IniTime
    w ← -m(1)
    wmax ← max(-m(1))
    if SGNo = 1
        q ← m(3)
        qmax ← max(m(3))
    else if SGNo = 2
        q ← m(4)
        qmax ← max(m(4))
    else if SGNo = 3
        q ← m(5)
        qmax ← max(m(5))
    else if SGNo = 4
        q ← m(6)
        qmax ← max(m(6))
```

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

$\text{if } LoopNo = 1$ $\quad t1 \leftarrow m_{1,0} - IniTime$ $\quad t2 \leftarrow o_1$ $\text{else if } LoopNo = 2$ $\quad t1 \leftarrow o_1$ $\quad t2 \leftarrow o_2$ $\text{else if } LoopNo = 3$ $\quad t1 \leftarrow o_2$ $\quad t2 \leftarrow o_3$ $\text{else if } LoopNo = 4$ $\quad t1 \leftarrow o_3$ $\quad t2 \leftarrow o_4$	
$tstart \leftarrow \text{lookup}(t1, (m^{(0)} - IniTime), (m^{(0)} - IniTime), \text{"near"})$ $tend \leftarrow \text{lookup}(t2, (m^{(0)} - IniTime), (m^{(0)} - IniTime), \text{"near"})$ $rowstart \leftarrow \text{match}(t1, (m^{(0)} - IniTime), \text{"near"})$ $rowend \leftarrow \text{match}(t2, (m^{(0)} - IniTime), \text{"near"})$ $\text{for } i \in rowstart_{0,0} \dots rowend_{0,0}$ $\quad r_i \leftarrow \left((w_i - w_{i-1}) \cdot \left(\frac{(q_i + q_{i-1})}{2} \right) \right)$ $area \leftarrow \sum r$ $EDR \leftarrow \begin{cases} \text{if } qmax = 0 \\ \quad 0 \\ \text{else if } wmax = 0 \\ \quad 0 \\ \text{else if } area = 0 \\ \quad 0 \\ \text{else} \\ \quad \frac{area}{qmax \cdot wmax} \end{cases}$	
$s \leftarrow \text{augment}((tstart + IniTime), (tend + IniTime), rowstart, rowend, qmax, wmax, area, EDR)$ EDR	

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

Functions for combining EDR from the load displacement curve for each cycles and each pseudostatic loads

$EDRPOPLSG(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, PileNo) :=$	$ \begin{aligned} &q1 \leftarrow EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1) \\ &q2 \leftarrow EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1) \\ &q3 \leftarrow EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1) \\ &q4 \leftarrow EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1) \\ &r1 \leftarrow EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2) \\ &r2 \leftarrow EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2) \\ &r3 \leftarrow EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2) \\ &r4 \leftarrow EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2) \\ &w1 \leftarrow \text{if } PileNo = 0 \\ &\quad \parallel 0 \\ &\quad \text{else} \\ &\quad \parallel EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 3) \\ &w2 \leftarrow \text{if } PileNo = 0 \\ &\quad \parallel 0 \\ &\quad \text{else} \\ &\quad \parallel EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 3) \\ &w3 \leftarrow \text{if } PileNo = 0 \\ &\quad \parallel 0 \\ &\quad \text{else} \\ &\quad \parallel EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 3) \\ &w4 \leftarrow \text{if } PileNo = 0 \\ &\quad \parallel 0 \\ &\quad \text{else} \\ &\quad \parallel EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3) \\ &s1 \leftarrow \text{if } PileNo = 0 \\ &\quad \parallel 0 \\ &\quad \text{else if } PileNo = 1 \\ &\quad \parallel 0 \\ &\quad \text{else} \\ &\quad \parallel EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 4) \\ &s2 \leftarrow \text{if } PileNo = 0 \\ &\quad \parallel 0 \\ &\quad \text{else if } PileNo = 1 \\ &\quad \parallel 0 \\ &\quad \text{else} \\ &\quad \parallel EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 4) \\ &s3 \leftarrow \text{if } PileNo = 0 \\ &\quad \parallel 0 \\ &\quad \text{else if } PileNo = 1 \\ &\quad \parallel - \end{aligned} $
--	--

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

$$NoLoop := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

```

    || 0
    || else
    || EDR(TDispTLdP0PL1,PseuPL1S,IniTimePL1S,IniDisp,3,4)
s4 ← if PileNo = 0
    || 0
    || else if PileNo = 1
    || 0
    || else
    || EDR(TDispTLdP0PL1,PseuPL1S,IniTimePL1S,IniDisp,4,4)
augment(stack(q1,q2,q3,q4),stack(r1,r2,r3,r4),stack(w1,w2,w3,w4),stack(s1,s2,s3,s4))

```

$$EDRP2PL1 := EDRPOPLSG(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, 2) = \begin{bmatrix} 0.285 & 1.19 & 0.525 & 0.547 \\ -0.033 & 0.04 & -0.027 & -0.021 \\ -0.072 & -0.005 & -0.045 & -0.035 \\ -0.094 & 0.029 & -0.051 & -0.047 \end{bmatrix}$$

$$EDRP2PL2 := EDRPOPLSG(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, 2) = \begin{bmatrix} 0.745 & 0.759 & 0.748 & 0.758 \\ 0.501 & 0.435 & 0.444 & 0.444 \\ 0.426 & 0.422 & 0.399 & 0.397 \\ 0.498 & 0.346 & 0.393 & 0.389 \end{bmatrix}$$

$$EDRP2PL3 := EDRPOPLSG(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, 2) = \begin{bmatrix} 0.327 & 0.327 & 0.391 & 0.389 \\ 0.022 & 0.076 & 0.11 & 0.109 \\ -0.008 & 0.038 & 0.063 & 0.056 \\ 0.012 & -0.01 & 0.04 & 0.037 \end{bmatrix}$$

$$EDRP2PL4 := EDRPOPLSG(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, 2) = \begin{bmatrix} 0.085 & 0.036 & 0.318 & 0.068 \\ 0.07 & 0.062 & 0.113 & 0.087 \\ 0.039 & 0.06 & 0.088 & 0.066 \\ 0.041 & 0.035 & 0.072 & 0.052 \end{bmatrix}$$

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Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

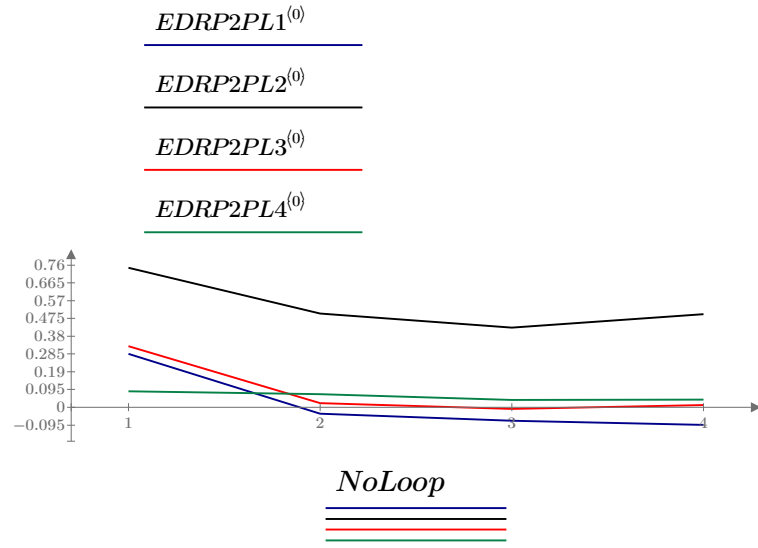


Fig D 34. EDR Load vs No of loops SG1

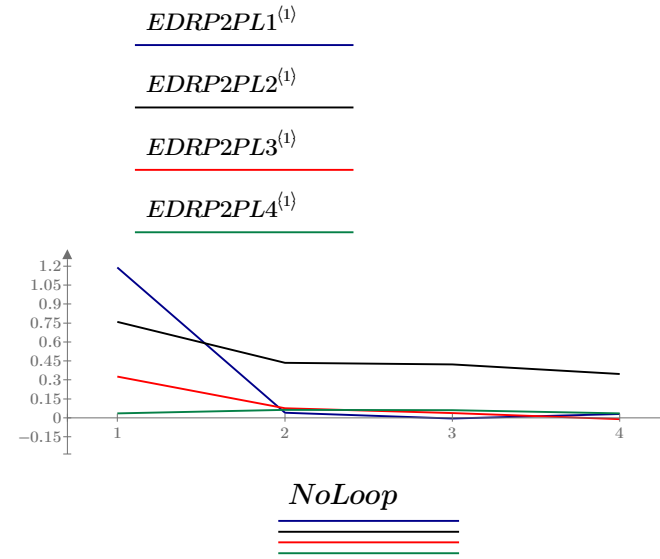


Fig D 35. EDR Load vs No of loops SG2

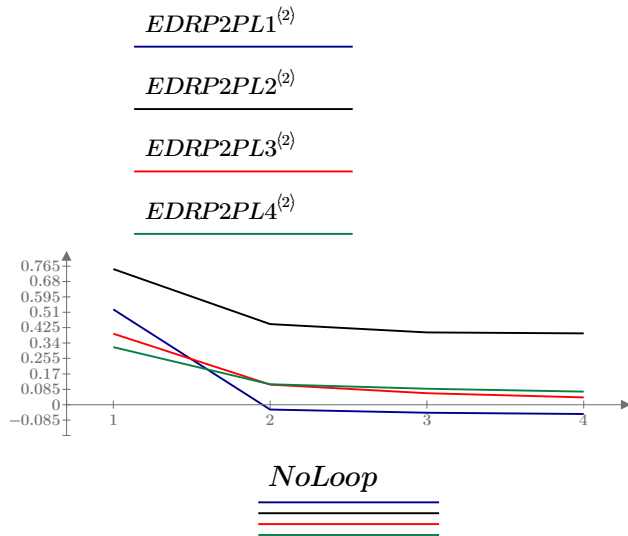


Fig D 36. EDR Load vs No of loops SG3

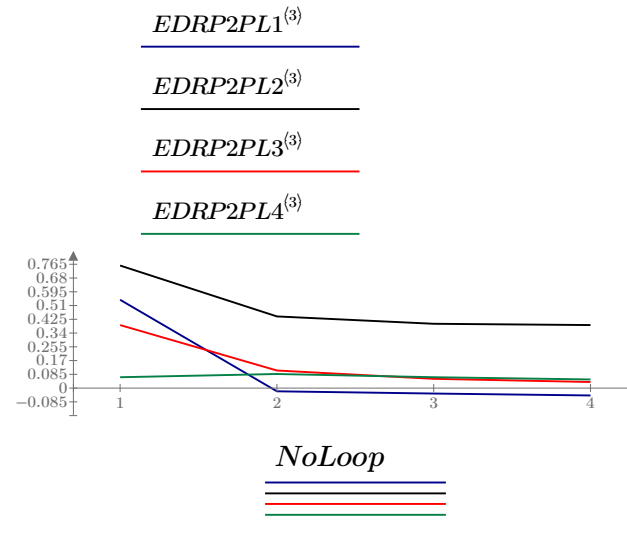


Fig D 37. EDR Load vs No of loops SG4

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

Functions for disintegrating the load-displacement curves into separate cycles

```

DispLd (TDispTLdP0PL1, Pseu1perS, IniTime, IniDisp, LoopNo, SGNo) :=
    m ← TDispTLdP0PL1
    o ← TimeCycLoop (Pseu1perS, IniTime, IniDisp) − IniTime
    w ← −m(1)
    if SGNo = 1
        q ← m(3)
    else if SGNo = 2
        q ← m(4)
    else if SGNo = 3
        q ← m(5)
    else if SGNo = 4
        q ← m(6)
    if LoopNo = 1
        t1 ← o0
        t2 ← o1
    else if LoopNo = 2
        t1 ← o1
        t2 ← o2
    else if LoopNo = 3
        t1 ← o2
        t2 ← o3
    else if LoopNo = 4
        t1 ← o3
        t2 ← o4
    tstart ← lookup (t1, (m(0) − IniTime), (m(0) − IniTime), “near”)
    tend ← lookup (t2, (m(0) − IniTime), (m(0) − IniTime), “near”)
    rowstart ← match (t1, (m(0) − IniTime), “near”)
    rowend ← match (t2, (m(0) − IniTime), “near”)
    for i ∈ rowstart0,0 .. rowend0,0
        di ← wi · 100
        ldi ← qi
    augment (d, ld · kN)

```


Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

$$DispLdP2PL1L1SG1 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 1, 1)$$

$$DispLdP2PL1L2SG1 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 2, 1)$$

$$DispLdP2PL1L3SG1 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 3, 1)$$

$$DispLdP2PL1L4SG1 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 4, 1)$$

$$DispLdP2PL2L1SG1 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 1, 1)$$

$$DispLdP2PL2L2SG1 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 2, 1)$$

$$DispLdP2PL2L3SG1 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 3, 1)$$

$$DispLdP2PL2L4SG1 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 4, 1)$$

$$DispLdP2PL3L1SG1 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 1, 1)$$

$$DispLdP2PL3L2SG1 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 2, 1)$$

$$DispLdP2PL3L3SG1 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 3, 1)$$

$$DispLdP2PL3L4SG1 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 4, 1)$$

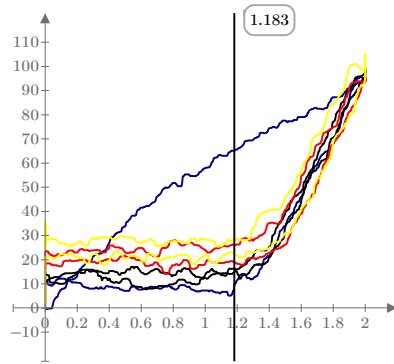
$$DispLdP2PL4L1SG1 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 1, 1)$$

$$DispLdP2PL4L2SG1 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 2, 1)$$

$$DispLdP2PL4L3SG1 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 3, 1)$$

$$DispLdP2PL4L4SG1 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 4, 1)$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile



$DispLdP2PL1L1SG1^{(0)}$

$DispLdP2PL1L2SG1^{(0)}$

$DispLdP2PL1L3SG1^{(0)}$

$DispLdP2PL1L4SG1^{(0)}$

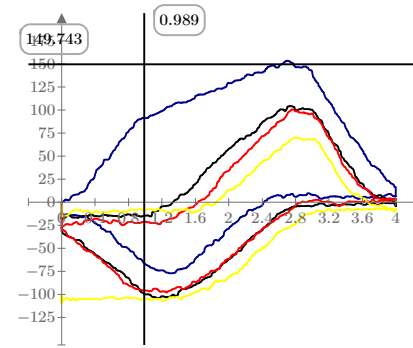
$DispLdP2PL1L1SG1^{(1)}$ (**kN**)

$DispLdP2PL1L2SG1^{(1)}$ (**kN**)

$DispLdP2PL1L3SG1^{(1)}$ (**kN**)

$DispLdP2PL1L4SG1^{(1)}$ (**kN**)

Fig D 38. Load-Displacement for P2 PL1 SG1



$DispLdP2PL2L1SG1^{(0)}$

$DispLdP2PL2L2SG1^{(0)}$

$DispLdP2PL2L3SG1^{(0)}$

$DispLdP2PL2L4SG1^{(0)}$

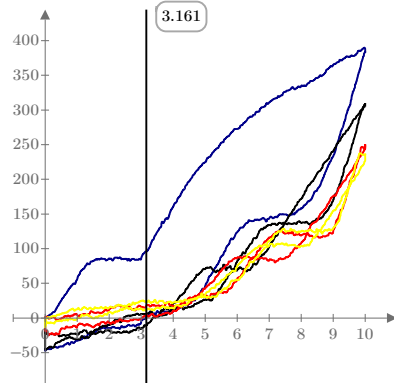
$DispLdP2PL2L1SG1^{(1)}$ (**kN**)

$DispLdP2PL2L2SG1^{(1)}$ (**kN**)

$DispLdP2PL2L3SG1^{(1)}$ (**kN**)

$DispLdP2PL2L4SG1^{(1)}$ (**kN**)

Fig D 39. Load-Displacement for P2 PL2 SG1



$DispLdP2PL3L1SG1^{(0)}$

$DispLdP2PL3L2SG1^{(0)}$

$DispLdP2PL3L3SG1^{(0)}$

$DispLdP2PL3L4SG1^{(0)}$

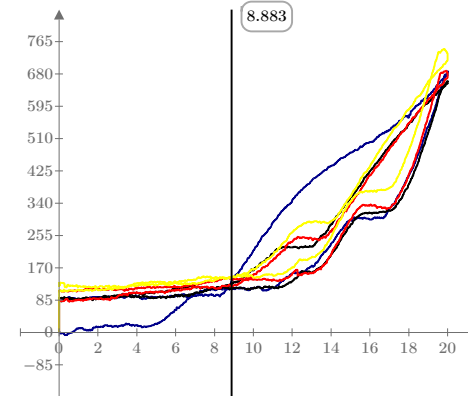
$DispLdP2PL3L1SG1^{(1)}$ (**kN**)

$DispLdP2PL3L2SG1^{(1)}$ (**kN**)

$DispLdP2PL3L3SG1^{(1)}$ (**kN**)

$DispLdP2PL3L4SG1^{(1)}$ (**kN**)

Fig D 40. Load-Displacement for P2 PL3 SG1



$DispLdP2PL4L1SG1^{(0)}$

$DispLdP2PL4L2SG1^{(0)}$

$DispLdP2PL4L3SG1^{(0)}$

$DispLdP2PL4L4SG1^{(0)}$

$DispLdP2PL4L1SG1^{(1)}$ (**kN**)

$DispLdP2PL4L2SG1^{(1)}$ (**kN**)

$DispLdP2PL4L3SG1^{(1)}$ (**kN**)

$DispLdP2PL4L4SG1^{(1)}$ (**kN**)

Fig D 41. Load-Displacement for P2 PL4 SG1

Appendix D
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

$DispLdP2PL1L1SG2 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 1, 2)$

$DispLdP2PL1L2SG2 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 2, 2)$

$DispLdP2PL1L3SG2 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 3, 2)$

$DispLdP2PL1L4SG2 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 4, 2)$

$DispLdP2PL2L1SG2 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 1, 2)$

$DispLdP2PL2L2SG2 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 2, 2)$

$DispLdP2PL2L3SG2 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 3, 2)$

$DispLdP2PL2L4SG2 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 4, 2)$

$DispLdP2PL3L1SG2 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 1, 2)$

$DispLdP2PL3L2SG2 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 2, 2)$

$DispLdP2PL3L3SG2 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 3, 2)$

$DispLdP2PL3L4SG2 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 4, 2)$

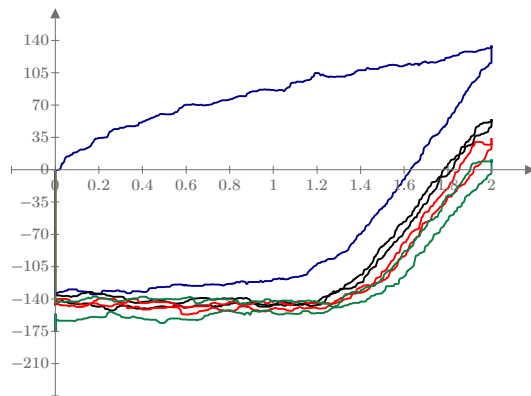
$DispLdP2PL4L1SG2 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 1, 2)$

$DispLdP2PL4L2SG2 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 2, 2)$

$DispLdP2PL4L3SG2 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 3, 2)$

$DispLdP2PL4L4SG2 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 4, 2)$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile



$DispLdP2PL1L1SG2^{(0)}$

$DispLdP2PL1L2SG2^{(0)}$

$DispLdP2PL1L3SG2^{(0)}$

$DispLdP2PL1L4SG2^{(0)}$

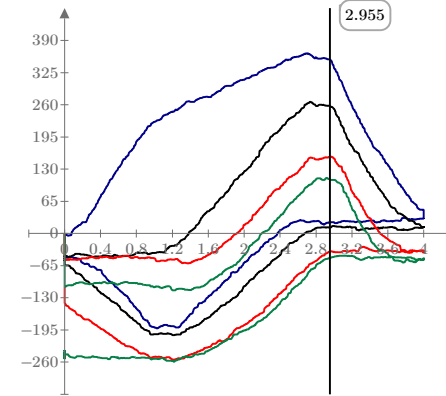
$DispLdP2PL1L1SG2^{(1)} (kN)$

$DispLdP2PL1L2SG2^{(1)} (kN)$

$DispLdP2PL1L3SG2^{(1)} (kN)$

$DispLdP2PL1L4SG2^{(1)} (kN)$

Fig D 42. Load-Displacement for P2 PL1 SG2



$DispLdP2PL2L1SG2^{(0)}$

$DispLdP2PL2L2SG2^{(0)}$

$DispLdP2PL2L3SG2^{(0)}$

$DispLdP2PL2L4SG2^{(0)}$

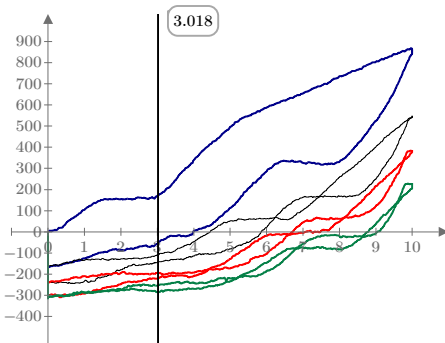
$DispLdP2PL2L1SG2^{(1)} (kN)$

$DispLdP2PL2L2SG2^{(1)} (kN)$

$DispLdP2PL2L3SG2^{(1)} (kN)$

$DispLdP2PL2L4SG2^{(1)} (kN)$

Fig D 43. Load-Displacement for P2 PL2 SG2



$DispLdP2PL3L1SG2^{(0)}$

$DispLdP2PL3L2SG2^{(0)}$

$DispLdP2PL3L3SG2^{(0)}$

$DispLdP2PL3L4SG2^{(0)}$

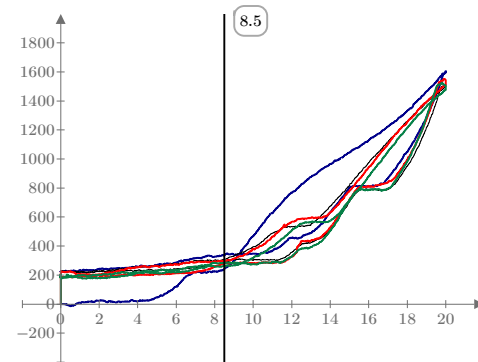
$DispLdP2PL3L1SG2^{(1)} (kN)$

$DispLdP2PL3L2SG2^{(1)} (kN)$

$DispLdP2PL3L3SG2^{(1)} (kN)$

$DispLdP2PL3L4SG2^{(1)} (kN)$

Fig D 44. Load-Displacement for P2 PL3 SG2



$DispLdP2PL4L1SG2^{(0)}$

$DispLdP2PL4L2SG2^{(0)}$

$DispLdP2PL4L3SG2^{(0)}$

$DispLdP2PL4L4SG2^{(0)}$

$DispLdP2PL4L1SG2^{(1)} (kN)$

$DispLdP2PL4L2SG2^{(1)} (kN)$

$DispLdP2PL4L3SG2^{(1)} (kN)$

$DispLdP2PL4L4SG2^{(1)} (kN)$

Fig D 45. Load-Displacement for P2 PL4 SG2

Appendix D
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

$DispLdP2PL1L1SG3 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 1, 3)$

$DispLdP2PL1L2SG3 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 2, 3)$

$DispLdP2PL1L3SG3 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 3, 3)$

$DispLdP2PL1L4SG3 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 4, 3)$

$DispLdP2PL2L1SG3 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 1, 3)$

$DispLdP2PL2L2SG3 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 2, 3)$

$DispLdP2PL2L3SG3 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 3, 3)$

$DispLdP2PL2L4SG3 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 4, 3)$

$DispLdP2PL3L1SG3 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 1, 3)$

$DispLdP2PL3L2SG3 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 2, 3)$

$DispLdP2PL3L3SG3 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 3, 3)$

$DispLdP2PL3L4SG3 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 4, 3)$

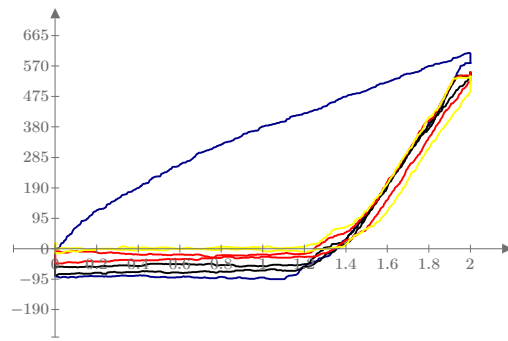
$DispLdP2PL4L1SG3 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 1, 3)$

$DispLdP2PL4L2SG3 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 2, 3)$

$DispLdP2PL4L3SG3 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 3, 3)$

$DispLdP2PL4L4SG3 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 4, 3)$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile



$DispLdP2PL1L1SG3^{(0)}$

$DispLdP2PL1L2SG3^{(0)}$

$DispLdP2PL1L3SG3^{(0)}$

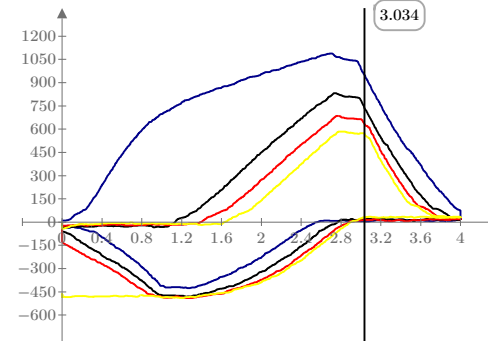
$DispLdP2PL1L4SG3^{(0)}$

$DispLdP2PL1L1SG3^{(1)} \text{ (kN)}$

$DispLdP2PL1L2SG3^{(1)} \text{ (kN)}$

$DispLdP2PL1L3SG3^{(1)} \text{ (kN)}$

$DispLdP2PL1L4SG3^{(1)} \text{ (kN)}$



$DispLdP2PL2L1SG3^{(0)}$

$DispLdP2PL2L2SG3^{(0)}$

$DispLdP2PL2L3SG3^{(0)}$

$DispLdP2PL2L4SG3^{(0)}$

$DispLdP2PL2L1SG3^{(1)} \text{ (kN)}$

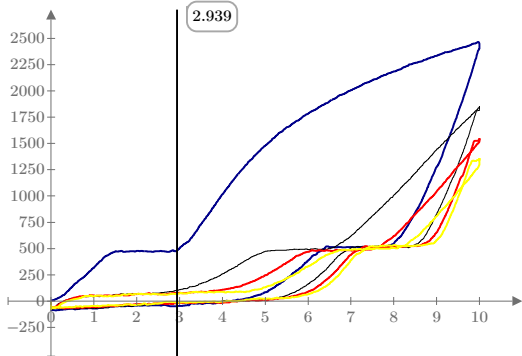
$DispLdP2PL2L2SG3^{(1)} \text{ (kN)}$

$DispLdP2PL2L3SG3^{(1)} \text{ (kN)}$

$DispLdP2PL2L4SG3^{(1)} \text{ (kN)}$

Fig D 46. Load-Displacement for P2 PL1 SG3

Fig D 47. Load-Displacement for P2 PL2 SG3



$DispLdP2PL3L1SG3^{(0)}$

$DispLdP2PL3L2SG3^{(0)}$

$DispLdP2PL3L3SG3^{(0)}$

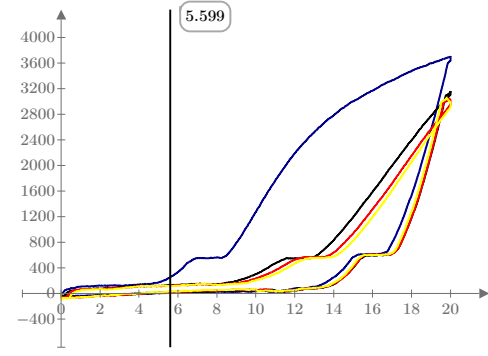
$DispLdP2PL3L4SG3^{(0)}$

$DispLdP2PL3L1SG3^{(1)} \text{ (kN)}$

$DispLdP2PL3L2SG3^{(1)} \text{ (kN)}$

$DispLdP2PL3L3SG3^{(1)} \text{ (kN)}$

$DispLdP2PL3L4SG3^{(1)} \text{ (kN)}$



$DispLdP2PL4L1SG3^{(0)}$

$DispLdP2PL4L2SG3^{(0)}$

$DispLdP2PL4L3SG3^{(0)}$

$DispLdP2PL4L4SG3^{(0)}$

$DispLdP2PL4L1SG3^{(1)} \text{ (kN)}$

$DispLdP2PL4L2SG3^{(1)} \text{ (kN)}$

$DispLdP2PL4L3SG3^{(1)} \text{ (kN)}$

$DispLdP2PL4L4SG3^{(1)} \text{ (kN)}$

Fig D 48. Load-Displacement for P2 PL3 SG3

Fig D 49. Load-Displacement for P2 PL4 SG3

Appendix D
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

$DispLdP2PL1L1SG4 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 1, 4)$

$DispLdP2PL1L2SG4 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 2, 4)$

$DispLdP2PL1L3SG4 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 3, 4)$

$DispLdP2PL1L4SG4 := DispLd(TDispTLdP2PL1, PseuPL1H, IniTimePL1H, IniDisp, 4, 4)$

$DispLdP2PL2L1SG4 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 1, 4)$

$DispLdP2PL2L2SG4 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 2, 4)$

$DispLdP2PL2L3SG4 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 3, 4)$

$DispLdP2PL2L4SG4 := DispLd(TDispTLdP2PL2, PseuPL2H, IniTimePL2H, IniDisp, 4, 4)$

$DispLdP2PL3L1SG4 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 1, 4)$

$DispLdP2PL3L2SG4 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 2, 4)$

$DispLdP2PL3L3SG4 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 3, 4)$

$DispLdP2PL3L4SG4 := DispLd(TDispTLdP2PL3, PseuPL3H, IniTimePL3H, IniDisp, 4, 4)$

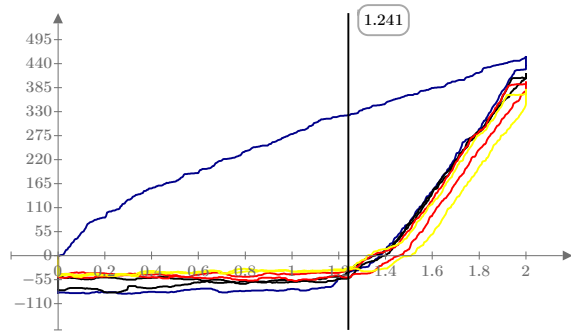
$DispLdP2PL4L1SG4 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 1, 4)$

$DispLdP2PL4L2SG4 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 2, 4)$

$DispLdP2PL4L3SG4 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 3, 4)$

$DispLdP2PL4L4SG4 := DispLd(TDispTLdP2PL4, PseuPL4H, IniTimePL4H, IniDisp, 4, 4)$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile



$DispLdP2PL1L1SG4^{(0)}$

$DispLdP2PL1L2SG4^{(0)}$

$DispLdP2PL1L3SG4^{(0)}$

$DispLdP2PL1L4SG4^{(0)}$

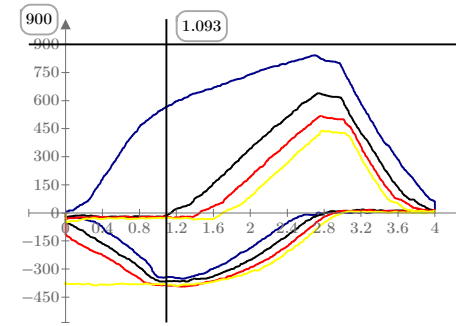
$DispLdP2PL1L1SG4^{(1)} (kN)$

$DispLdP2PL1L2SG4^{(1)} (kN)$

$DispLdP2PL1L3SG4^{(1)} (kN)$

$DispLdP2PL1L4SG4^{(1)} (kN)$

Fig D 50. Load-Displacement for P2 PL1 SG4



$DispLdP2PL2L1SG4^{(0)}$

$DispLdP2PL2L2SG4^{(0)}$

$DispLdP2PL2L3SG4^{(0)}$

$DispLdP2PL2L4SG4^{(0)}$

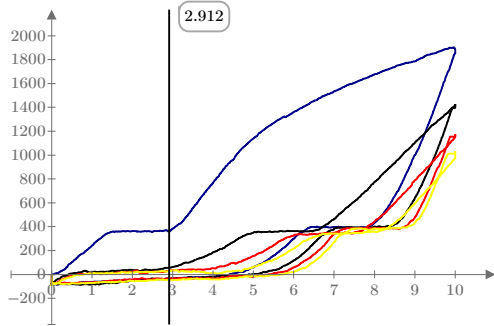
$DispLdP2PL2L1SG4^{(1)} (kN)$

$DispLdP2PL2L2SG4^{(1)} (kN)$

$DispLdP2PL2L3SG4^{(1)} (kN)$

$DispLdP2PL2L4SG4^{(1)} (kN)$

Fig D 51. Load-Displacement for P2 PL2 SG4



$DispLdP2PL3L1SG4^{(0)}$

$DispLdP2PL3L2SG4^{(0)}$

$DispLdP2PL3L3SG4^{(0)}$

$DispLdP2PL3L4SG4^{(0)}$

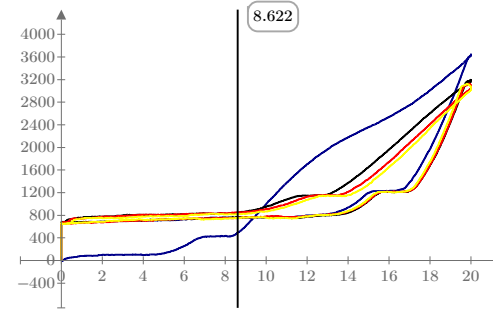
$DispLdP2PL3L1SG4^{(1)} (kN)$

$DispLdP2PL3L2SG4^{(1)} (kN)$

$DispLdP2PL3L3SG4^{(1)} (kN)$

$DispLdP2PL3L4SG4^{(1)} (kN)$

Fig D 52. Load-Displacement for P2 PL3 SG4



$DispLdP2PL4L1SG4^{(0)}$

$DispLdP2PL4L2SG4^{(0)}$

$DispLdP2PL4L3SG4^{(0)}$

$DispLdP2PL4L4SG4^{(0)}$

$DispLdP2PL4L1SG4^{(1)} (kN)$

$DispLdP2PL4L2SG4^{(1)} (kN)$

$DispLdP2PL4L3SG4^{(1)} (kN)$

$DispLdP2PL4L4SG4^{(1)} (kN)$

Fig D 53. Load-Displacement for P2 PL4 SG4

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

Functions for determining the Qmax profile from each loads

TOL := 0.00000001

```

QmaxSG (TDispTLdP2PL1, PileNum) :=
  ||
  || QP0 ← max (TDispTLdP2PL1(3))
  || QP1 ← max (TDispTLdP2PL1(4))
  || QP2 ← max (TDispTLdP2PL1(5))
  || QP3 ← max (TDispTLdP2PL1(6))
  ||
  || combined ← if PileNum = 0
  ||   || stack (QP0, QP1, QP1, QP1, QP1, QP1)
  ||   || else if PileNum = 1
  ||   ||   || stack (QP0, QP1, QP1, QP2, QP2, QP2)
  ||   ||   || else
  ||   ||   ||   || stack (QP0, QP1, QP1, QP2, QP2, QP3)
  || combined
  ||

```

$Q_{maxP2PL1} := Q_{maxSG}(TDispTLdP2PL1, 2) \cdot \mathbf{kN}$

$Q_{maxP2PL2} := Q_{maxSG}(TDispTLdP2PL2, 2) \mathbf{kN}$

$Q_{maxP2PL3} := Q_{maxSG}(TDispTLdP2PL3, 2) \mathbf{kN}$

$Q_{maxP2PL4} := Q_{maxSG}(TDispTLdP2PL4, 2) \mathbf{kN}$

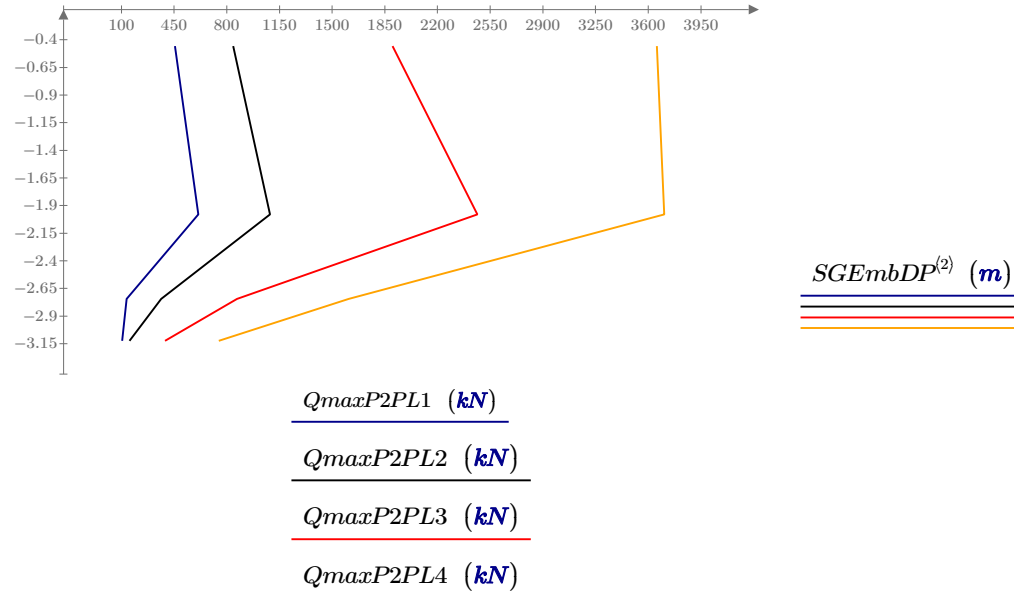
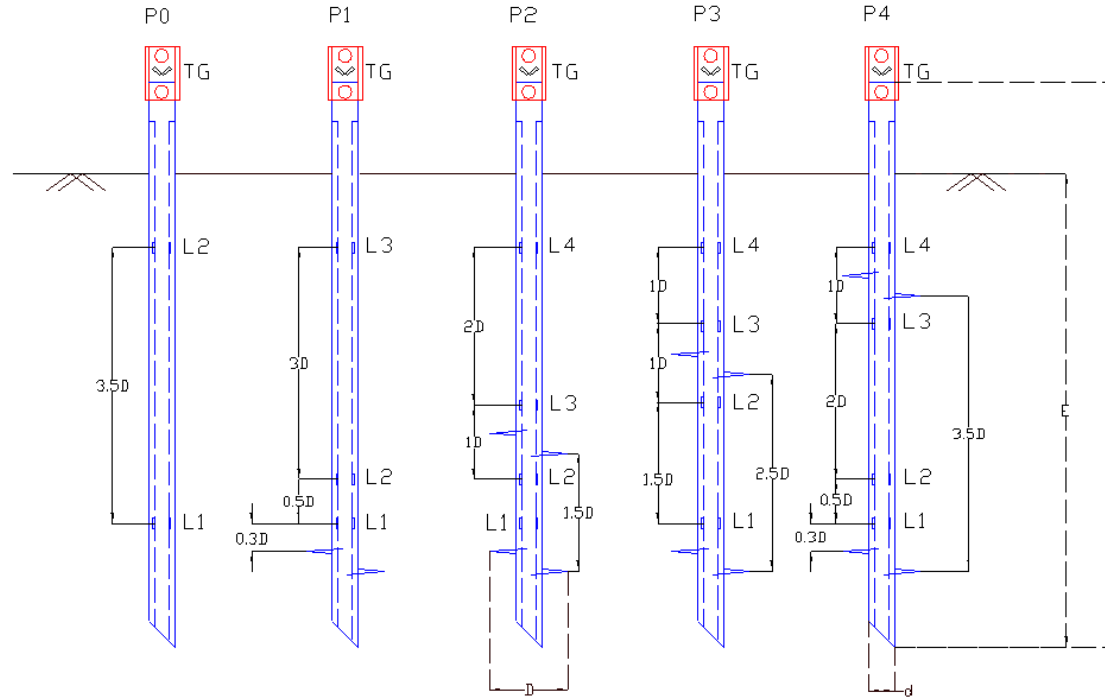


Fig D 54. SG Depth vs Q max from each load amplitude for P2 pile

2.3.3 Skin Friction vs Depth



Strain gauge locations in model piles.

$$HgtShaft := \begin{bmatrix} 3.5 & 0.5 & 0.5 & 1.5 & 0.5 \\ 0 & 3 & 1 & 1 & 2 \\ 0 & 0 & 2 & 1 & 1 \end{bmatrix} \cdot D \cdot Nscale^{sclfac_{0,0}} = \begin{bmatrix} 2.667 & 0.381 & 0.381 & 1.143 & 0.381 \\ 0 & 2.286 & 0.762 & 0.762 & 1.524 \\ 0 & 0 & 1.524 & 0.762 & 0.762 \end{bmatrix} m$$

Height in the shaft segment between two stations in prototype scale. Here, colm 0-4 represents P0 to P4. Row 0 to 2 represents height between SG 1-2, 2-3 & 3-4

$$SurfArea := HgtShaft \cdot \pi \cdot d \cdot Nscale^{sclfac_{0,0}} = \begin{bmatrix} 2.128 & 0.304 & 0.304 & 0.912 & 0.304 \\ 0 & 1.824 & 0.608 & 0.608 & 1.216 \\ 0 & 0 & 1.216 & 0.608 & 0.608 \end{bmatrix} m^2$$

Surface Area of the shaft segment between two stations in prototype scale. Here, colm 0-4 represents P0 to P4. Row 0 to 2 represents surface area between SG 1-2, 2-3 & 3-4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

Function for determining the Unit Shaft Resistance within the shaft segment

```

UntShtRes(LdP, PileNum) :=
  for i ∈ 0, 1 .. rows(LdP) - 1
    for j ∈ 0, 1 .. cols(LdP) - 1
      shaft12i,0 ←  $\frac{(LdP_{i,4} - LdP_{i,3}) \text{ kN}}{\text{submatrix}(\text{SurfArea}, 0, 2, \text{PileNum}, \text{PileNum})_{0,0}}$ 
      shaft23i,1 ← if submatrix(SurfArea, 0, 2, PileNum, PileNum)1 = 0
                     0
                     else
                      $\frac{(LdP_{i,5} - LdP_{i,4}) \text{ kN}}{\text{submatrix}(\text{SurfArea}, 0, 2, \text{PileNum}, \text{PileNum})_1}$ 
      shaft34i,2 ← if submatrix(SurfArea, 0, 2, PileNum, PileNum)2 = 0
                     0
                     else
                      $\frac{-(LdP_{i,6} - LdP_{i,5}) \text{ kN}}{\text{submatrix}(\text{SurfArea}, 0, 2, \text{PileNum}, \text{PileNum})_2}$ 
    augment(shaft12(0), shaft23(1), shaft34(2))
  
```

$$ShftResP2PL1 := UntShtRes(TDispTLdP2PL1, 2)$$

$$ShftResP2PL2 := UntShtRes(TDispTLdP2PL2, 2)$$

$$ShftResP2PL3 := UntShtRes(TDispTLdP2PL3, 2)$$

$$ShftResP2PL4 := UntShtRes(TDispTLdP2PL4, 2)$$

$$ShftResP2CL := UntShtRes(TDispTLdP2CL, 2)$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

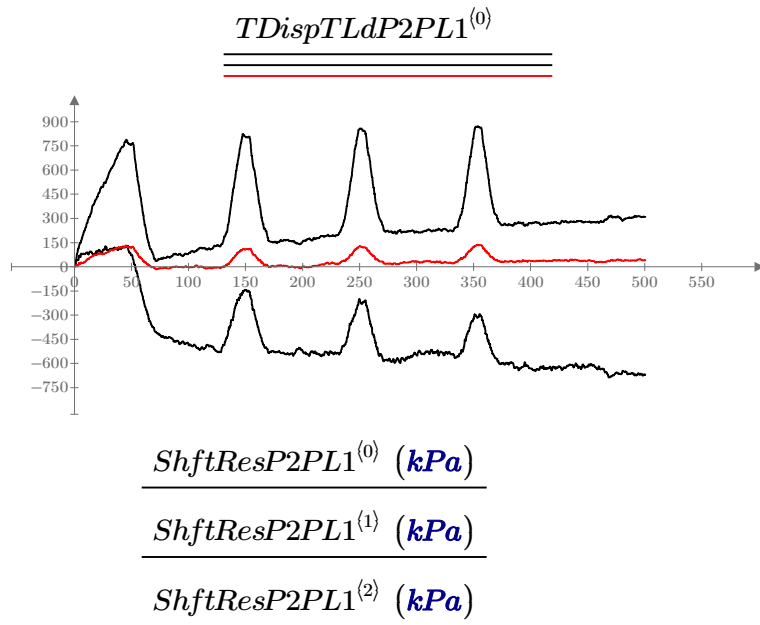


Fig D 55. Shaft Resistances vs Time, P2 PL1

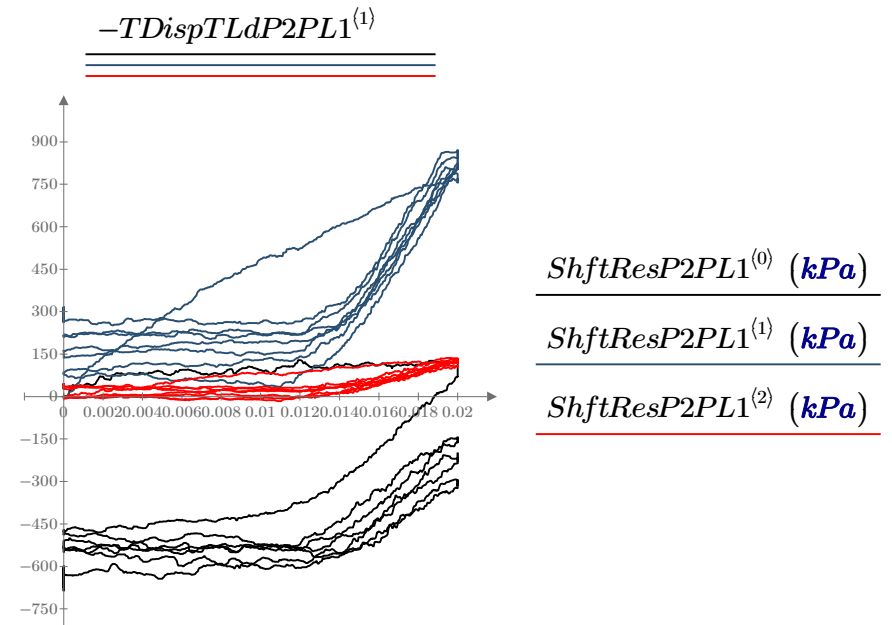


Fig D 56. Shaft Resistances vs Displacement, P2 PL1

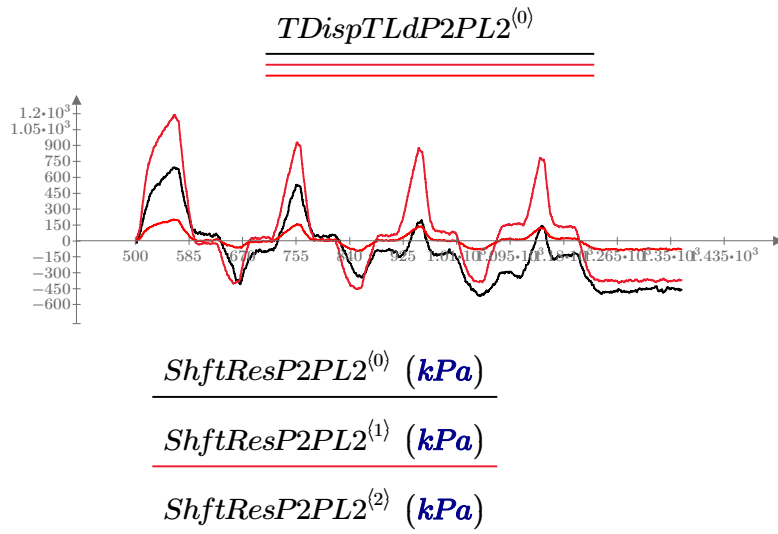


Fig D 57. Shaft Resistances vs Time, P2 PL2

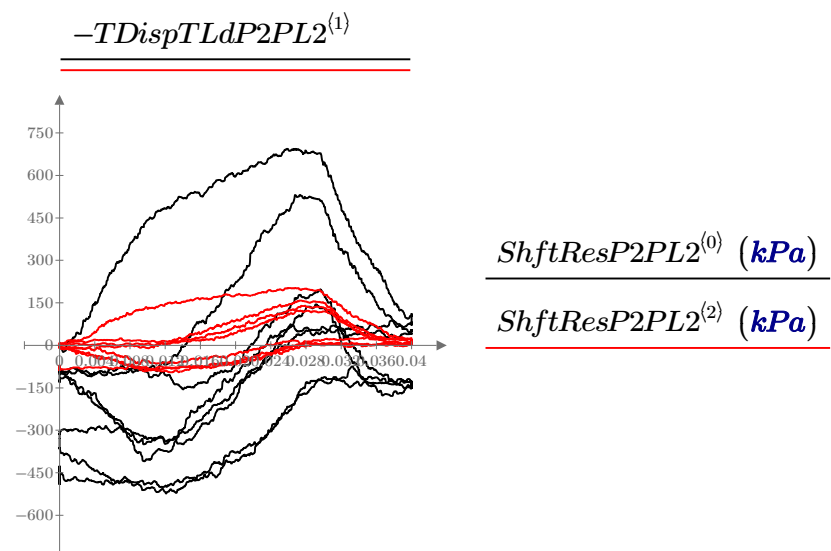


Fig D 58. Shaft Resistances vs Displacement, P2 PL2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

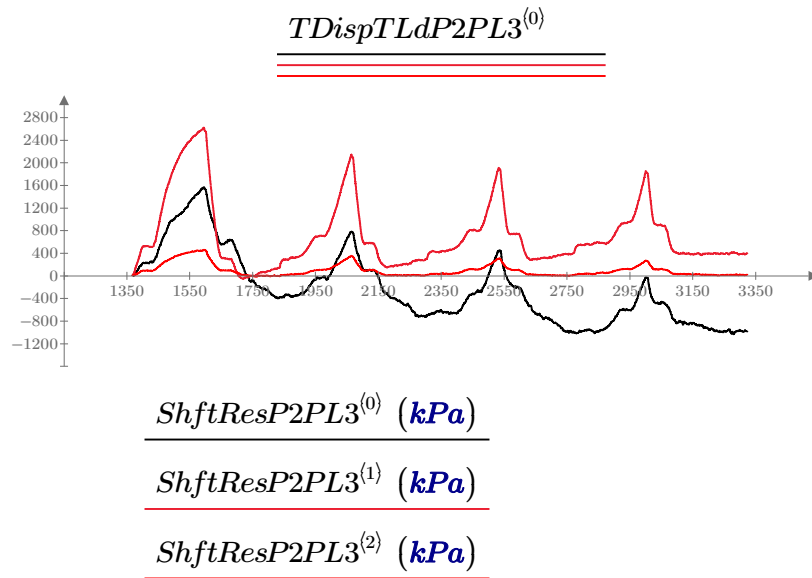


Fig D 59. Shaft Resistances vs Time, P2 PL3

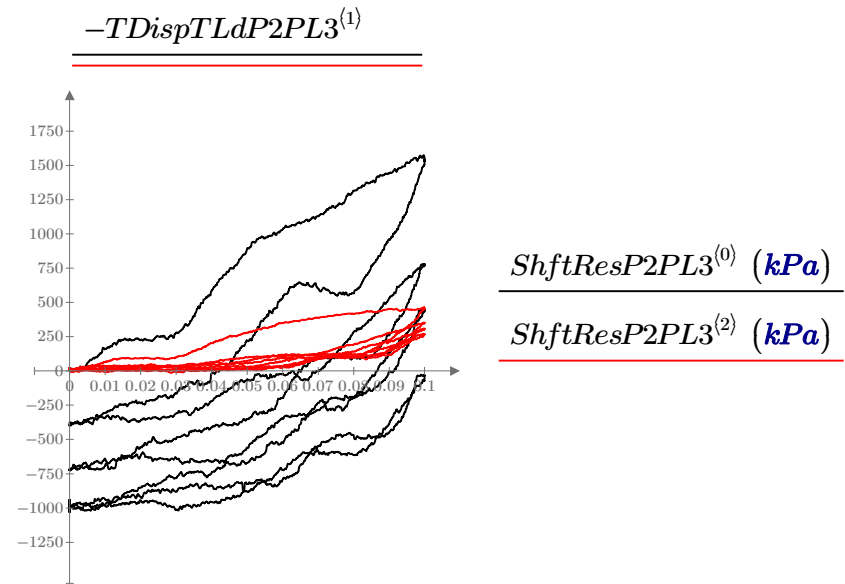


Fig D 60. Shaft Resistances vs Displacement, P2 PL3

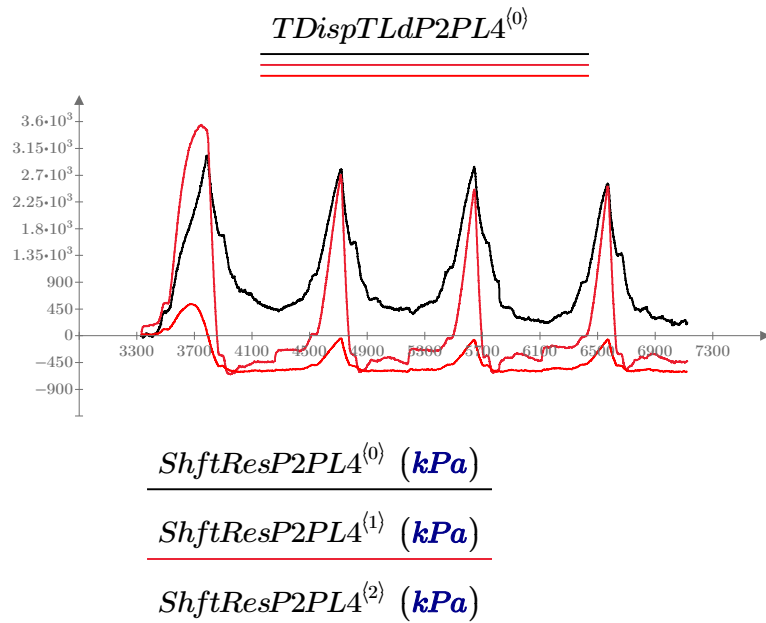


Fig D 61. Shaft Resistances vs Time, P2 PL4

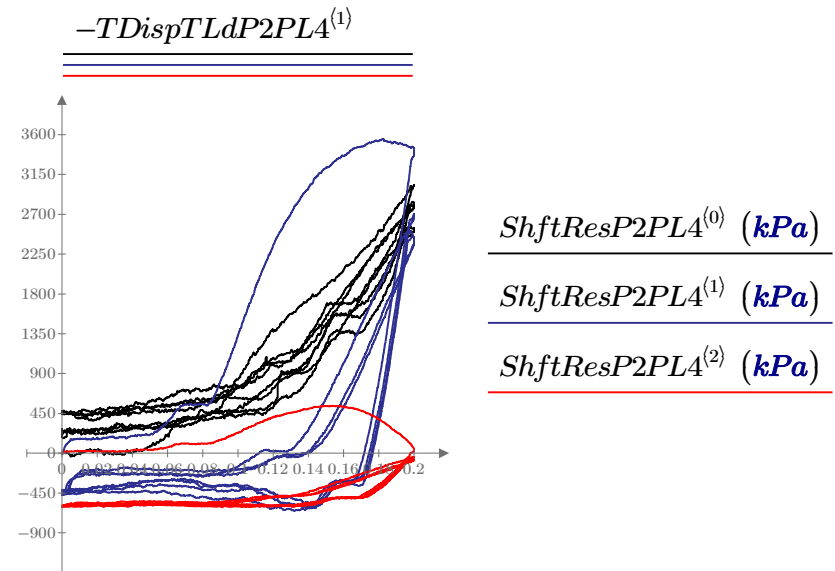


Fig D 62. Shaft Resistances vs Displacement, P2 PL4

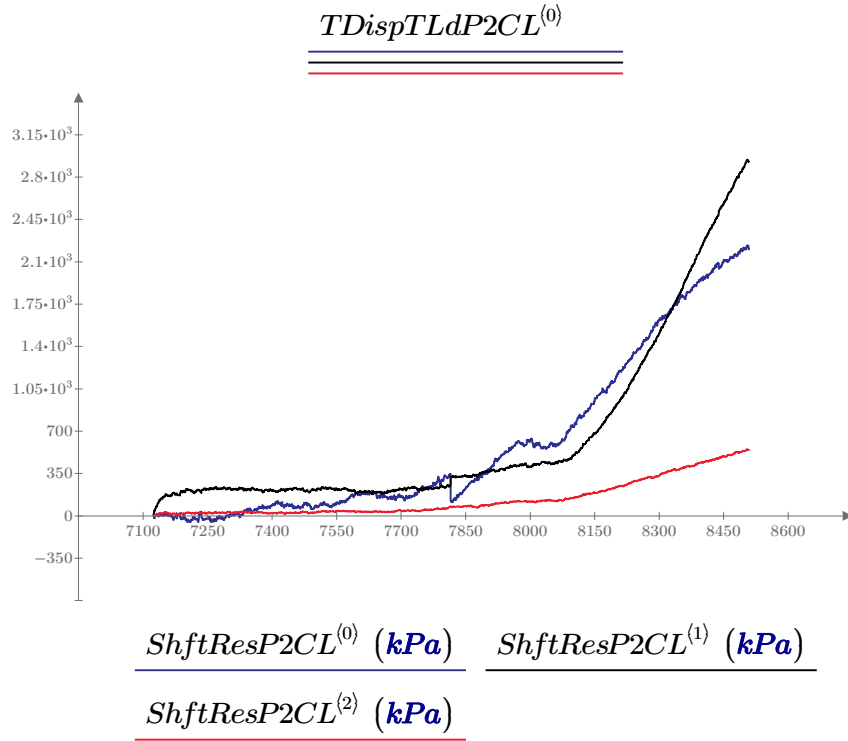


Fig D 63. Shaft Resistances vs Time, P2 CL

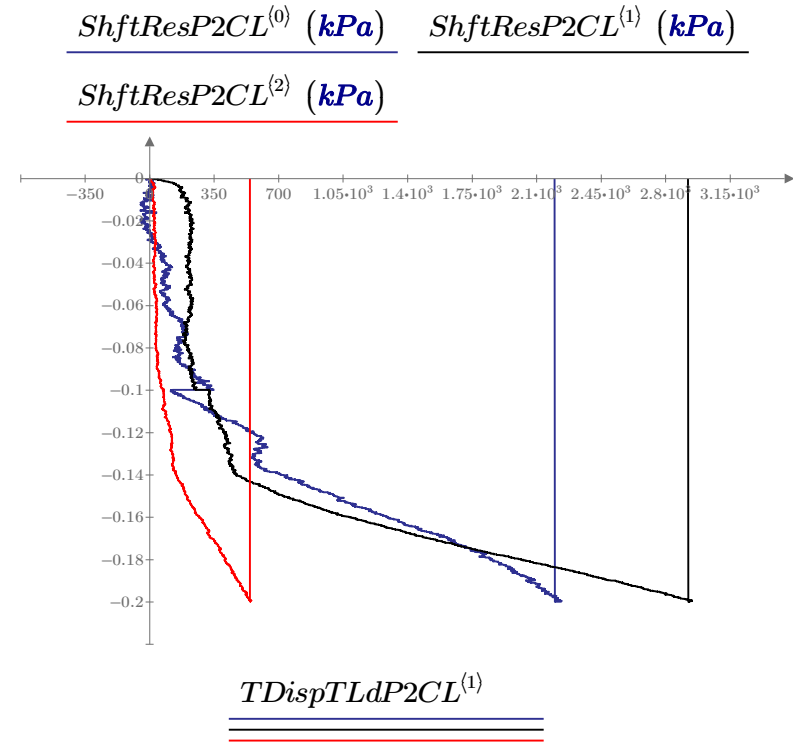


Fig D 64. Shaft Resistances vs Displacement, P2 CL

$$ShftP2CL := \text{augment} \left(TDispTLdP2CL^{(1)}, \frac{ShftResP2CL^{(0)}}{\text{kPa}}, \frac{ShftResP2CL^{(1)}}{\text{kPa}}, \frac{ShftResP2CL^{(2)}}{\text{kPa}} \right)$$

$$UltShReP2_2 := \text{lookup}(-0.05, ShftP2CL^{(0)}, ShftP2CL^{(3)}, \text{"near"}) = [37.43]$$

$$UltShReP2_1 := \text{lookup}(-0.05, ShftP2CL^{(0)}, ShftP2CL^{(2)}, \text{"near"}) = [226.561]$$

$$UltShReP2_0 := \text{lookup}(-0.05, ShftP2CL^{(0)}, ShftP2CL^{(1)}, \text{"near"}) = [82.154]$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

Functions for calculating the ultimate unit shaft resistance along the depth

```

ShftResplot(ShftP0CL, PileNum) := for i ∈ 0, 1 .. cols(ShftP0CL) - 1
    ||
    || UltShReP0 ← if PileNum = 0
    ||     || lookup(-0.15, ShftP0CL(0), ShftP0CL(1), "near")
    ||     || else
    ||     || lookup(-0.05, ShftP0CL(0), ShftP0CL(1), "near")
    ||
    || UltShReP1 ← if PileNum = 0
    ||     || 0
    ||     || else
    ||     || lookup(-0.05, ShftP0CL(0), ShftP0CL(2), "near")
    ||
    || UltShReP2 ← if PileNum = 0
    ||     || 0
    ||     || else if PileNum = 1
    ||     || 0
    ||     || else
    ||     || lookup(-0.05, ShftP0CL(0), ShftP0CL(3), "near")
    ||
    || combined ← if PileNum = 0
    ||     || stack(UltShReP0, UltShReP0, UltShReP0, UltShReP0, UltShReP0, UltShReP0)
    ||     || else if PileNum = 1
    ||     || stack(UltShReP0, UltShReP0, UltShReP1, UltShReP1, UltShReP1, UltShReP1)
    ||     || else
    ||     || stack(UltShReP0, UltShReP0, UltShReP1, UltShReP1, UltShReP2, UltShReP2)

```

$$ShftResPlotP2CL := ShftResplot(ShftP2CL, 2) \text{ kPa} = \begin{bmatrix} 82.154 \\ 82.154 \\ 226.561 \\ 226.561 \\ 37.43 \\ 37.43 \end{bmatrix} \text{ kPa}$$

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

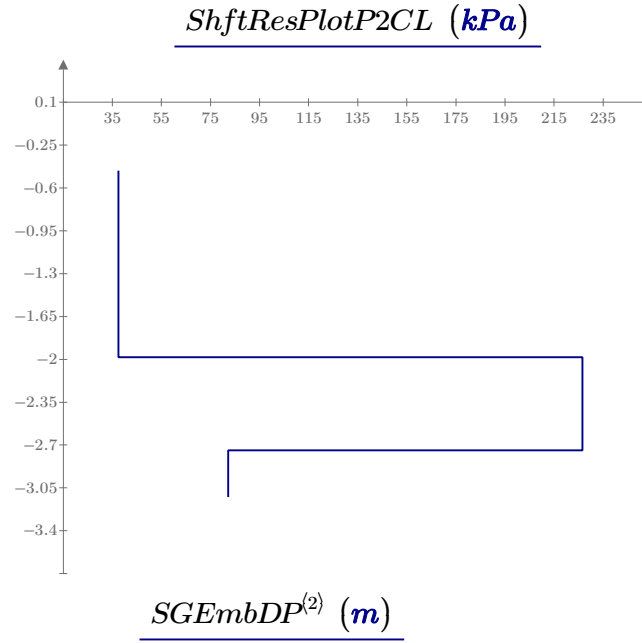


Fig D 65. Strain Gauge Depth vs Unit Shaft Resistance for post cyclic pile P2.

$ShftResplotP_C := \text{augment}(ShftResPlotP2CL, ShftResPlotP2CL, ShftResPlotP2CL, ShftResPlotP2CL, ShftResPlotP2CL)$
Ultimate Shaft resistance on the five compression piles between SGS

Function for estimating Mid depth of SGs on each piles

```
MidDSGsgmt(PileNum) :=
    shaft12 ← mean(submatrix(SGEmbDP, 0, 1, PileNum, PileNum))
    shaft23 ← if mean(submatrix(SGEmbDP, 2, 3, PileNum, PileNum)) = 0
                0
            else
                mean(submatrix(SGEmbDP, 2, 3, PileNum, PileNum))
    shaft34 ← if mean(submatrix(SGEmbDP, 4, 5, PileNum, PileNum)) = 0
                0
            else
                mean(submatrix(SGEmbDP, 4, 5, PileNum, PileNum))
    stack(shaft12, shaft23, shaft34)
```


Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

Function for estimating Ks of each piles

$$\begin{aligned}
 Ks(ShftResplotP, PileNum) := & \begin{aligned} & shaft12 \leftarrow \frac{\text{mean}(\text{submatrix}(ShftResplotP, 0, 1, PileNum, PileNum))}{\text{mean}(\text{submatrix}(SGEmbDP, 0, 1, PileNum, PileNum)) \cdot \gamma \cdot \tan(\delta)} \\ & shaft23 \leftarrow \begin{aligned} & \text{if } PileNum = 2 \\ & \quad 0 \\ & \text{else if } PileNum = 3 \\ & \quad 0 \\ & \text{else} \\ & \quad \text{if } \text{mean}(\text{submatrix}(SGEmbDP, 2, 3, PileNum, PileNum)) = 0 \\ & \quad \quad 0 \\ & \quad \text{else} \\ & \quad \quad \frac{\text{mean}(\text{submatrix}(ShftResplotP, 2, 3, PileNum, PileNum))}{\text{mean}(\text{submatrix}(SGEmbDP, 2, 3, PileNum, PileNum)) \cdot \gamma \cdot \tan(\delta)} \end{aligned} \\ & shaft34 \leftarrow \begin{aligned} & \text{if } PileNum = 4 \\ & \quad 0 \\ & \text{else} \\ & \quad \text{if } \text{mean}(\text{submatrix}(SGEmbDP, 4, 5, PileNum, PileNum)) = 0 \\ & \quad \quad 0 \\ & \quad \text{else} \\ & \quad \quad \frac{\text{mean}(\text{submatrix}(ShftResplotP, 4, 5, PileNum, PileNum))}{\text{mean}(\text{submatrix}(SGEmbDP, 4, 5, PileNum, PileNum)) \cdot \gamma \cdot \tan(\delta)} \end{aligned} \\ & \text{stack}(-shaft12, -shaft23, -shaft34) \end{aligned}
 \end{aligned}$$

$$KsP_C := Ks(ShftResplotP_C, 2)$$

$$MidDSGsgmtP := \text{augment}(MidDSGsgmt(0), MidDSGsgmt(1), MidDSGsgmt(2), MidDSGsgmt(3), MidDSGsgmt(4))$$

$$\begin{aligned}
 Ko &:= \begin{bmatrix} 1 - \sin(\varphi) & 1 - \sin(\varphi) \end{bmatrix} & Kp &:= \begin{bmatrix} \frac{1 + \sin(\varphi)}{1 - \sin(\varphi)} & \frac{1 + \sin(\varphi)}{1 - \sin(\varphi)} \end{bmatrix} & Ka &:= \begin{bmatrix} \frac{1 - \sin(\varphi)}{1 + \sin(\varphi)} & \frac{1 - \sin(\varphi)}{1 + \sin(\varphi)} \end{bmatrix} = \begin{bmatrix} 0.317 & 0.317 \end{bmatrix} \\
 K &:= \begin{bmatrix} 0.09 \cdot e^{0.08 \cdot \left(\varphi \cdot \frac{180}{\pi}\right)} & 0.09 \cdot e^{0.08 \cdot \left(\varphi \cdot \frac{180}{\pi}\right)} \end{bmatrix} & & & & \text{Mitsch and Clemence 1985}
 \end{aligned}$$

$$ProtEmbed := \begin{bmatrix} 0 & -E \cdot Nscale^{sclfac_{0,0}} \end{bmatrix} = \begin{bmatrix} 0 & -3.382 \end{bmatrix} \text{ m} \quad \text{Pile Embedment in prototype scale unit}$$

$$\begin{aligned}
 KsP_C &= \begin{bmatrix} 4.019 \\ 0 \\ 4.406 \end{bmatrix} & MidDSGsgmtP &= \begin{bmatrix} -1.791 & -2.934 & -2.934 & -2.553 & -2.934 \\ 0 & -1.6 & -2.362 & -1.6 & -1.981 \\ 0 & 0 & -1.219 & -0.838 & -0.838 \end{bmatrix} \text{ m}
 \end{aligned}$$

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

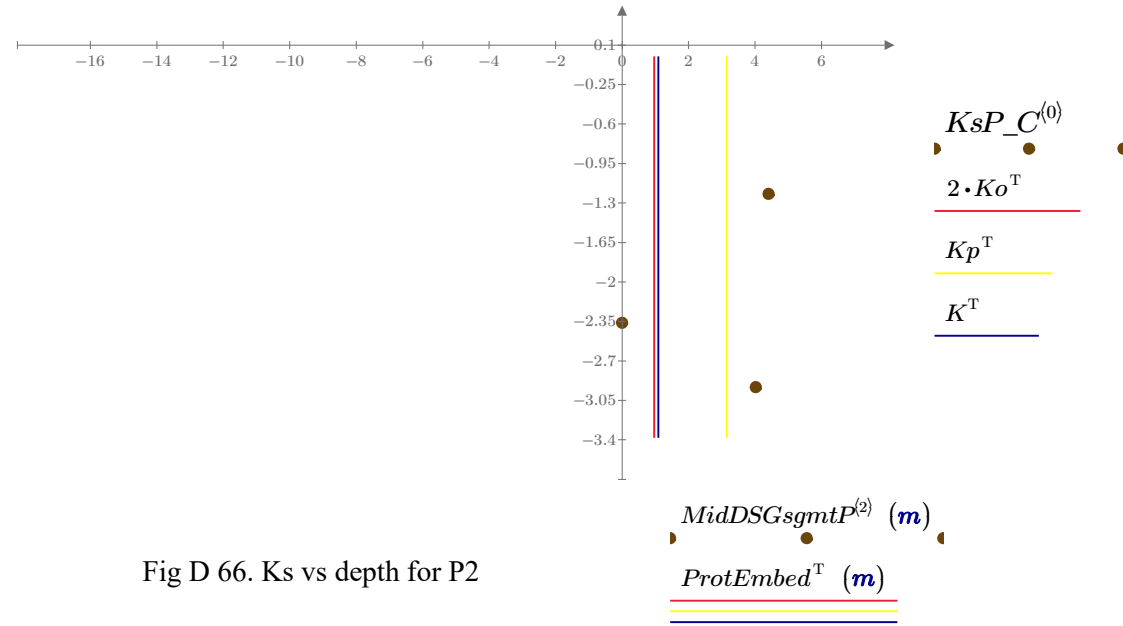


Fig D 66. Ks vs depth for P2

Function for estimating the shaft resistance EDR

```

ShftEDR (TDispTLdP0PL1, ShftResP2PL1, Pseu1perS, IniTime, IniDisp, LoopNo, ShftNo) :=
  m ← TDispTLdP0PL1
  n ← ShftResP2PL1
  n ← kPa
  o ← TimeCycLoop (Pseu1perS, IniTime, IniDisp) - IniTime
  w ← -m(1)
  wmax ← max (-m(1))
  if ShftNo = 1
    q ← n(0)
    qmax ← max (n(0))
  else if ShftNo = 2
    q ← n(1)
    qmax ← max (n(1))
  else if ShftNo = 3
    q ← n(2)
    qmax ← max (n(2))
  if LoopNo = 1
    t1 ← m1,0 - IniTime
    t2 ← o1
  else if LoopNo = 2
    t1 ← o1
    t2 ← o2
  else if LoopNo = 3

```

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

```

|||
|||   $t1 \leftarrow o_2$ 
|||   $t2 \leftarrow o_3$ 
|||
|||  else if  $LoopNo = 4$ 
|||
|||   $t1 \leftarrow o_3$ 
|||   $t2 \leftarrow o_4$ 
|||
|||
|||   $tstart \leftarrow \text{lookup}(t1, (m^{(0)} - IniTime), (m^{(0)} - IniTime), \text{"near"})$ 
|||   $tend \leftarrow \text{lookup}(t2, (m^{(0)} - IniTime), (m^{(0)} - IniTime), \text{"near"})$ 
|||   $rowstart \leftarrow \text{match}(t1, (m^{(0)} - IniTime), \text{"near"})$ 
|||   $rowend \leftarrow \text{match}(t2, (m^{(0)} - IniTime), \text{"near"})$ 
|||  for  $i \in rowstart_{0,0} \dots rowend_{0,0}$ 
|||
|||   $r_i \leftarrow \left( (w_i - w_{i-1}) \cdot \left( \frac{q_i + q_{i-1}}{2} \right) \right)$ 
|||
|||   $area \leftarrow \sum r$ 
|||
|||   $EDR \leftarrow$ 
|||  if  $qmax = 0$ 
|||  || 0
|||  else if  $wmax = 0$ 
|||  || 0
|||  else if  $area = 0$ 
|||  || 0
|||  else
|||  ||  $\frac{area}{qmax \cdot wmax}$ 
|||
|||   $s \leftarrow \text{augment}((tstart + IniTime), (tend + IniTime), rowstart, rowend, qmax, wmax, area, EDR)$ 
|||   $EDR$ 
|||

```

Function for combining the shaft resistance EDR

```

ShftEDRPOPLSG (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, PileNo) :=
|||
|||   $q1 \leftarrow \text{ShftEDR}(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1)$ 
|||   $q2 \leftarrow \text{ShftEDR}(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1)$ 
|||   $q3 \leftarrow \text{ShftEDR}(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1)$ 
|||   $q4 \leftarrow \text{ShftEDR}(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1)$ 
|||   $r1 \leftarrow \text{ShftEDR}(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2)$ 
|||   $r2 \leftarrow \text{ShftEDR}(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2)$ 
|||   $r3 \leftarrow \text{ShftEDR}(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2)$ 
|||   $r4 \leftarrow \text{ShftEDR}(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2)$ 
|||   $w1 \leftarrow$  if  $PileNo = 0$ 
|||  || 0
|||  || else
|||  ||  $\text{ShftEDR}(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 3)$ 
|||   $w2 \leftarrow$  if  $PileNo = 0$ 
|||  || 0
|||  || else
|||  ||  $\text{ShftEDR}(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 3)$ 
|||   $w3 \leftarrow$  if  $PileNo = 0$ 
|||  || 0
|||  || else
|||  ||  $\text{ShftEDR}(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 3)$ 
|||   $w4 \leftarrow$  if  $PileNo = 0$ 
|||  || 0
|||  || else
|||  ||  $\text{ShftEDR}(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3)$ 
|||

```

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

$$NoLoop := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

$$\begin{cases} 0 \\ \text{else} \\ ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3) \\ \text{augment}(\text{stack}(q1, q2, q3, q4), \text{stack}(r1, r2, r3, r4), \text{stack}(w1, w2, w3, w4)) \end{cases}$$

$$ShftEDRP2PL1 := ShftEDRPOPLSG(TDispTLdP2PL1, ShftResP2PL1, PseuPL1H, IniTimePL1H, 2) = \begin{bmatrix} 3.266 & 0.304 & 0.429 \\ 0.224 & -0.041 & -0.042 \\ 0.172 & -0.051 & -0.071 \\ 0.348 & -0.067 & -0.06 \end{bmatrix}$$

$$ShftEDRP2PL2 := ShftEDRPOPLSG(TDispTLdP2PL2, ShftResP2PL2, PseuPL2H, IniTimePL2H, 2) = \begin{bmatrix} 0.767 & 0.742 & 0.706 \\ 0.386 & 0.448 & 0.443 \\ 0.418 & 0.387 & 0.404 \\ 0.236 & 0.416 & 0.403 \end{bmatrix}$$

$$ShftEDRP2PL3 := ShftEDRPOPLSG(TDispTLdP2PL3, ShftResP2PL3, PseuPL3H, IniTimePL3H, 2) = \begin{bmatrix} 0.326 & 0.426 & 0.395 \\ 0.121 & 0.128 & 0.112 \\ 0.076 & 0.077 & 0.086 \\ -0.029 & 0.068 & 0.05 \end{bmatrix}$$

$$ShftEDRP2PL4 := ShftEDRPOPLSG(TDispTLdP2PL4, ShftResP2PL4, PseuPL4H, IniTimePL4H, 2) = \begin{bmatrix} -0.007 & 0.519 & 1.423 \\ 0.052 & 0.148 & 0.156 \\ 0.073 & 0.106 & 0.125 \\ 0.027 & 0.097 & 0.115 \end{bmatrix}$$

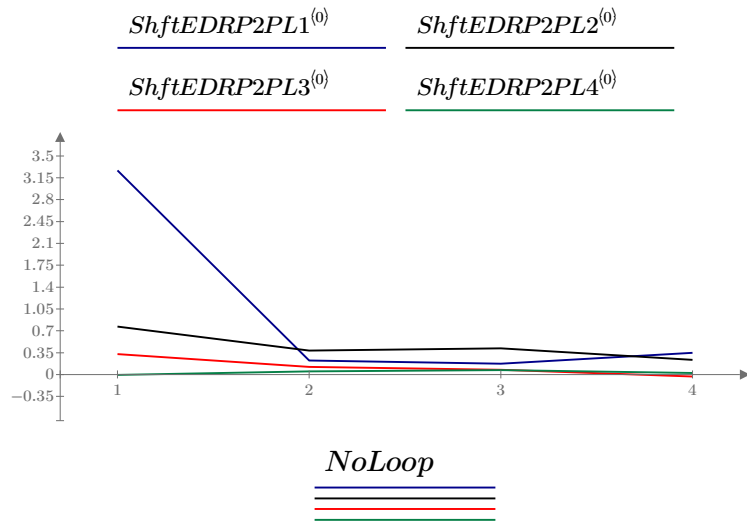


Fig D 67. Shaft EDR vs No of loops Seg1

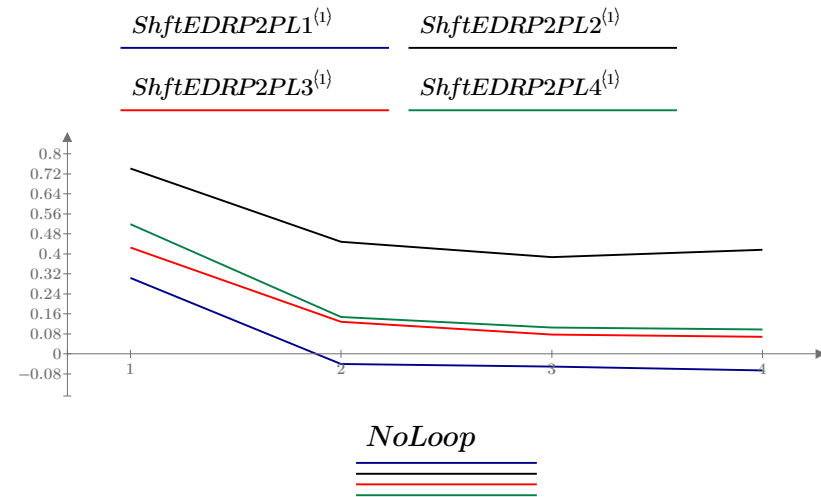


Fig D 68. Shaft EDR vs No of loops Seg 2

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

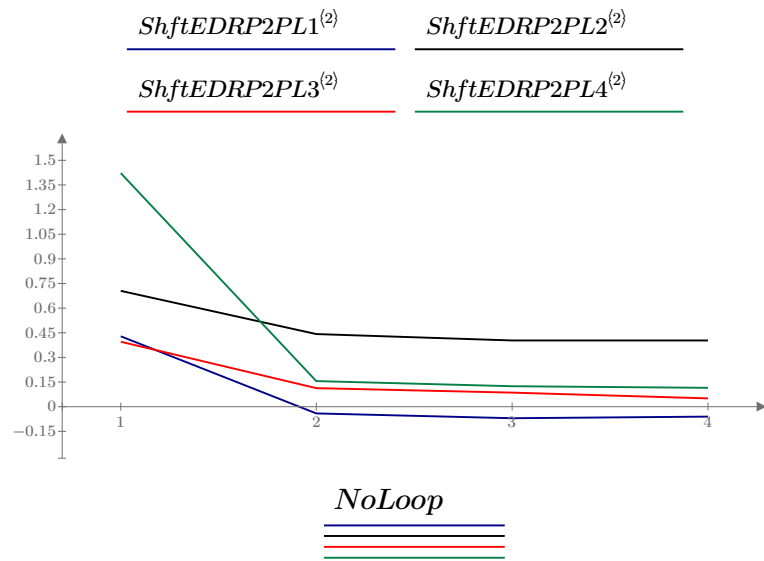
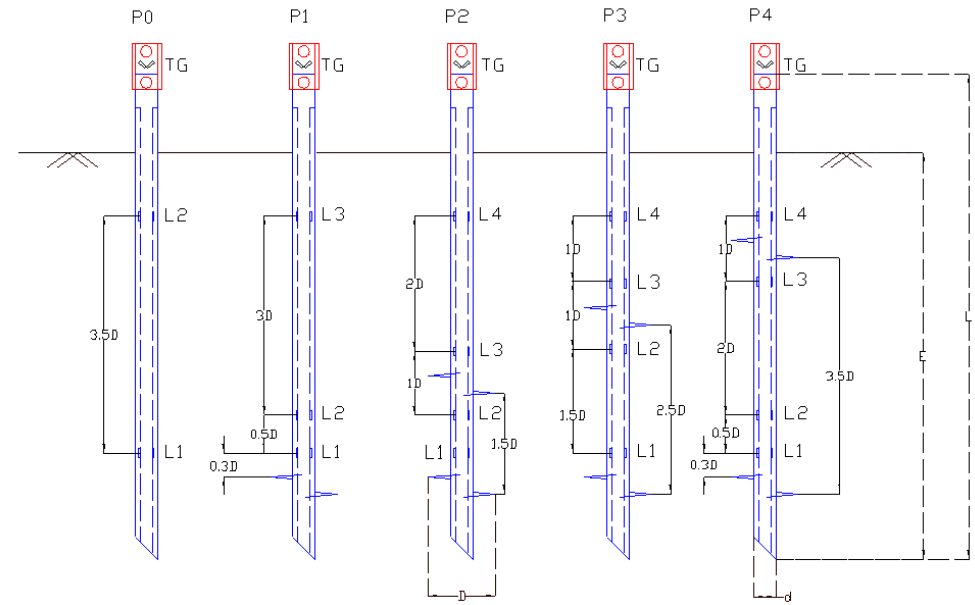


Fig D 69. EDR vs No of loops Seg 3



2.3.4 End Bearing vs Depth

$$A_b := \pi \cdot \frac{\left(D \cdot Nscale^{scale_{0,0}}\right)^2}{4} = 0.456 \text{ m}^2$$

Total area at the helix in prototype scale

$$A_d := \pi \cdot \frac{\left(d \cdot Nscale^{scale_{0,0}}\right)^2}{4} = 0.051 \text{ m}^2$$

Total area at the shaft in prototype scale

Function for determining the end bearing

```

EndBrng (TDispTLdP0CL, PileNum) := for i ∈ 0, 1..rows (TDispTLdP0CL) - 1
    for j ∈ 0, 1..cols (TDispTLdP0CL) - 1
        qb1i,0 ← if PileNum = 0
            (TDispTLdP0CLi,3) kN
            Ad
        else
            (TDispTLdP0CLi,3) kN
            Ab - Ad
        qb23i,1 ← if PileNum = 2
            (TDispTLdP0CLi,5 - TDispTLdP0CLi,4) kN
            Ab - Ad
        else if PileNum = 3
            (TDispTLdP0CLi,5 - TDispTLdP0CLi,4) kN
            Ab - Ad
        else
            0
        qb34i,2 ← if PileNum = 4
            (TDispTLdP0CLi,6 - TDispTLdP0CLi,5) kN
            Ab - Ad
        else
            0
    augment (qb1(0), qb23(1), qb34(2))
    
```

Appendix D
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

$$EndBrng(TDispTLdP2CL, 2) = \begin{matrix} 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ \vdots \\ 13855 \end{matrix} \begin{bmatrix} -1.934 & 3.229 & 0 \\ -1.934 & 3.229 & 0 \\ -1.934 & 2.089 & 0 \\ -1.934 & 2.248 & 0 \\ -2.418 & 3.387 & 0 \\ -2.418 & 4.527 & 0 \\ -2.418 & 4.527 & 0 \\ -2.418 & 8.422 & 0 \\ -2.902 & 8.422 & 0 \\ -2.418 & 14.912 & 0 \\ -2.418 & 14.912 & 0 \\ -0.484 & 22.733 & 0 \\ \vdots & & \vdots \end{bmatrix} \text{ kPa}$$

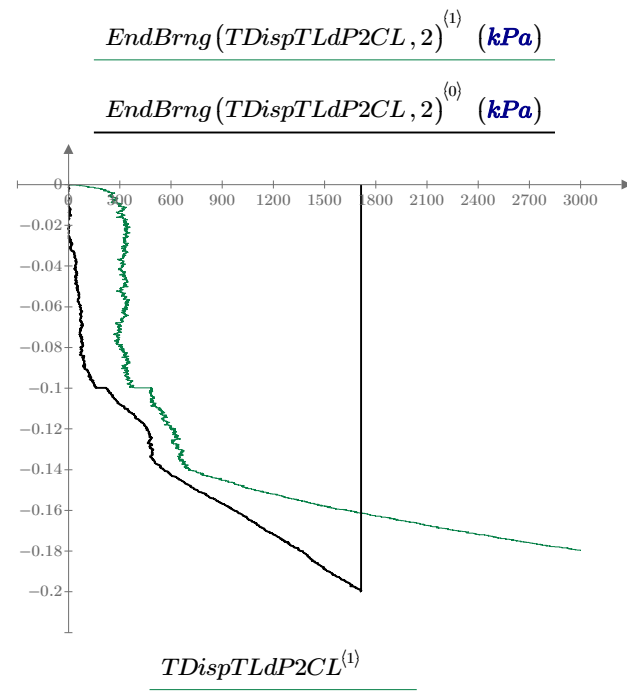


Fig D 70. Depth vs End Bearing for post cyclic compression pile P2

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

$$UltEndBrngP2_1 := \text{lookup}\left(-0.05, TDispTLdP2CL^{(1)}, EndBrng(TDispTLdP2CL, 2)^{(1)}, \text{"near"}\right) = [339.841] \text{ } \mathbf{kPa}$$

$$UltEndBrngP2_0 := \text{lookup}\left(-0.05, TDispTLdP2CL^{(1)}, EndBrng(TDispTLdP2CL, 2)^{(0)}, \text{"near"}\right) = [50.293] \text{ } \mathbf{kPa}$$

$$HelixLoc := - \begin{bmatrix} 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 \\ 0 & 0 & 0.6 + 2 + 0.3 + 0.17 & 0.6 + 1 + 0.3 + 0.17 & 0.6 + 0.3 + 0.17 \end{bmatrix} \cdot D \cdot Nscale^{scifac_{0,0}}$$

$$\text{stack}\left(\frac{UltEndBrngP2_0}{-HelixLoc_{0,2} \cdot \gamma}, \frac{UltEndBrngP2_1}{-HelixLoc_{1,2} \cdot \gamma}\right) = \begin{bmatrix} 0.897 \\ 9.023 \end{bmatrix} \quad HelixLoc = \begin{bmatrix} -3.482 & -3.482 & -3.482 & -3.482 & -3.482 \\ 0 & 0 & -2.339 & -1.577 & -0.815 \end{bmatrix} \text{ } \mathbf{m}$$

$$BrngP2PL1 := EndBrng(TDispTLdP2PL1, 2)$$

$$BrngP2PL2 := EndBrng(TDispTLdP2PL2, 2)$$

$$BrngP2PL3 := EndBrng(TDispTLdP2PL3, 2)$$

$$BrngP2PL4 := EndBrng(TDispTLdP2PL4, 2)$$

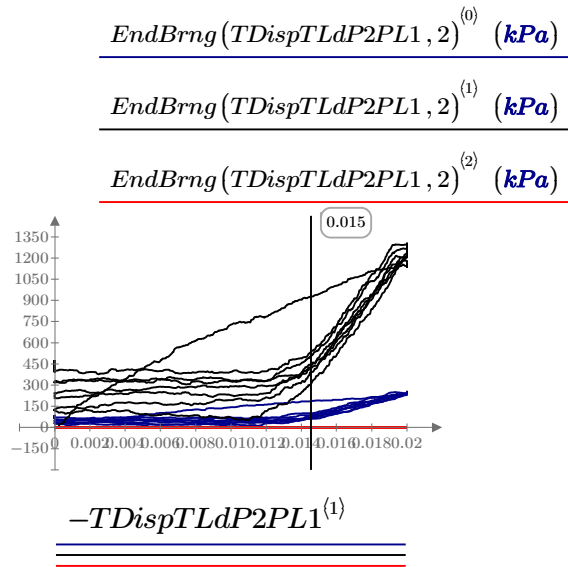


Fig D 71. End Bearing vs Depth for P2 PL1

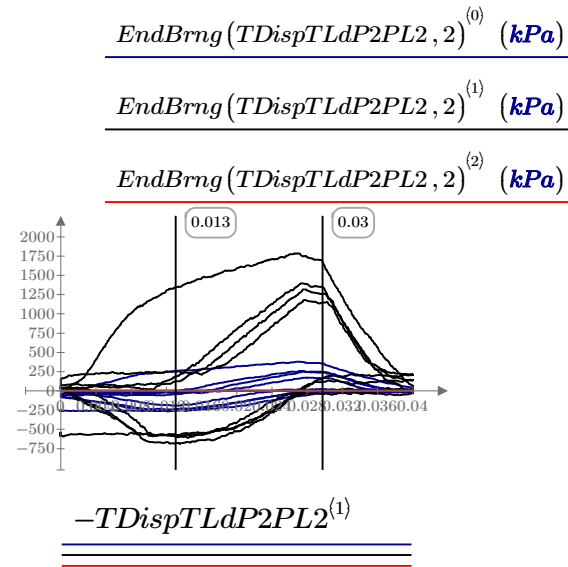


Fig D 72. End Bearing vs Depth for P2 PL2

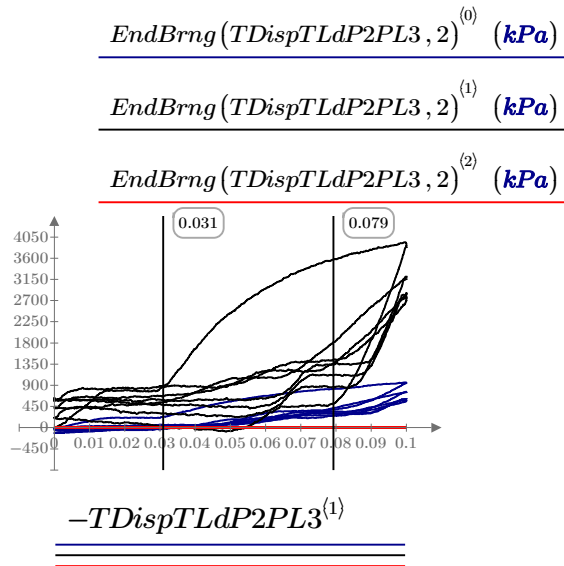


Fig D 73. End Bearing vs Depth for P2 PL3

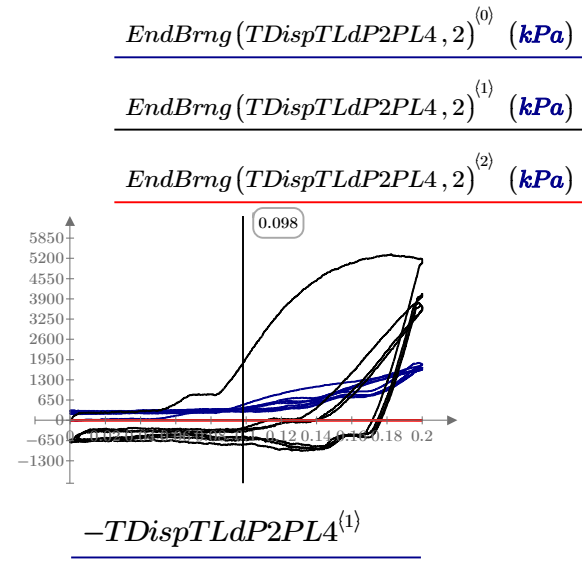


Fig D 74. End Bearing vs Depth for P2 PL4

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

Functions for calculating the EDR from the bearing resistances

```

BrngEDR (TDispTLdP0PL1 , BrngP2PL1 , Pseu1perS , IniTime , IniDisp , LoopNo , ShftNo) :=
    m ← TDispTLdP0PL1
    n ←  $\frac{BrngP2PL1}{kPa}$ 
    o ← TimeCycLoop (Pseu1perS , IniTime , IniDisp) - IniTime
    w ←  $-m^{(1)}$ 
    wmax ← max ( $-m^{(1)}$ )
    if ShftNo = 1
        q ←  $n^{(0)}$ 
        qmax ← max ( $n^{(0)}$ )
    else if ShftNo = 2
        q ←  $n^{(1)}$ 
        qmax ← max ( $n^{(1)}$ )
    else if ShftNo = 3
        q ←  $n^{(2)}$ 
        qmax ← max ( $n^{(2)}$ )
    if LoopNo = 1
        t1 ←  $m_{1,0} - IniTime$ 
        t2 ←  $o_1$ 
    else if LoopNo = 2
        t1 ←  $o_1$ 
        t2 ←  $o_2$ 
    else if LoopNo = 3
        t1 ←  $o_2$ 
        t2 ←  $o_3$ 
    else if LoopNo = 4
        t1 ←  $o_3$ 
        t2 ←  $o_4$ 
    tstart ← lookup (t1 , ( $m^{(0)} - IniTime$ ) , ( $m^{(0)} - IniTime$ ) , "near")
    tend ← lookup (t2 , ( $m^{(0)} - IniTime$ ) , ( $m^{(0)} - IniTime$ ) , "near")
    rowstart ← match (t1 , ( $m^{(0)} - IniTime$ ) , "near")
    rowend ← match (t2 , ( $m^{(0)} - IniTime$ ) , "near")
    for i ∈ rowstart0,0 .. rowend0,0
         $r_i \leftarrow \left( (w_i - w_{i-1}) \cdot \left( \frac{(q_i + q_{i-1})}{2} \right) \right)$ 
    area ←  $\sum r$ 
    EDR ← if qmax = 0
        0
    else if wmax = 0
        0
    else if area = 0
        0
    else
         $\frac{area}{qmax \cdot wmax}$ 
    s ← augment ((tstart + IniTime) , (tend + IniTime) , rowstart , rowend , qmax , wmax , area , EDR)
    EDR

```

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

Function for compiling EDR for the end bearing in loading cycles

$$BrngEDRPOPLSG(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, PileNo) := \begin{array}{l} q1 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1) \\ q2 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1) \\ q3 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1) \\ q4 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1) \\ r1 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2) \\ r2 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2) \\ r3 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2) \\ r4 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2) \\ w1 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 3) \\ w2 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 3) \\ w3 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 3) \\ w4 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3) \\ \text{augment}(\text{stack}(q1, q2, q3, q4), \text{stack}(r1, r2, r3, r4), \text{stack}(w1, w2, w3, w4)) \end{array}$$

$$NoLoop := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

$$BrngEDRP2PL1 := BrngEDRPOPLSG(TDispTLdP2PL1, BrngP2PL1, PseuPL1H, IniTimePL1H, 2) = \begin{bmatrix} 0.285 & 0.304 & 0 \\ -0.033 & -0.041 & 0 \\ -0.072 & -0.051 & 0 \\ -0.094 & -0.067 & 0 \end{bmatrix}$$

$$BrngEDRP2PL2 := BrngEDRPOPLSG(TDispTLdP2PL2, BrngP2PL2, PseuPL2H, IniTimePL2H, 2) = \begin{bmatrix} 0.745 & 0.742 & 0 \\ 0.501 & 0.448 & 0 \\ 0.426 & 0.387 & 0 \\ 0.498 & 0.416 & 0 \end{bmatrix}$$

$$BrngEDRP2PL3 := BrngEDRPOPLSG(TDispTLdP2PL3, BrngP2PL3, PseuPL3H, IniTimePL3H, 2) = \begin{bmatrix} 0.327 & 0.426 & 0 \\ 0.022 & 0.128 & 0 \\ -0.008 & 0.077 & 0 \\ 0.012 & 0.068 & 0 \end{bmatrix}$$

Appendix D

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P2 Helix Pile

$$BrngEDRP2PLA := BrngEDRPOPLSG(TDispTLdP2PLA, BrngP2PLA, PseuPLAH, IniTimePLAH, 2) = \begin{bmatrix} 0.085 & 0.519 & 0 \\ 0.07 & 0.148 & 0 \\ 0.039 & 0.106 & 0 \\ 0.041 & 0.097 & 0 \end{bmatrix}$$

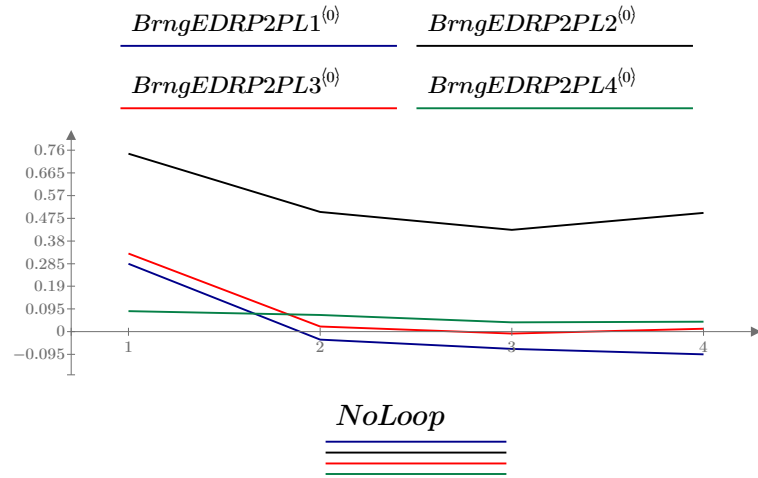


Fig D 75. Shaft EDR vs No of loops Helix Location 1 SG 1

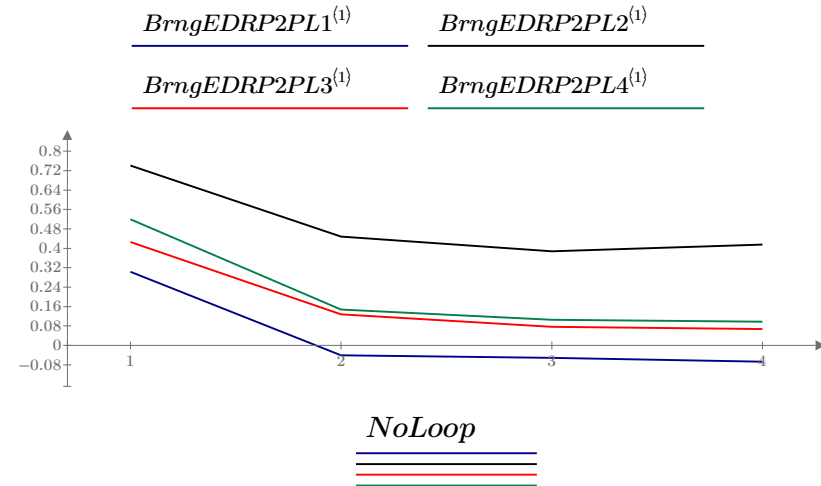


Fig D 76. Shaft EDR vs No of loops Helix Location 2 SG 2-3

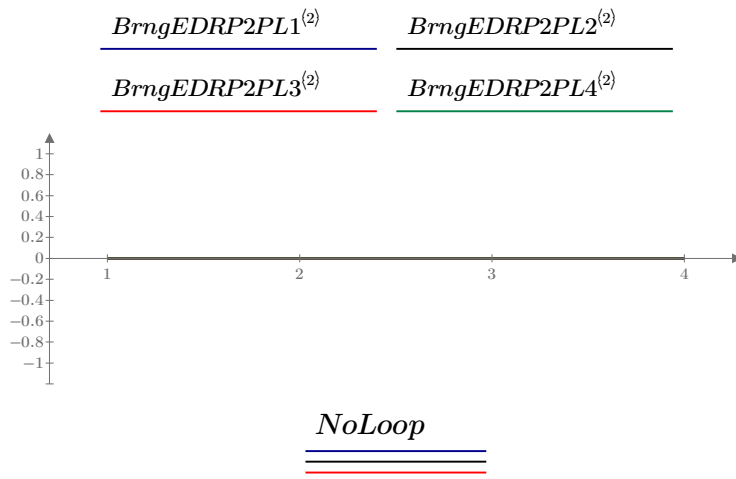
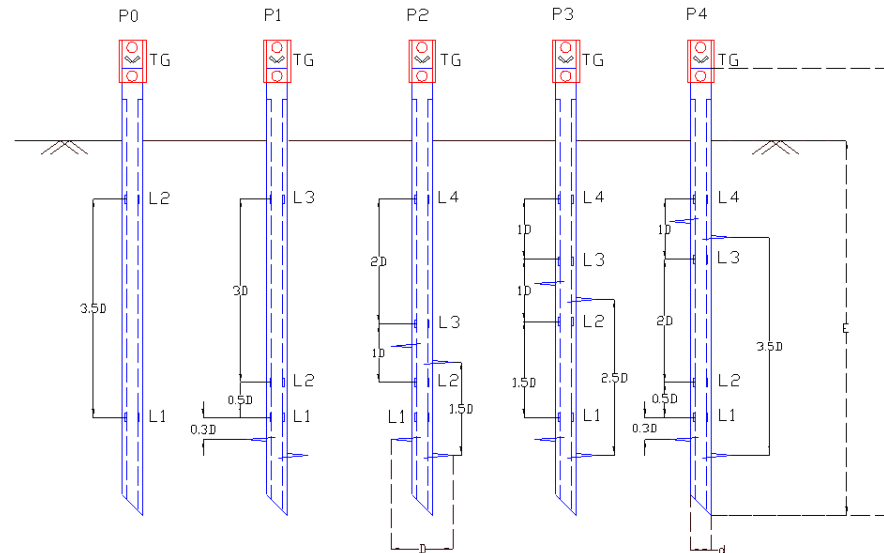


Fig D 77. EDR vs No of loops Helix Location 3 SG 3-4



Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

1. Introduction

The series of sheets in Appendix B contains the data conversion and processing procedures specifically for the NI02 centrifuge test series on P3 Helix Pile. For the data conversion procedures, the raw data files were first corrected by subtracting the initial value of pre spin data depending on file index. The data were then converted into engineering units through recalibrations of the strain gauges in the centrifuge data logger.

2. HBM Data Conversion

HBM data were recorded by the HBM Data Logger connected to the main computer unit of the GeoCerf centrifuge.

2.1 General Information

2.1.1 Model Pile Dimensions

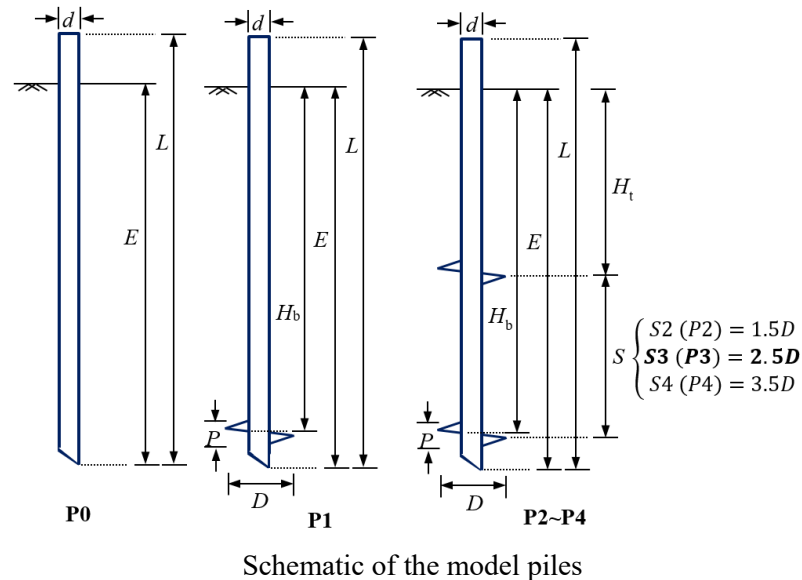
$L := 271.8 \text{ mm}$	Length of the Pile
$d := 12.7 \text{ mm}$	Diameter of the shaft
$D := 38.1 \text{ mm}$	Diameter of the helix
$E := 169.1 \text{ mm}$	Embedment depth of pile
$H_b := 150 \text{ mm}$	Depth to bottom helix
$H_t := [150] \text{ mm}$	Depth to top helix
$P_s := \pi \cdot D = 0.12 \text{ m}$	Perimeter of the Helical Pile Shaft
$H_{eff} := (H_b - D)$	Effective Shaft Length
$P := 12.7 \text{ mm}$	Pitch of the helix

2.1.2 Properties of Sand

$\gamma := 16.1 \frac{\text{kN}}{\text{m}^3}$	Unit Weight
$\varphi := 31.2 \text{ deg}$	CV Friction Angle
$\delta := \left(\frac{3}{4} \cdot \varphi\right) = 23.4 \text{ deg}$	CV Dilation Angle

2.1.3 Centrifuge Scale

$NoSGages := 4$	1 refers to the Strain Gage at the bottom and 4 the Strain Gage at the top of the pile; Total No of Strain Gages: P0=2, P1=3, P2 to P4= 4
$Nscale := 20$	Centrifuge g-level



Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

$sclfac := [1 \ 2 \ 3]$ Centrifuge scale factor N^{scale} , 1 for displacement, 2 for force, 3 for Torque

2.1.4 Pseudostatic Loading Stages

2.1.4.1 Actuator Scale Factors

$$RateScale := \frac{8}{\frac{mm}{sec}} \quad \leq 1V8 = 1mm/sec$$

$$DistanScale := \frac{64000}{mm} \quad \leq 1D64000 = 1mm$$

2.1.4.2 Pseudostatic Loading Stages for Helix Piles (P1 to P4)

$$LDisp := \begin{bmatrix} 0.01 \\ 0.02 \\ 0.05 \\ 0.10 \\ 0.10 \end{bmatrix} \quad LNoLoop := \begin{bmatrix} 8 \\ 8 \\ 8 \\ 8 \\ 1 \end{bmatrix} \quad PsdoTLag := 5 \text{ s} \quad LRate := \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 0.33 \end{bmatrix} \frac{mm}{min}$$

$$LTime(Dia) := \left\| \begin{array}{l} \text{for } i \in 0, 1 \dots \text{rows}(LDisp) - 1 \\ \left\| \begin{array}{l} 2 \cdot LDisp_i \cdot Dia \cdot LNoLoop_i \\ k_i \leftarrow \frac{\quad}{LRate_i} + (PsdoTLag \cdot (LNoLoop_i - 1)) \end{array} \right\| \\ k \end{array} \right\|$$

$$LTime(D) = \begin{bmatrix} 400.76 \\ 766.52 \\ 1863.8 \\ 3692.6 \\ 1385.455 \end{bmatrix} \text{ s} \quad LTime(d) = \begin{bmatrix} 156.92 \\ 278.84 \\ 644.6 \\ 1254.2 \\ 461.818 \end{bmatrix} \text{ s}$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

2.2 Calibration of the Strain Gages in HBM Data Logger

2.2.1 Calibration of Axial Strain Gages

RawDataCalib := READEXCEL (“..\Finalized NI01\Calibration SGages HBM Centrifuge Corrected.xlsx”, “Sheet1!A1:G12”)

$$\text{RawDataCalib} = \begin{bmatrix} 4.427 & 1 & 0.076 & 0.104 & 0.149 & 0.098 & 0.132 \\ 7.97 & 1 & 0.152 & 0.171 & 0.23 & 0.195 & 0.244 \\ 13.606 & 1 & 0.391 & 0.295 & 0.343 & 0.287 & 0.336 \\ 4.427 & 2 & 0.048 & 0.06 & 0.078 & 0.091 & 0.1 \\ 7.97 & 2 & 0.053 & 0.114 & 0.114 & 0.136 & 0.194 \\ 13.606 & 2 & 0.088 & 0.214 & 0.161 & 0.225 & 0.231 \\ 4.427 & 3 & 0 & 0.043 & 0.028 & 0.052 & 0.037 \\ 7.97 & 3 & 0 & 0.063 & 0.151 & 0.087 & 0.078 \\ 13.606 & 3 & 0 & 0.127 & 0.199 & 0.149 & 0.112 \\ 4.427 & 4 & 0 & 0 & 0.089 & 0.035 & 0.028 \\ 7.97 & 4 & 0 & 0 & 0.109 & 0.067 & 0.055 \\ 13.606 & 4 & 0 & 0 & 0.145 & 0.127 & 0.141 \end{bmatrix}$$

Colm 0 represents calibration loads in kg, Colm 1 represents Strain Gage Number, Colm 2-6 represents Strain Gage HBM readings for piles P0,P1,P2,P3 and P4 respectively

CmbLdAx := RawDataCalib⁽⁰⁾ **kg · g** Load Combinations

CalibdataPile := submatrix(RawDataCalib, 0, rows(RawDataCalib) - 1, 2, 6) · 10⁻³ · $\frac{mV}{V}$ HBM Strain Gage Data

Function for Calibration factor for all strain gages in each pile

$$CF := \begin{bmatrix} \text{for } i \in 0, 1 \dots \text{rows}(\text{CalibdataPile}) - 1 \\ \text{for } j \in 0, 1 \dots \text{cols}(\text{CalibdataPile}) - 1 \\ k_{i,j} \leftarrow \text{CmbLdAx}_{i,0} \\ q_{i,j} \leftarrow \text{CalibdataPile}_{i,j} \\ m_{i,j} \leftarrow \text{if } q_{i,j} = 0 \\ \quad 0 \\ \text{else} \\ \quad \frac{k_{i,j}}{q_{i,j}} \end{bmatrix} = \begin{bmatrix} 571.237 & 417.443 & 291.369 & 443 & 328.894 \\ 514.204 & 457.07 & 339.822 & 400.815 & 320.324 \\ 341.251 & 452.303 & 389.007 & 464.91 & 397.111 \\ 904.459 & 723.567 & 556.59 & 477.077 & 434.14 \\ 1474.698 & 685.605 & 685.605 & 574.699 & 402.881 \\ 1516.242 & 623.501 & 828.753 & 593.019 & 577.616 \\ 0 & 1009.629 & 1550.501 & 834.885 & 1173.352 \\ 0 & 1240.619 & 517.609 & 898.379 & 1002.038 \\ 0 & 1050.624 & 670.499 & 895.499 & 1191.333 \\ 0 & 0 & 487.798 & 1240.401 & 1550.501 \\ 0 & 0 & 717.055 & 1166.552 & 1421.073 \\ 0 & 0 & 920.202 & 1050.624 & 946.307 \end{bmatrix} \frac{kN}{mV}$$

Calibration Factor. Here, the columns represents the Piles from P0 to P4 (left to right) and the rows represents the Strain Gage readings SG1 to SG4 (top to bottom) for three load combinations

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

2.2.1 Calibration of Torque Strain Gages

RawDataTorque := READEXCEL (“..\Finalized NI01\Calibration Torque S Gages HBM Centrifuge .xlsx”, “Sheet1!J34:K36”)

$$\text{RawDataTorque} = \begin{bmatrix} 0.144 & 0.022 \\ 0.206 & 0.03 \\ 0.35 & 0.052 \end{bmatrix} \quad \text{CmbLdTr} := \text{RawDataTorque}^{(0)} \text{ N} \cdot \text{m} \quad \text{CalibdataTr} := \text{RawDataTorque}^{(1)} \cdot 10^{-3} \cdot \frac{\text{mV}}{\text{V}}$$

Function for Calibration factor for all torsional load on strain gages in each pile

$$\text{CFTr} := \left\| \begin{array}{l} \text{for } i \in 0, 1 \dots \text{rows}(\text{CalibdataTr}) - 1 \\ \quad \left\| \begin{array}{l} \text{for } j \in 0, 1 \dots \text{cols}(\text{CalibdataTr}) - 1 \\ \quad \left\| \begin{array}{l} k_{i,j} \leftarrow \text{CmbLdTr}_{i,0} \\ q_{i,j} \leftarrow \text{CalibdataTr}_{i,j} \\ m_{i,j} \leftarrow \text{if } q_{i,j} = 0 \\ \quad \left\| 0 \\ \quad \text{else} \\ \quad \left\| \frac{k_{i,j}}{q_{i,j}} \end{array} \right\| \end{array} \right\| \end{array} \right\| \end{array} \right\| = \begin{bmatrix} 6.674 \\ 6.813 \\ 6.763 \end{bmatrix} \text{ m} \cdot \frac{\text{kN}}{\frac{\text{mV}}{\text{V}}}$$

2.3 Pseudostatic Cyclic Centrifuge Test on Piles

Five piles were tested in compression and four piles were tested in tension in two separate model boxes two ascertain the axial load transfer mechanism within the pile.

2.3.1 Pseudostatic Cyclic Displacement Time History

$$\begin{array}{llll} \text{Lag} := 5 & \text{LagCyc} := 100 & \text{LoadCycRate} := 1 \frac{\text{mm}}{\text{min}} = 0.017 \frac{\text{mm}}{\text{s}} & \text{LoadCompRate} := 0.33 \frac{\text{mm}}{\text{min}} = 0.006 \frac{\text{mm}}{\text{s}} \\ & & \text{Actuator Loading rate in cyclic} & \text{Actuator Loading rate in compression} \end{array}$$

$$\text{NormDisp} := \begin{bmatrix} 0.01 \\ 0.02 \\ 0.05 \\ 0.1 \\ 0.2 \end{bmatrix}$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

Function for calculating time required for each pseudostatic load

$$\begin{aligned}
 \text{Time}(Dia) := & \text{for } j \in 0, 1..3 \\
 & \text{for } i \in 0, 1..4 \\
 & k \leftarrow \text{NormDisp} \\
 & p \leftarrow \frac{Dia}{m} \\
 & z \leftarrow \frac{LoadCycRate}{\frac{m}{s}} \\
 & x \leftarrow \frac{LoadCompRate}{\frac{m}{s}} \\
 & q_{0,0} \leftarrow k_{0,0} \cdot \frac{p}{z} \\
 & q_{1,0} \leftarrow k_{1,0} \cdot \frac{p}{z} \\
 & q_{2,0} \leftarrow k_{2,0} \cdot \frac{p}{z} \\
 & q_{3,0} \leftarrow k_{3,0} \cdot \frac{p}{z} \\
 & q_{4,0} \leftarrow k_{4,0} \cdot \frac{p}{x} \\
 & q
 \end{aligned}$$

$$\text{TimeHelix} := \text{Time}(D) = \begin{bmatrix} 22.86 \\ 45.72 \\ 114.3 \\ 228.6 \\ 1385.455 \end{bmatrix}$$

$$\text{TimeShaft} := \text{Time}(d) = \begin{bmatrix} 7.62 \\ 15.24 \\ 38.1 \\ 76.2 \\ 461.818 \end{bmatrix}$$

Function for calculating initial time required for each pseudostatic load

$$\begin{aligned}
 \text{DispIniTime}(\text{DispHelixShaft}) := & \text{for } j \in 0, 1..3 \\
 & \text{for } i \in 0, 1..5 \\
 & q_{0,0} \leftarrow 0 \\
 & q_{1,0} \leftarrow \left((16 \cdot \text{DispHelixShaft}_{0,0}) + (7 \cdot \text{Lag}) + \text{LagCyc} \right) \\
 & q_{2,0} \leftarrow q_{1,0} + \left((16 \cdot \text{DispHelixShaft}_{1,0}) + (7 \cdot \text{Lag}) + (\text{LagCyc}) \right) \\
 & q_{3,0} \leftarrow q_{2,0} + \left((16 \cdot \text{DispHelixShaft}_{2,0}) + (7 \cdot \text{Lag}) + (\text{LagCyc}) \right) \\
 & q_{4,0} \leftarrow q_{3,0} + \left((16 \cdot \text{DispHelixShaft}_{3,0}) + (7 \cdot \text{Lag}) + (\text{LagCyc}) \right) \\
 & q
 \end{aligned}$$

$$\text{IniTimeHelix} := \text{DispIniTime}(\text{TimeHelix}) = \begin{bmatrix} 0 \\ 500.76 \\ 1367.28 \\ 3331.08 \\ 7123.68 \end{bmatrix}$$

$$\text{IniTimeShaft} := \text{DispIniTime}(\text{TimeShaft}) = \begin{bmatrix} 0 \\ 256.92 \\ 635.76 \\ 1380.36 \\ 2734.56 \end{bmatrix}$$

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

$PseuPL1H := \begin{bmatrix} TimeHelix_{0,0} & NormDisp_{0,0} \end{bmatrix}$	$IniTimePL1H := DispIniTime(TimeHelix)_{0,0} = 0$	$IniDisp := 0$
$PseuPL2H := \begin{bmatrix} TimeHelix_{1,0} & NormDisp_{1,0} \end{bmatrix}$	$IniTimePL2H := DispIniTime(TimeHelix)_{1,0} = 500.76$	
$PseuPL3H := \begin{bmatrix} TimeHelix_{2,0} & NormDisp_{2,0} \end{bmatrix}$	$IniTimePL3H := DispIniTime(TimeHelix)_{2,0} = 1.367 \cdot 10^3$	
$PseuPL4H := \begin{bmatrix} TimeHelix_{3,0} & NormDisp_{3,0} \end{bmatrix}$	$IniTimePL4H := DispIniTime(TimeHelix)_{3,0} = 3.331 \cdot 10^3$	
$PseuCLH := \begin{bmatrix} TimeHelix_{4,0} & NormDisp_{4,0} \end{bmatrix}$	$IniTimeCLH := DispIniTime(TimeHelix)_{4,0} = 7.124 \cdot 10^3$	
$PseuPL1S := \begin{bmatrix} TimeShaft_{0,0} & NormDisp_{0,0} \end{bmatrix}$	$IniTimePL1S := DispIniTime(TimeShaft)_{0,0} = 0$	$IniDisp := 0$
$PseuPL2S := \begin{bmatrix} TimeShaft_{1,0} & NormDisp_{1,0} \end{bmatrix}$	$IniTimePL2S := DispIniTime(TimeShaft)_{1,0} = 256.92$	
$PseuPL3S := \begin{bmatrix} TimeShaft_{2,0} & NormDisp_{2,0} \end{bmatrix}$	$IniTimePL3S := DispIniTime(TimeShaft)_{2,0} = 635.76$	
$PseuPL4S := \begin{bmatrix} TimeShaft_{3,0} & NormDisp_{3,0} \end{bmatrix}$	$IniTimePL4S := DispIniTime(TimeShaft)_{3,0} = 1.38 \cdot 10^3$	
$PseuCLS := \begin{bmatrix} TimeShaft_{4,0} & NormDisp_{4,0} \end{bmatrix}$	$IniTimeCLS := DispIniTime(TimeShaft)_{4,0} = 2.735 \cdot 10^3$	

Function for calculating time required for each cycle of the pseudostatic loads

```

TimeCycLoop(Pseu1per, IniTimeHelix, IniDisp) :=
  for j ∈ 0, 1 .. 3
    for i ∈ 0, 1 .. 40000
      q0,0 ← IniTimeHelix
      diff ← 0.1
      qi+1,0 ← qi,0 + diff
      q0,1 ← IniDisp
      Lag ← 5
      LagCyc ← 100
      k0,0 ← q0,0
      k1,0 ← ((q0,0 + 4 · Pseu1per0,0) + (2 · Lag))
      k2,0 ← ((q0,0 + 8 · Pseu1per0,0) + (4 · Lag))
      k3,0 ← ((q0,0 + 12 · Pseu1per0,0) + (6 · Lag))
      k4,0 ← ((q0,0 + 16 · Pseu1per0,0) + (7 · Lag) + LagCyc)
    k
  
```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

Function for calculating displacement increments for each cycles of the pseudostatic loads

```

DispCyc(Pseu1per, IniTimeHelix, IniDisp) :=
  for j ∈ 0, 1..3
  for i ∈ 0, 1..40000
    q0,0 ← IniTimeHelix
    diff ← 0.1
    qi+1,0 ← qi,0 + diff
    q0,1 ← IniDisp
    Lag ← 5
    LagCyc ← 100
    qi+1,0 ← if qi+1,0 ≤ ((q0,0 + 16 • Pseu1per0,0) + (7 • Lag) + LagCyc)
      || qi+1,0
    else if qi+1,0 > ((q0,0 + 16 • Pseu1per0,0) + (7 • Lag) + LagCyc)
      || break
    qi+1,1 ← if (qi+1,0) ≤ (q0,0 + 2 • Pseu1per0,0)
      ||  $\frac{(q_{i+1,0} - q_{0,0})}{((q_{0,0} + 2 \cdot Pseu1per_{0,0}) - q_{0,0})} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if (q0,0 + 2 • Pseu1per0,0) < qi+1,0 ≤ ((q0,0 + 2 • Pseu1per0,0) + Lag)
      || 2 • Pseu1per0,1
    else if ((q0,0 + 2 • Pseu1per0,0) + Lag) < qi+1,0 ≤ ((q0,0 + 4 • Pseu1per0,0) + Lag)
      ||  $\frac{(((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + Lag) - q_{i+1,0})}{(((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + Lag) - ((q_{0,0} + 2 \cdot Pseu1per_{0,0}) + Lag))} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if ((q0,0 + 4 • Pseu1per0,0) + Lag) < qi+1,0 ≤ ((q0,0 + 4 • Pseu1per0,0) + (2 • Lag))
      || q0,1
    else if ((q0,0 + 4 • Pseu1per0,0) + (2 • Lag)) < qi+1,0 ≤ ((q0,0 + 6 • Pseu1per0,0) + (2 • Lag))
      ||  $\frac{(q_{i+1,0} - ((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + (2 \cdot Lag)))}{(((q_{0,0} + 6 \cdot Pseu1per_{0,0}) + 2 \cdot Lag) - ((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + (2 \cdot Lag)))} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if ((q0,0 + 6 • Pseu1per0,0) + (2 • Lag)) < qi+1,0 ≤ ((q0,0 + 6 • Pseu1per0,0) + (3 • Lag))
      || 2 • Pseu1per0,1
    else if ((q0,0 + 6 • Pseu1per0,0) + (3 • Lag)) < qi+1,0 ≤ ((q0,0 + 8 • Pseu1per0,0) + (3 • Lag))
      ||  $\frac{(((q_{0,0} + 8 \cdot Pseu1per_{0,0}) + (3 \cdot Lag)) - q_{i+1,0})}{(((q_{0,0} + 8 \cdot Pseu1per_{0,0}) + (3 \cdot Lag)) - ((q_{0,0} + 6 \cdot Pseu1per_{0,0}) + (3 \cdot Lag)))} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if ((q0,0 + 8 • Pseu1per0,0) + (3 • Lag)) < qi+1,0 ≤ ((q0,0 + 8 • Pseu1per0,0) + (4 • Lag))
      || q0,1
    else if ((q0,0 + 8 • Pseu1per0,0) + (4 • Lag)) < qi+1,0 ≤ ((q0,0 + 10 • Pseu1per0,0) + (4 • Lag))

```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

8

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

Function for calculating displacement for the monotonic loads

```

DispComp(Pseu1per, IniTime, IniDisp) :=
  for j ∈ 0, 1..3
    for i ∈ 0, 1..40000
      q0,0 ← IniTime
      diff ← 0.1
      qi+1,0 ← qi,0 + diff
      qi+1,0 ← if (qi+1,0) ≤ (q0,0 + Pseu1per0,0)
                qi+1,0
                else if qi+1,0 > (q0,0 + Pseu1per0,0)
                break
      q0,1 ← IniDisp
      qi+1,1 ← if (qi+1,0) ≤ (q0,0 + Pseu1per0,0)
                (qi+1,0 - q0,0) / ((q0,0 + Pseu1per0,0) - q0,0) * (Pseu1per0,1)
                else
                qi+1,1
  q

```

$LdTimePL1H := DispCyc(PseuPL1H, IniTimePL1H, IniDisp)$

$LdTimePL2H := DispCyc(PseuPL2H, IniTimePL2H, IniDisp)$

$LdTimePL3H := DispCyc(PseuPL3H, IniTimePL3H, IniDisp)$

$LdTimePL4H := DispCyc(PseuPL4H, IniTimePL4H, IniDisp)$

$LdTimeCLH := DispComp(PseuCLH, IniTimeCLH, IniDisp)$

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

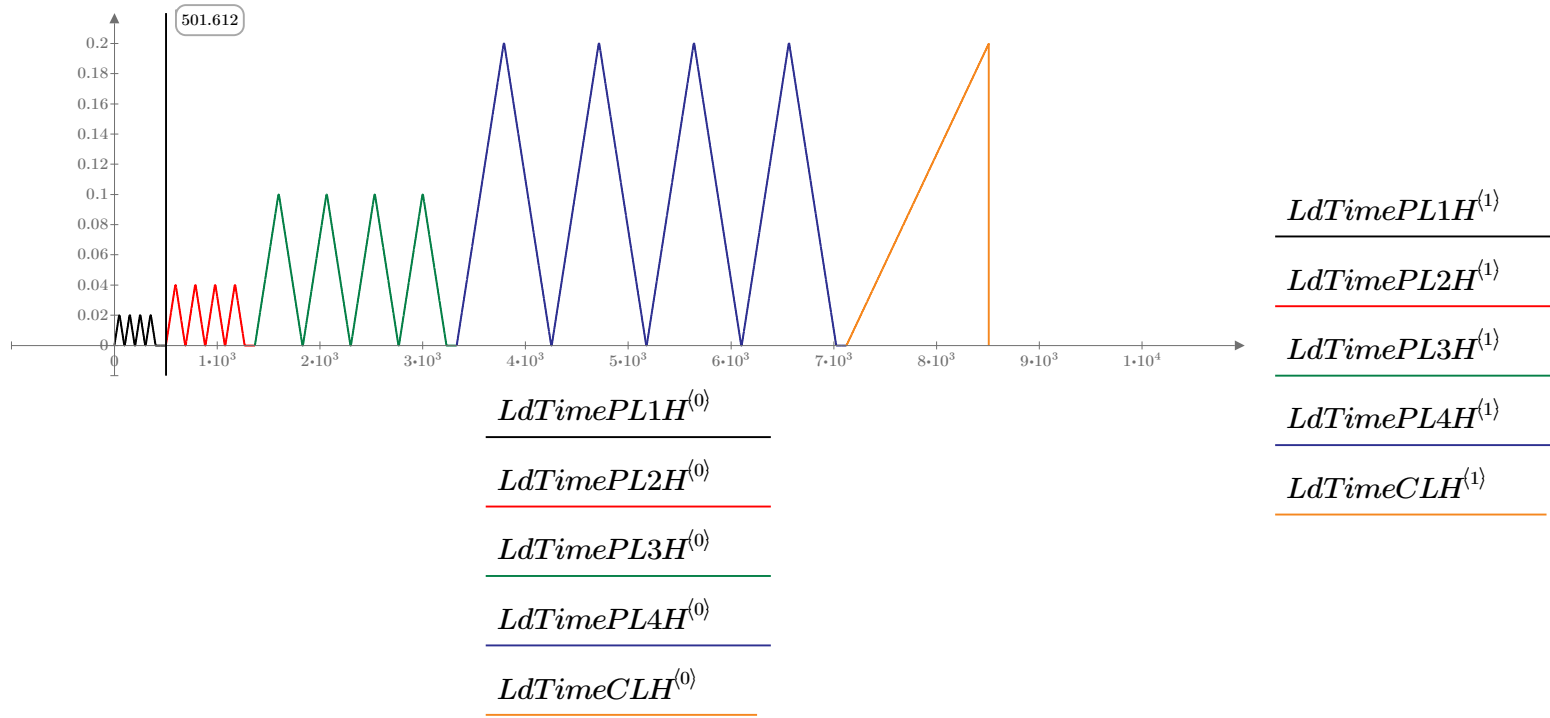


Fig E 1. DisplacementTime History for the Helix Piles

$$LdTimePL1S := DispCyc(PseuPL1S, IniTimePL1S, IniDisp)$$

$$LdTimePL2S := DispCyc(PseuPL2S, IniTimePL2S, IniDisp)$$

$$LdTimePL3S := DispCyc(PseuPL3S, IniTimePL3S, IniDisp)$$

$$LdTimePL4S := DispCyc(PseuPL4S, IniTimePL4S, IniDisp)$$

$$LdTimeCLS := DispComp(PseuCLS, IniTimeCLS, IniDisp)$$

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

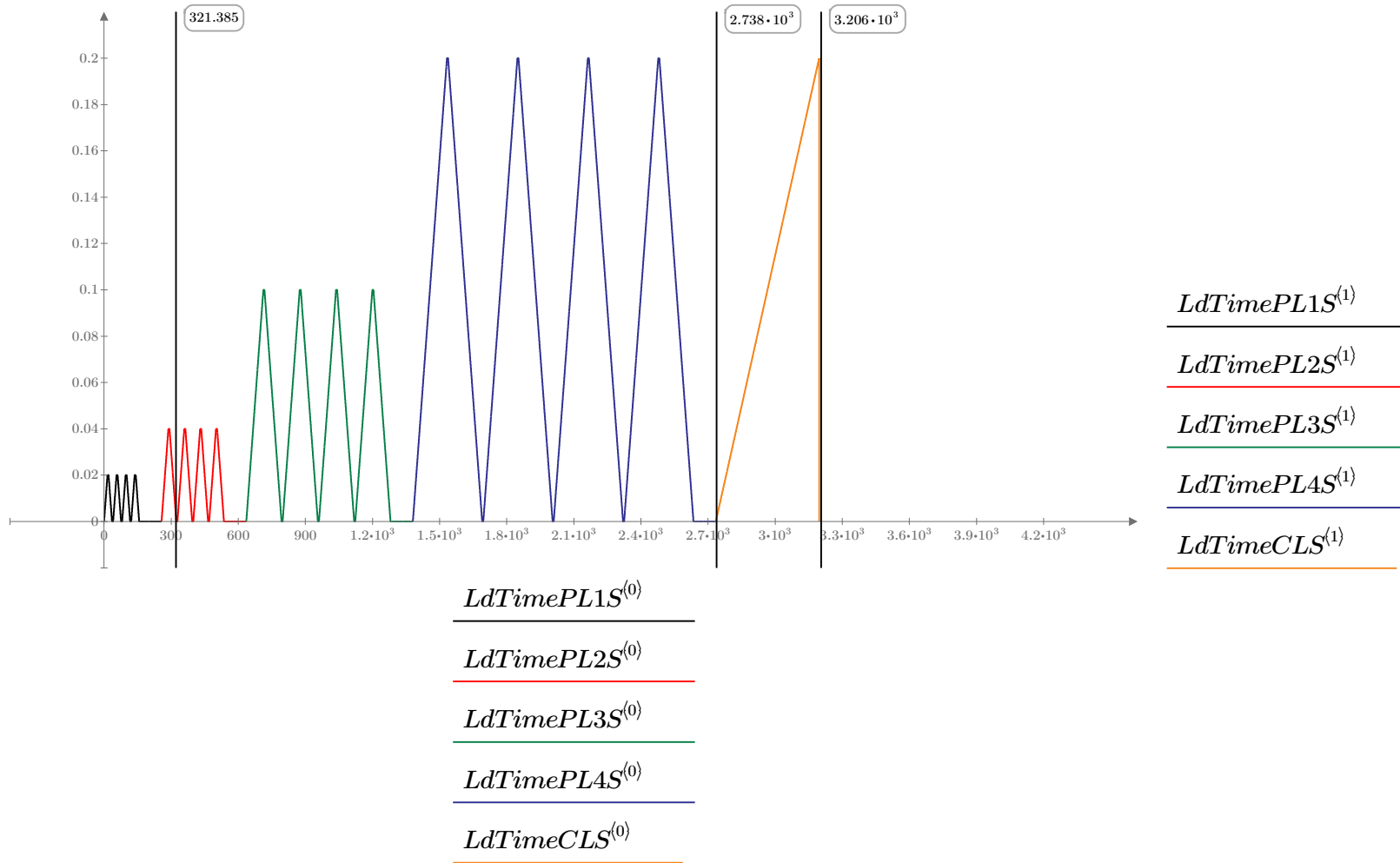


Fig E 2. DisplacementTime History for the smooth pile.

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

2.3.2 Axial Load vs Time

Function for determining the Axial Load Distribution in each pile

```

AxlLd (Rawdata , PileNum) :=
  for i ∈ 0, 1 .. rows (Rawdata) - 1
  for j ∈ 0, 1 .. cols (Rawdata) - 1
  || qi,j ← Rawdatai,j - Rawdata0,j
  || SG1i,0 ← qi,0 • mean (submatrix (CF, 0, 2, PileNum, PileNum)) • Nscalesclfac0,1
  || SG2i,1 ← qi,1 • mean (submatrix (CF, 3, 5, PileNum, PileNum)) • Nscalesclfac0,1
  || SG3i,2 ← qi,2 • mean (submatrix (CF, 6, 8, PileNum, PileNum)) • Nscalesclfac0,1
  || SG4i,3 ← qi,3 • mean (submatrix (CF, 9, 11, PileNum, PileNum)) • Nscalesclfac0,1
  || augment (SG1(0), SG2(1), SG3(2), SG4(3))

```

Function for determining the Time, Displacement Input to Time Axial Load Distribution output in each pile

```

TDispTLd (LdTime1perS, TimeP0, AxLdP0, LdNo) :=
  m ← TimeP0
  n ← AxLdP0
  p ← LdTime1perS
  q ← if LdNo = 1
  || m0
  || else if LdNo = 2
  || m1
  || else if LdNo = 3
  || m2
  || else if LdNo = 4
  || m3
  || else if LdNo = 5
  || m4
  k ← if LdNo = 1
  || n0
  || else if LdNo = 2
  || n1
  || else if LdNo = 3
  || n2
  || else if LdNo = 4
  || n3
  || else if LdNo = 5
  || n

```


Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

$$\begin{aligned}
 & \text{if } \text{rows}(p) > \text{rows}(q) \\
 & \quad q \\
 & \text{else if } \text{rows}(p) < \text{rows}(q) \\
 & \quad p \\
 & tdisp \leftarrow \text{submatrix}(LdTime1perS^{(0)}, 0, \text{rows}(o) - 1, 0, 0) \\
 & disp \leftarrow \text{submatrix}(-LdTime1perS^{(1)}, 0, \text{rows}(o) - 1, 0, 0) \\
 & tld \leftarrow \text{submatrix}\left(\frac{q}{s}, 0, \text{rows}(o) - 1, 0, 0\right) \\
 & ld1 \leftarrow \text{medsmooth}\left(\text{submatrix}\left(\frac{k^{(0)}}{kN}, 0, \text{rows}(o) - 1, 0, 0\right), 11\right) \\
 & ld2 \leftarrow \text{medsmooth}\left(\text{submatrix}\left(\frac{k^{(1)}}{kN}, 0, \text{rows}(o) - 1, 0, 0\right), 11\right) \\
 & ld3 \leftarrow \text{medsmooth}\left(\text{submatrix}\left(\frac{k^{(2)}}{kN}, 0, \text{rows}(o) - 1, 0, 0\right), 11\right) \\
 & ld4 \leftarrow \text{medsmooth}\left(\text{submatrix}\left(\frac{k^{(3)}}{kN}, 0, \text{rows}(o) - 1, 0, 0\right), 11\right) \\
 & \text{augment}(tdisp, disp, tld, ld1, ld2, ld3, ld4)
 \end{aligned}$$

There were four strain gages placed within the P3 pile. The following sub sections provides the details on the load distributions:

$$P3HBM := \begin{bmatrix} \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P3_PL1!A1:E5952"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P3_PL2!A1:E8067"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P3_PL3!A1:E20399"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P3_PL4!A1:E39157"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P3_CL!A1:E15432"}) \end{bmatrix} = \begin{bmatrix} [5952 \times 5] \\ [8067 \times 5] \\ [20399 \times 5] \\ [39157 \times 5] \\ [15432 \times 5] \end{bmatrix}$$

$$TimeP3 := \begin{bmatrix} \text{for } i \in 0, 1 \dots 4 \\ \quad q_i \leftarrow \text{submatrix}(P3HBM_i, 0, \text{rows}(P3HBM_i) - 1, 0, 0) \\ \quad s \end{bmatrix} = \begin{bmatrix} [5952 \times 1] s \\ [8067 \times 1] s \\ [20399 \times 1] s \\ [39157 \times 1] s \\ [15432 \times 1] s \end{bmatrix}$$

$$RawdataP3 := \begin{bmatrix} \text{for } i \in 0, 1 \dots 4 \\ \quad q_i \leftarrow \text{submatrix}(P3HBM_i, 0, \text{rows}(P3HBM_i) - 1, 1, 4) \\ \quad \frac{mV}{V} \end{bmatrix} = \begin{bmatrix} [5952 \times 4] \\ [8067 \times 4] \\ [20399 \times 4] \\ [39157 \times 4] \\ [15432 \times 4] \end{bmatrix}$$

$$AxLdP3 := \begin{bmatrix} \text{for } i \in 0, 1 \dots 4 \\ \quad q_i \leftarrow AxLd(RawdataP3_i, 3) \\ \quad kN \end{bmatrix} = \begin{bmatrix} [5952 \times 4] \\ [8067 \times 4] \\ [20399 \times 4] \\ [39157 \times 4] \\ [15432 \times 4] \end{bmatrix}$$

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

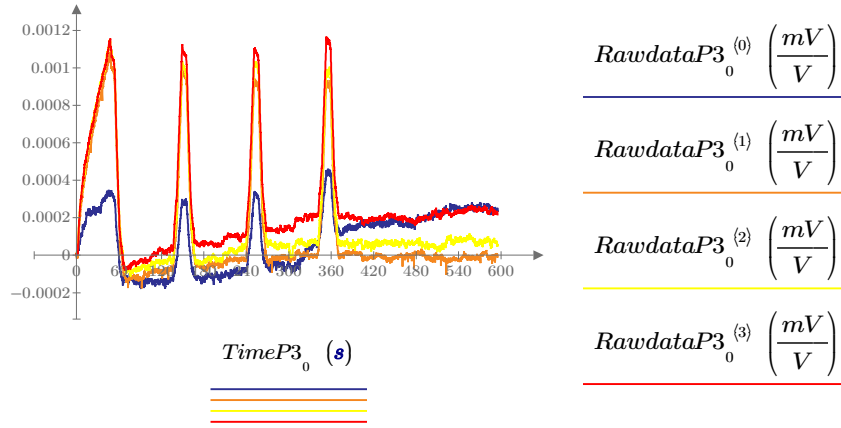


Fig E 3. Rawdata time history for compression pile P3 PL1

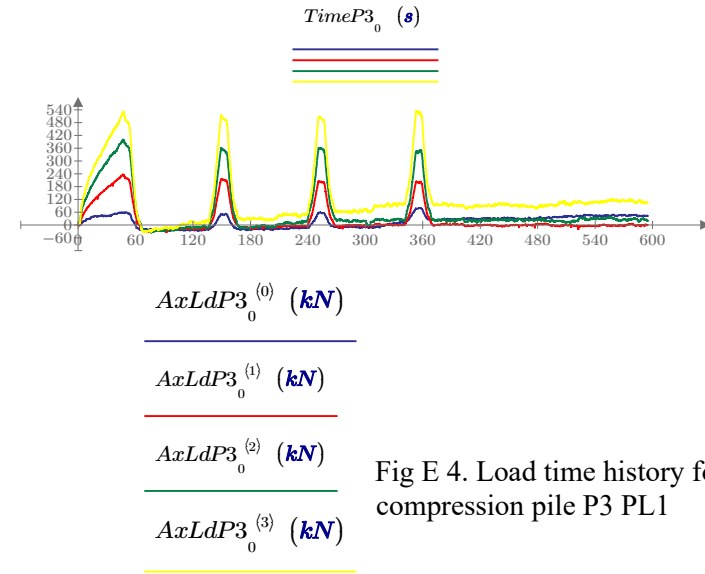


Fig E 4. Load time history for compression pile P3 PL1

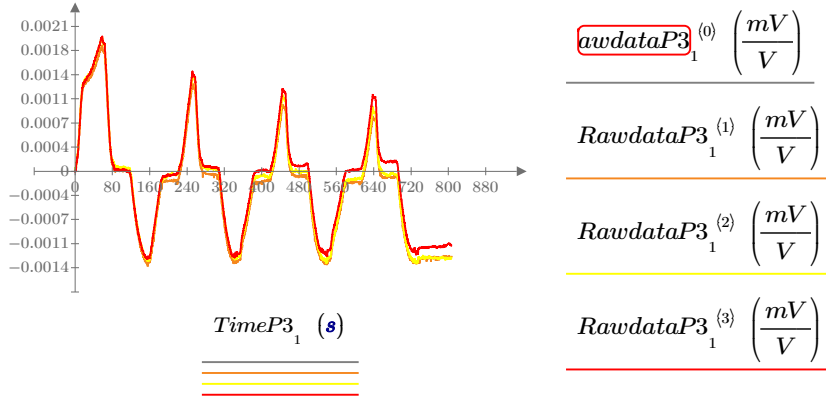


Fig E 5. Rawdata time history for compression pile P3 PL2

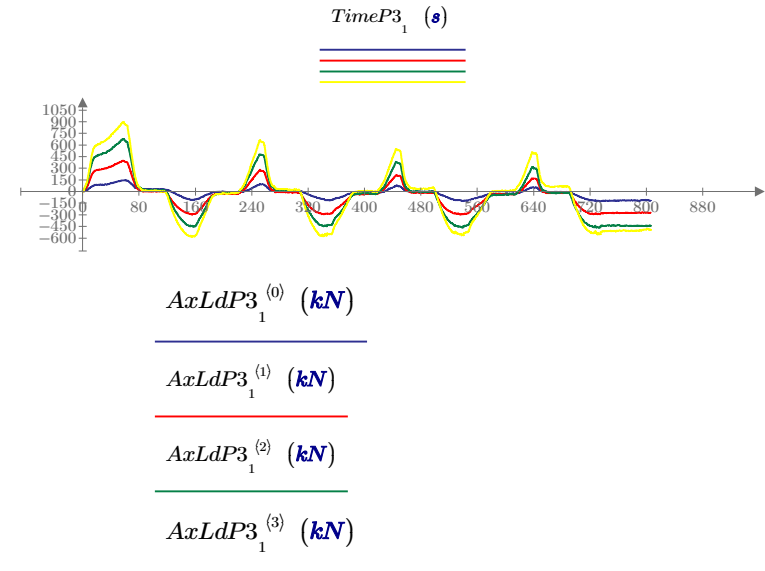


Fig E 6. Load time history for compression pile P3 PL2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

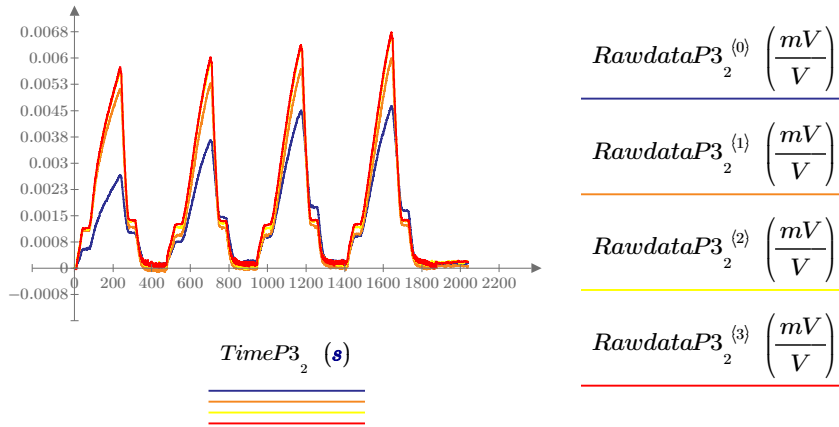


Fig E 7. Rawdata time history for compression pile P3 PL3

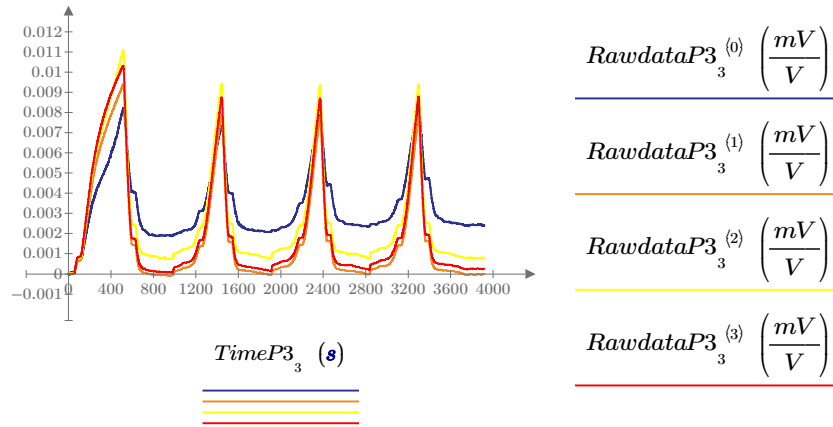


Fig E 9. Rawdata time history for compression pile P3 PL4

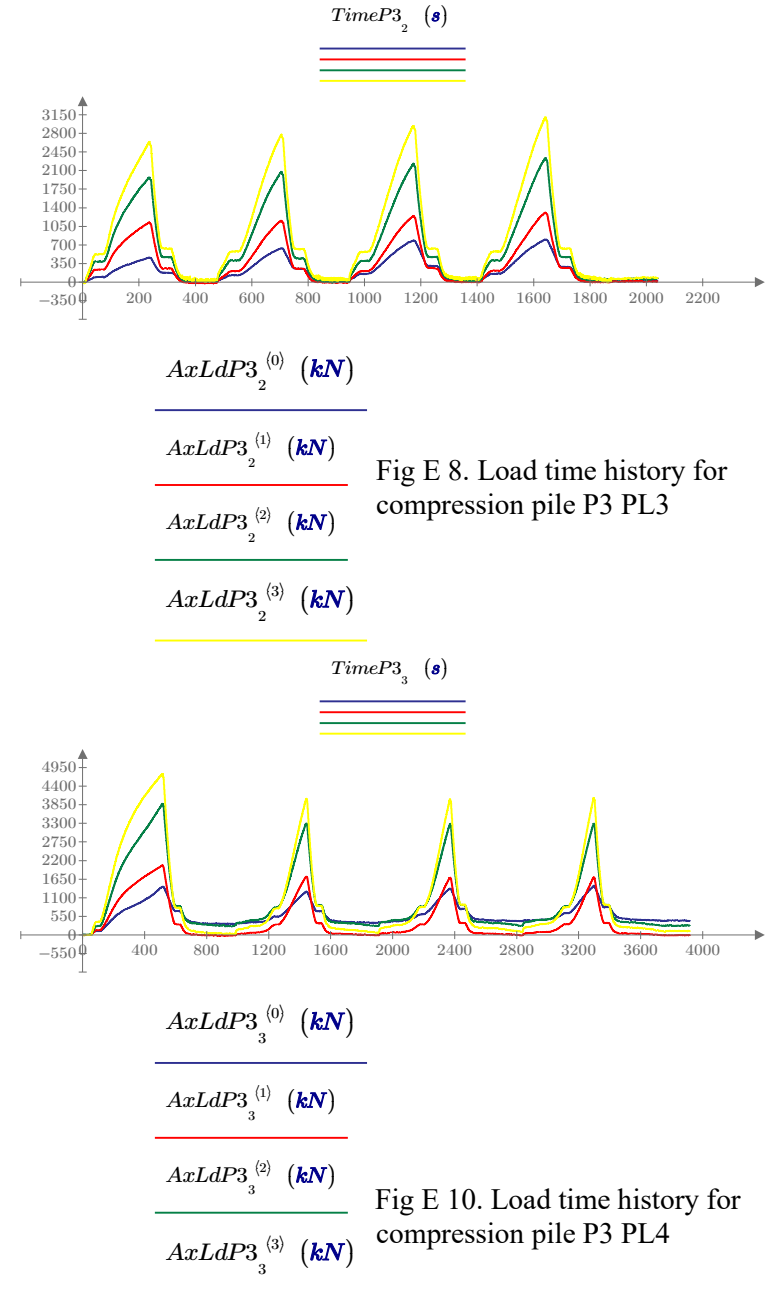


Fig E 8. Load time history for compression pile P3 PL3

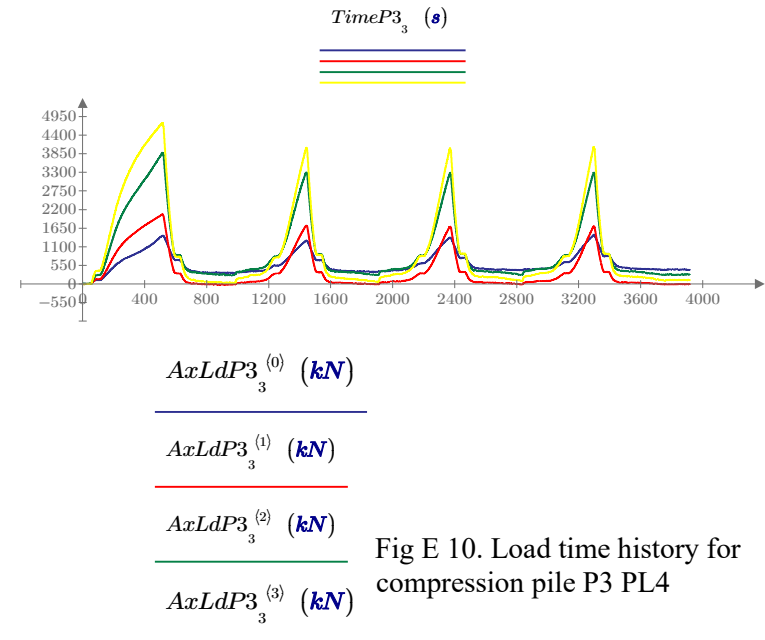


Fig E 10. Load time history for compression pile P3 PL4

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

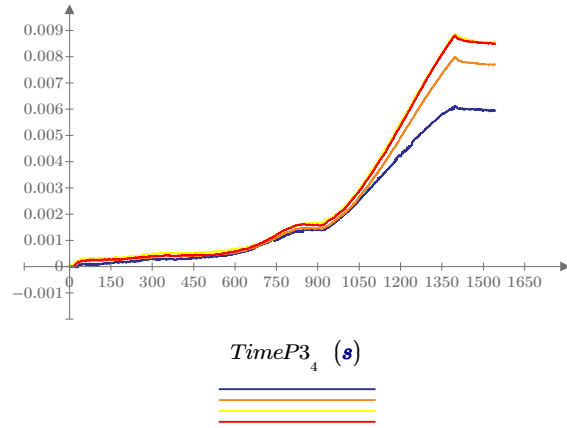


Fig E 11. Rawdata time history for compression pile P3 CL

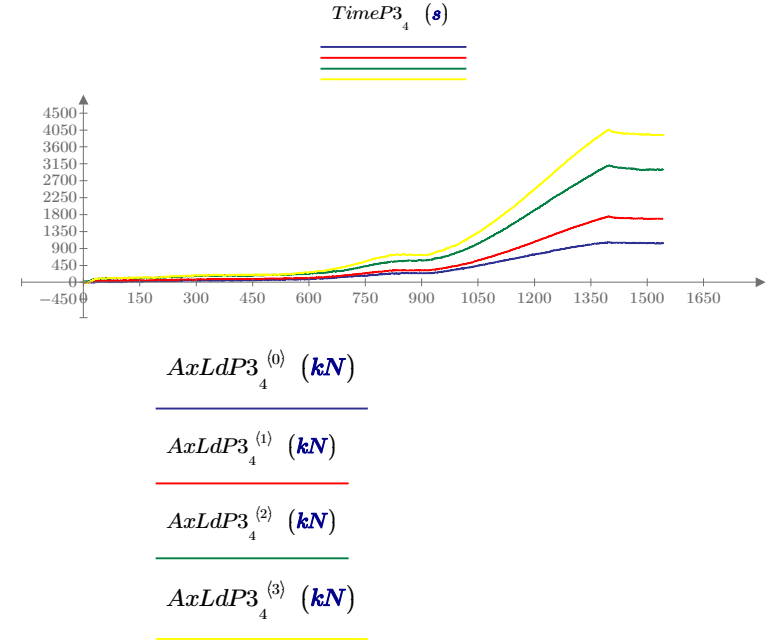


Fig E 12. Load time history for compression pile P3 CL

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for psuedostatic load PL1

$$TDispTLdP3PL1 := TDispTLd(LdTimePL1H, TimeP3, AxLdP3, 1) =$$

0	0	0	0	0.25	-1.422	2.02	1.993
1	0.1	$-4.374 \cdot 10^{-5}$	0.1	0.499	-1.58	2.02	2.657
2	0.2	$-8.749 \cdot 10^{-5}$	0.2	0.624	-1.264	3.031	2.657
3	0.3	$-1.312 \cdot 10^{-4}$	0.3	0.749	-0.948	4.041	2.657
4	0.4	$-1.75 \cdot 10^{-4}$	0.4	0.624	-0.948	4.293	2.657
5	0.5	$-2.187 \cdot 10^{-4}$	0.5	0.749	-0.948	4.546	2.657
6	0.6	$-2.625 \cdot 10^{-4}$	0.6	0.998	-0.948	5.051	3.322
7	0.7	$-3.062 \cdot 10^{-4}$	0.7	0.998	-1.58	5.051	3.322
8	0.8	$-3.5 \cdot 10^{-4}$	0.8	0.749	-1.896	5.051	3.322
9	0.9	$-3.937 \cdot 10^{-4}$	0.9	0.998	-1.896	6.061	3.322
10	1	$-4.374 \cdot 10^{-4}$	1	0.998	-1.58	6.566	3.322
11	1.1	$-4.812 \cdot 10^{-4}$	1.1	0.998	-1.264	6.566	3.322
⋮							⋮
5008							

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

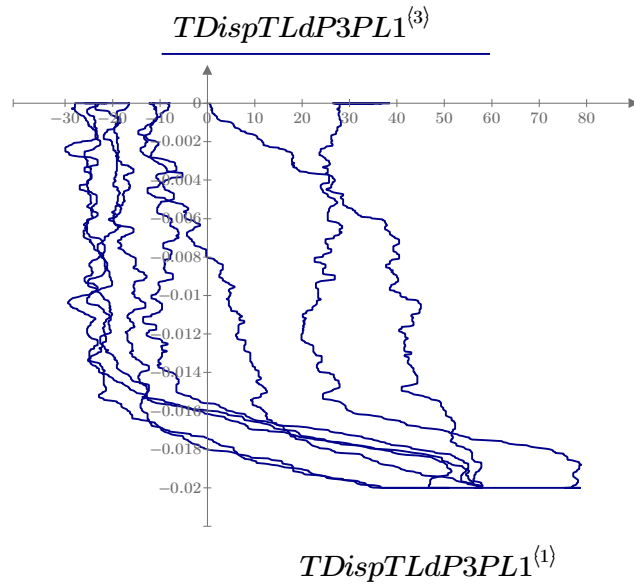


Fig E 13. Load displacement for compression pile P3 PL1 SG1

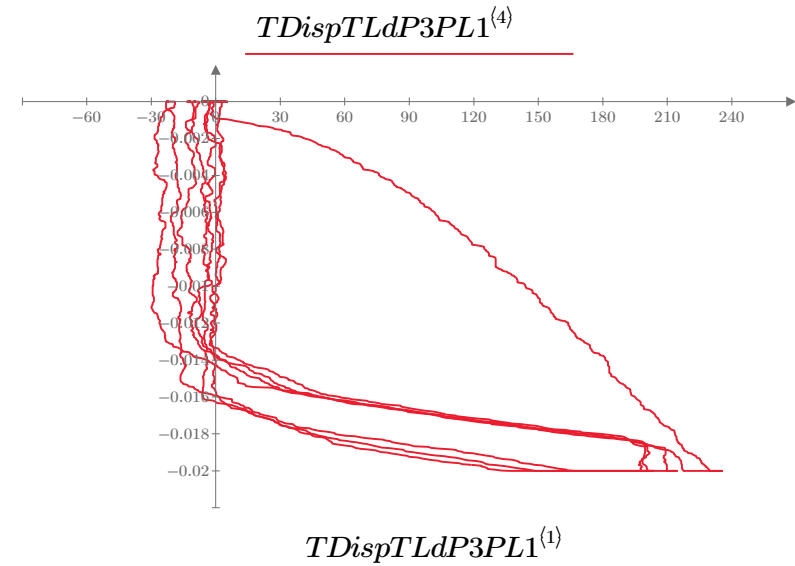


Fig E 14. Load displacement for compression pile P3 PL1 SG2

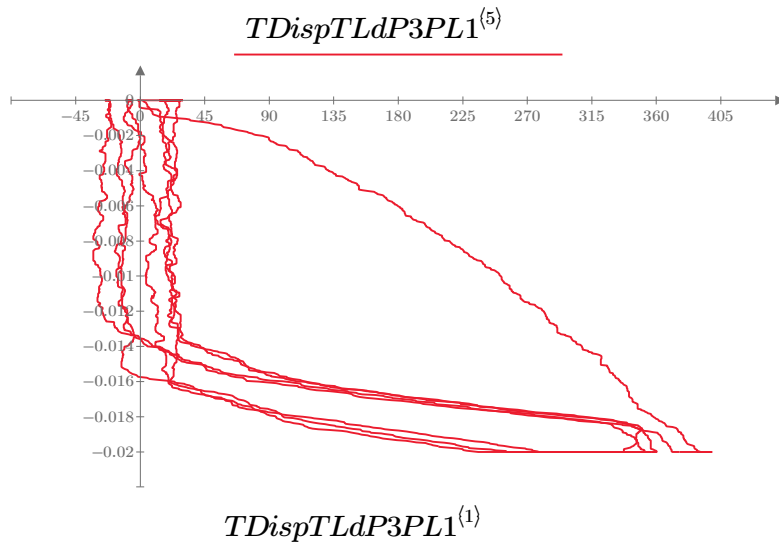


Fig E 15. Load displacement for compression pile P3 PL1 SG3

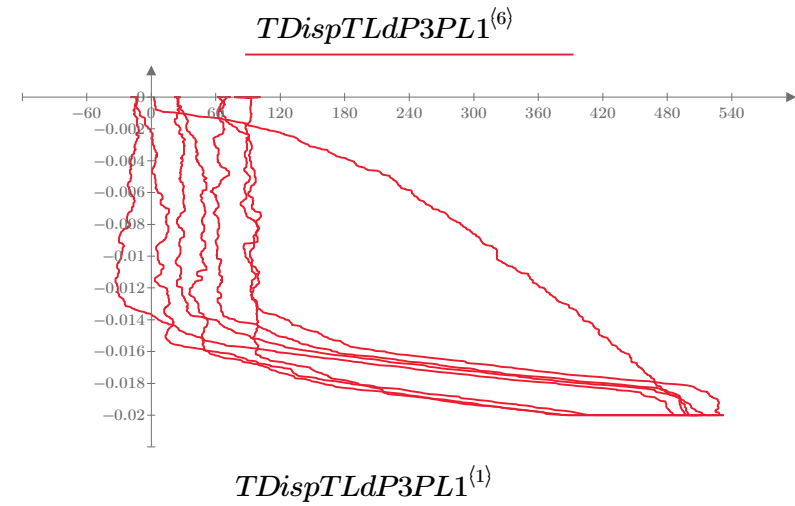


Fig E 16. Load displacement for compression pile P3 PL1 SG4

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for psuedostatic load PL2

$$TDispTLdP3PL2 := TDispTLd(LdTimePL2H, TimeP3, AxLdP3, 2) =$$

0	500.76	0	0	-1.509	0.948	17.679	-3.654
1	500.86	$-4.374 \cdot 10^{-5}$	0.1	-1.006	0.948	17.679	-3.322
2	500.96	$-8.749 \cdot 10^{-5}$	0.2	-0.629	1.106	17.931	-2.99
3	501.06	$-1.312 \cdot 10^{-4}$	0.3	-0.251	0.948	18.184	-2.657
4	501.16	$-1.75 \cdot 10^{-4}$	0.4	-0.126	0.948	18.689	-2.657
5	501.26	$-2.187 \cdot 10^{-4}$	0.5	0	0.948	18.184	-2.657
6	501.36	$-2.625 \cdot 10^{-4}$	0.6	-0.251	1.264	18.184	-2.657
7	501.46	$-3.062 \cdot 10^{-4}$	0.7	-1.006	1.264	17.679	-1.993
8	501.56	$-3.5 \cdot 10^{-4}$	0.8	-0.251	2.212	17.679	-1.993
9	501.66	$-3.937 \cdot 10^{-4}$	0.9	-0.251	2.528	17.679	1.329
10	501.76	$-4.374 \cdot 10^{-4}$	1	0	4.425	17.679	1.329
11	501.86	$-4.812 \cdot 10^{-4}$	1.1	0	4.425	16.164	5.315
⋮							⋮
8066							

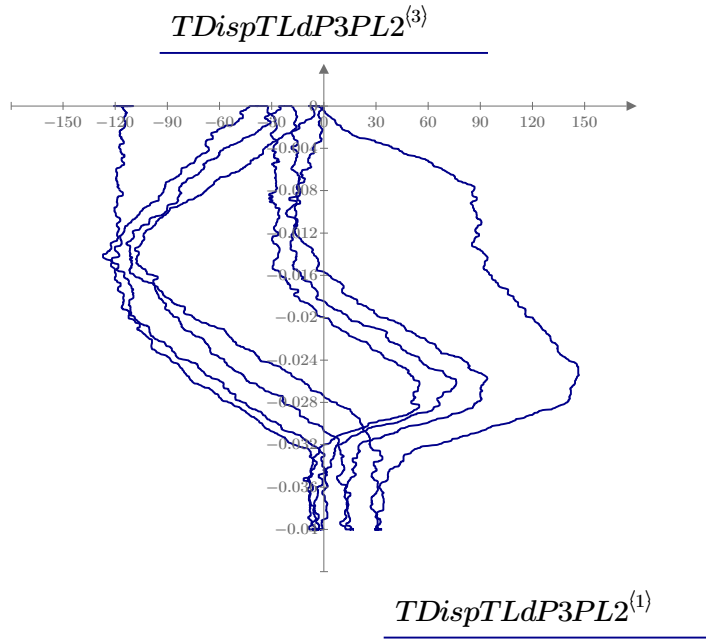


Fig E 17. Load displacement for compression pile P3 PL2 SG1

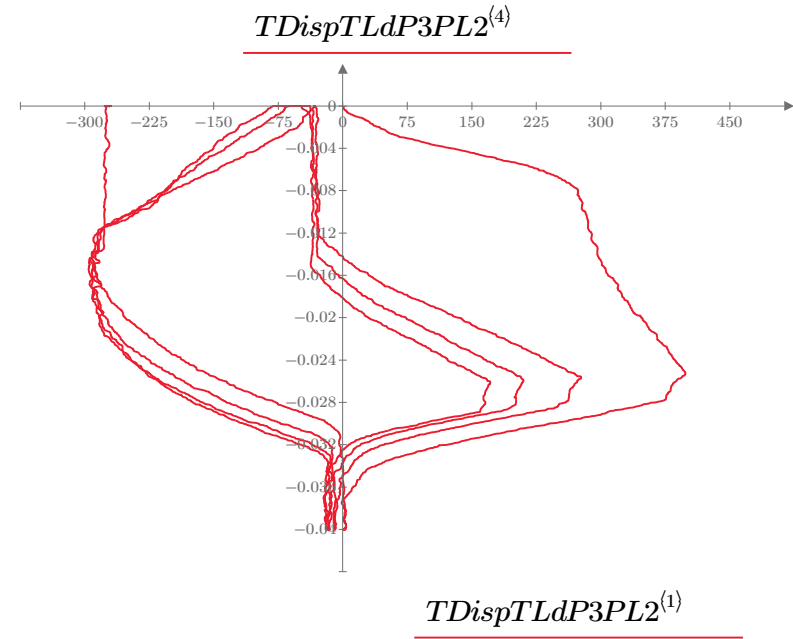


Fig E 18. Load displacement for compression pile P3 PL2 SG2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

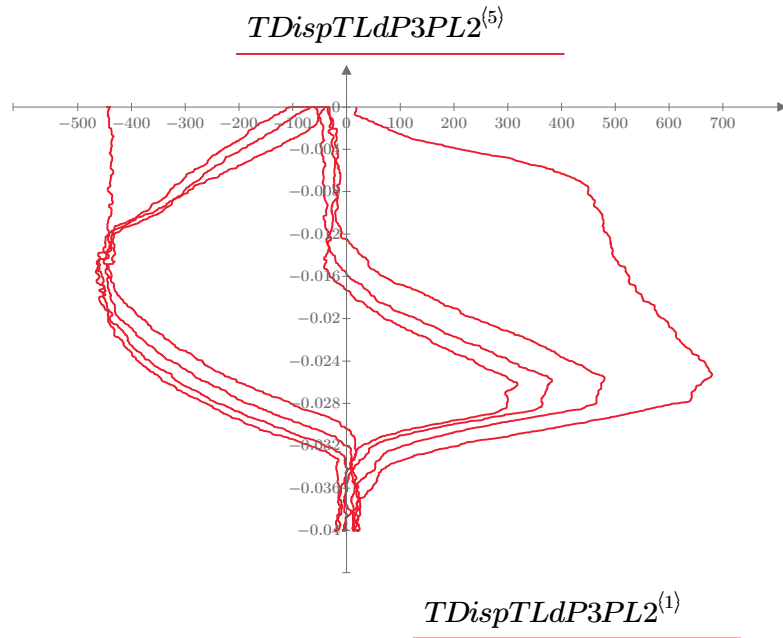


Fig E 19. Load displacement for compression pile P3 PL2 SG3

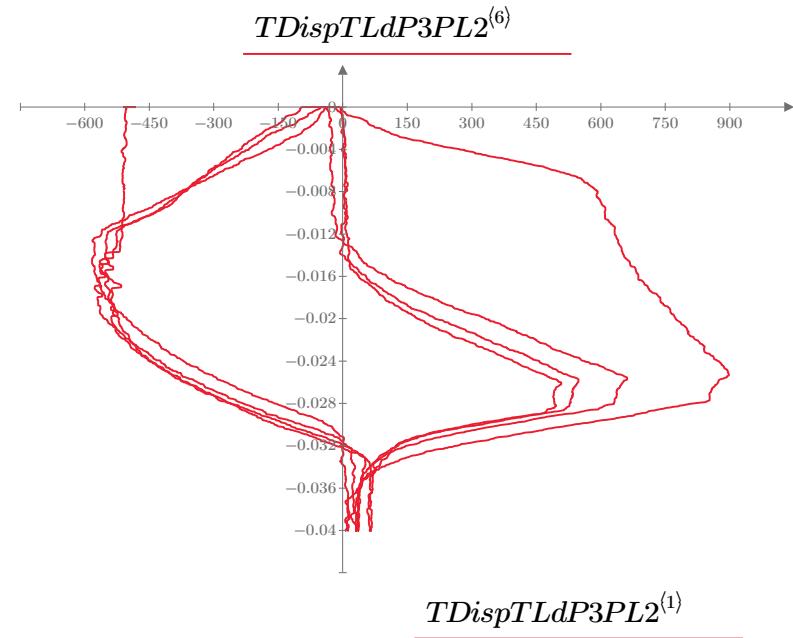


Fig E 20. Load displacement for compression pile P3 PL2 SG4

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for pseudostatic load PL3

$$TDispTLdP3PL3 := TDispTLd(LdTimePL3H, TimeP3, AxLdP3, 3) =$$

0	$1.367 \cdot 10^3$	0	0	-0.251	0.158	2.02	-4.983
1	$1.367 \cdot 10^3$	$-4.374 \cdot 10^{-5}$	0.1	0	0.316	1.01	-5.315
2	$1.367 \cdot 10^3$	$-8.749 \cdot 10^{-5}$	0.2	0	0.948	2.02	-4.983
3	$1.368 \cdot 10^3$	$-1.312 \cdot 10^{-4}$	0.3	0	1.58	1.01	-4.651
4	$1.368 \cdot 10^3$	$-1.75 \cdot 10^{-4}$	0.4	0	1.58	1.01	-4.651
5	$1.368 \cdot 10^3$	$-2.187 \cdot 10^{-4}$	0.5	0	1.58	1.01	-4.651
6	$1.368 \cdot 10^3$	$-2.625 \cdot 10^{-4}$	0.6	0	1.896	1.01	-4.651
7	$1.368 \cdot 10^3$	$-3.062 \cdot 10^{-4}$	0.7	0	1.896	1.01	-4.651
8	$1.368 \cdot 10^3$	$-3.5 \cdot 10^{-4}$	0.8	0	1.896	1.515	-4.651
9	$1.368 \cdot 10^3$	$-3.937 \cdot 10^{-4}$	0.9	0	1.896	1.515	-3.986
10	$1.368 \cdot 10^3$	$-4.374 \cdot 10^{-4}$	1	0	1.896	1.515	-3.986
11	$1.368 \cdot 10^3$	$-4.812 \cdot 10^{-4}$	1.1	0	1.896	1.515	-4.651
⋮							⋮

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

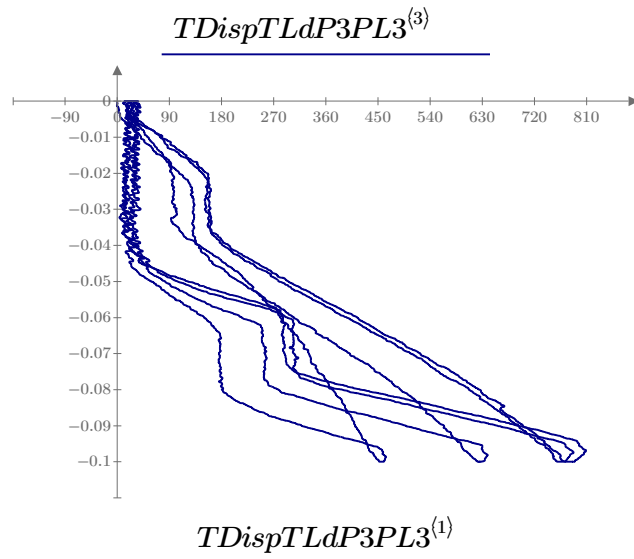


Fig E 21. Load displacement for compression pile P3 PL3 SG1

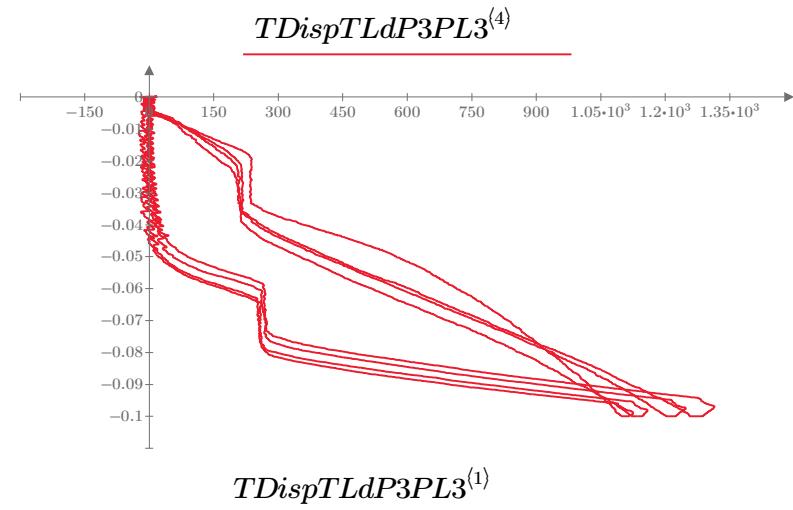


Fig E 22. Load displacement for compression pile P3 PL3 SG2

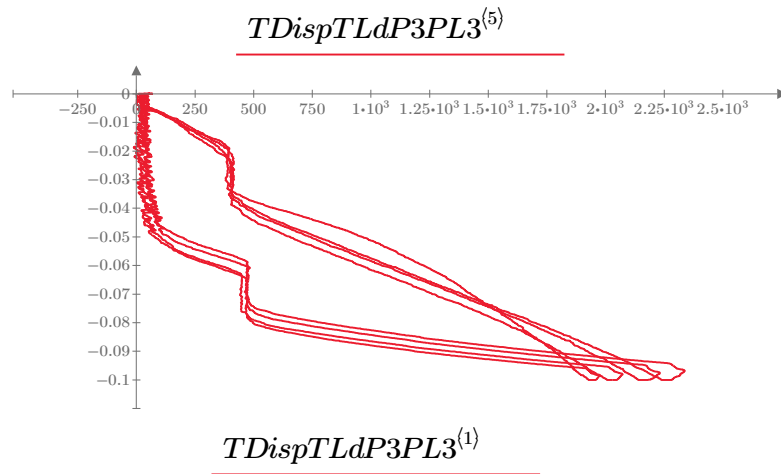


Fig E 23. Load displacement for compression pile P3 PL3 SG3

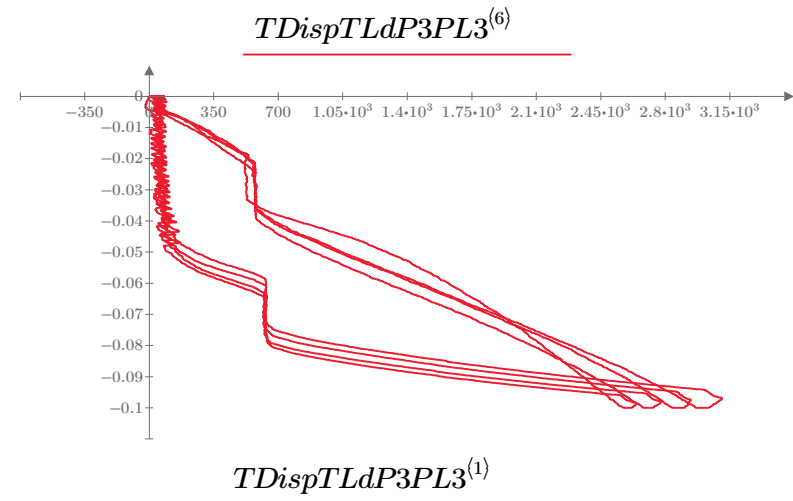


Fig E 24. Load displacement for compression pile P3 PL3 SG4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for psuedostatic load PL4

$$TDispTLdP3PL4 := TDispTLd(LdTimePL4H, TimeP3, AxLdP3, 4) =$$

0	$3.331 \cdot 10^3$	0	0	1.257	-0.158	2.02	0
1	$3.331 \cdot 10^3$	$-4.374 \cdot 10^{-5}$	0.1	1.257	0	3.031	0
2	$3.331 \cdot 10^3$	$-8.749 \cdot 10^{-5}$	0.2	1.257	0.316	3.031	0.997
3	$3.331 \cdot 10^3$	$-1.312 \cdot 10^{-4}$	0.3	1.257	0.632	3.031	0
4	$3.331 \cdot 10^3$	$-1.75 \cdot 10^{-4}$	0.4	1.509	0.316	3.283	0.664
5	$3.332 \cdot 10^3$	$-2.187 \cdot 10^{-4}$	0.5	1.76	0	3.536	1.329
6	$3.332 \cdot 10^3$	$-2.625 \cdot 10^{-4}$	0.6	2.012	0.632	3.536	1.329
7	$3.332 \cdot 10^3$	$-3.062 \cdot 10^{-4}$	0.7	2.515	0.948	4.546	1.329
8	$3.332 \cdot 10^3$	$-3.5 \cdot 10^{-4}$	0.8	2.515	1.264	4.546	0
9	$3.332 \cdot 10^3$	$-3.937 \cdot 10^{-4}$	0.9	2.515	1.264	7.072	1.329
10	$3.332 \cdot 10^3$	$-4.374 \cdot 10^{-4}$	1	2.263	1.264	7.072	1.329
11	$3.332 \cdot 10^3$	$-4.812 \cdot 10^{-4}$	1.1	2.263	1.264	7.072	1.329
⋮							⋮

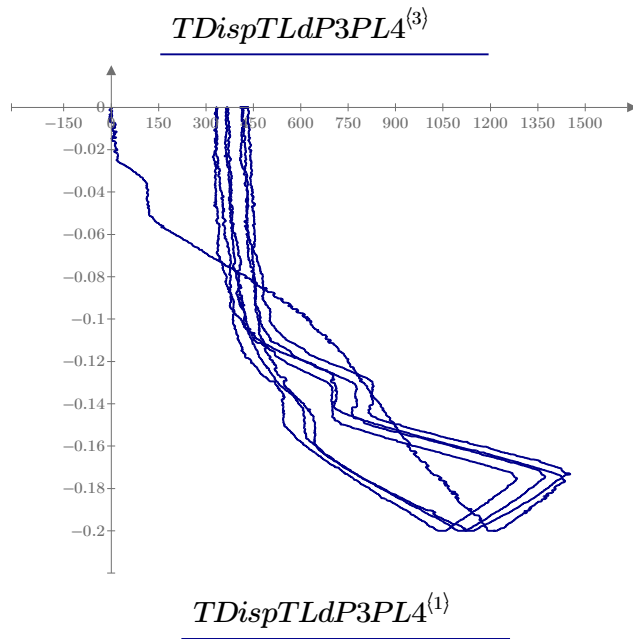


Fig E 25. Load displacement for compression pile P3 PL4 SG1

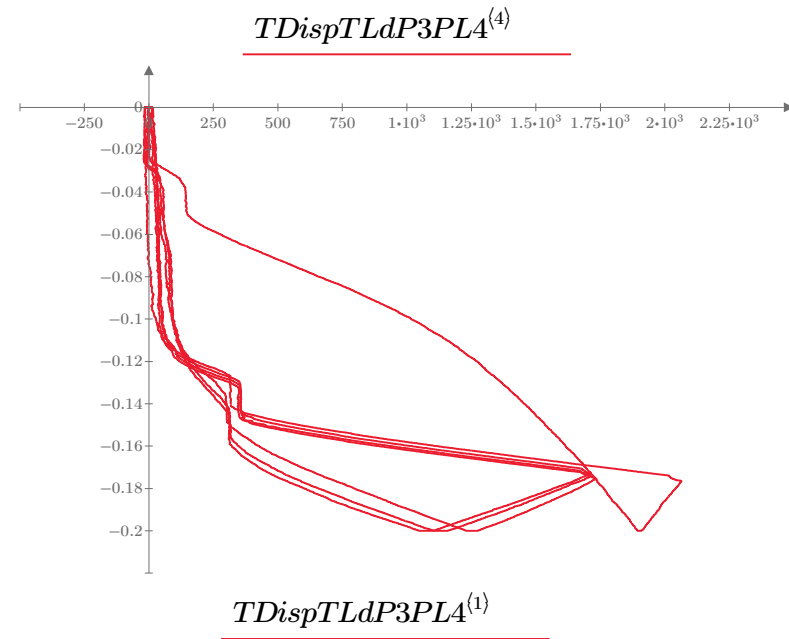


Fig E 26. Load displacement for compression pile P3 PL4 SG2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

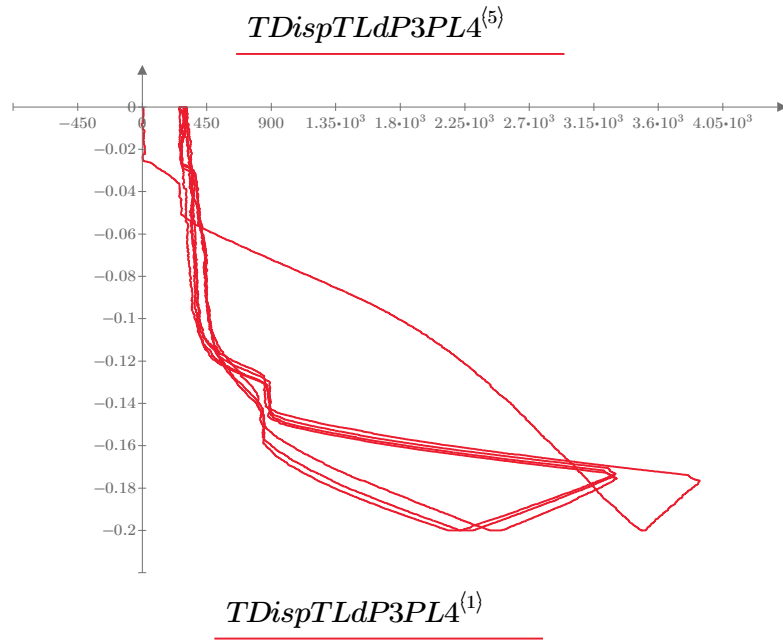


Fig E 27. Load displacement for compression pile P3 PL4 SG3

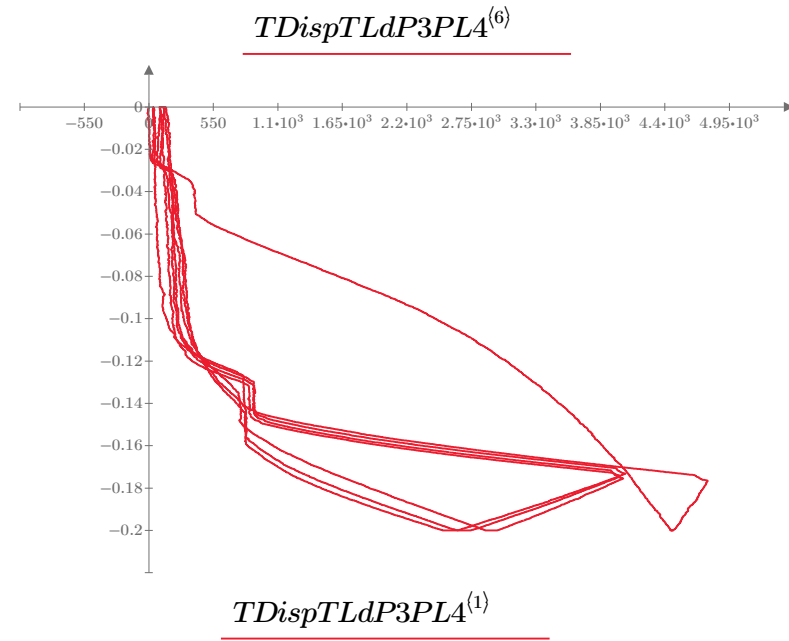


Fig E 28. Load displacement for compression pile P3 PL4 SG4

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for compressive load CL

$$TDispTLdP3CL := TDispTLd(LdTimeCLH, TimeP3, AxLdP3, 5) =$$

0	$7.124 \cdot 10^3$	0	0	0.629	-2.528	17.679	-0.664
1	$7.124 \cdot 10^3$	$-1.444 \cdot 10^{-5}$	0.1	1.006	-2.528	18.184	-1.329
2	$7.124 \cdot 10^3$	$-2.887 \cdot 10^{-5}$	0.2	1.383	-2.844	18.437	-1.329
3	$7.124 \cdot 10^3$	$-4.331 \cdot 10^{-5}$	0.3	1.76	-3.16	18.689	-1.329
4	$7.124 \cdot 10^3$	$-5.774 \cdot 10^{-5}$	0.4	2.137	-3.318	19.194	-0.997
5	$7.124 \cdot 10^3$	$-7.218 \cdot 10^{-5}$	0.5	1.76	-3.476	19.699	-1.329
6	$7.124 \cdot 10^3$	$-8.661 \cdot 10^{-5}$	0.6	1.76	-3.476	19.699	-1.329
7	$7.124 \cdot 10^3$	$-1.01 \cdot 10^{-4}$	0.7	1.76	-4.109	20.204	-1.329
8	$7.124 \cdot 10^3$	$-1.155 \cdot 10^{-4}$	0.8	1.76	-4.109	20.204	-1.993
9	$7.125 \cdot 10^3$	$-1.299 \cdot 10^{-4}$	0.9	1.76	-4.109	20.204	-1.993
10	$7.125 \cdot 10^3$	$-1.444 \cdot 10^{-4}$	1	1.006	-4.109	20.204	-1.329
11	$7.125 \cdot 10^3$	$-1.588 \cdot 10^{-4}$	1.1	1.006	-4.109	21.215	-2.657
⋮							⋮
13855							

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

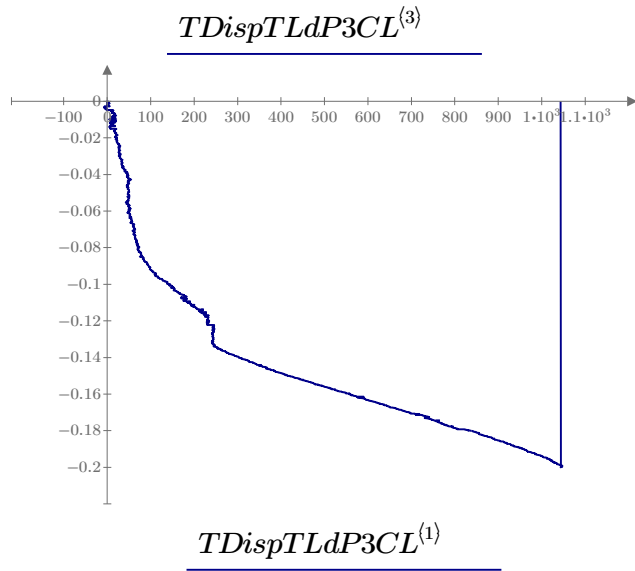


Fig E 29. Load displacement for compression pile P3 CL SG1

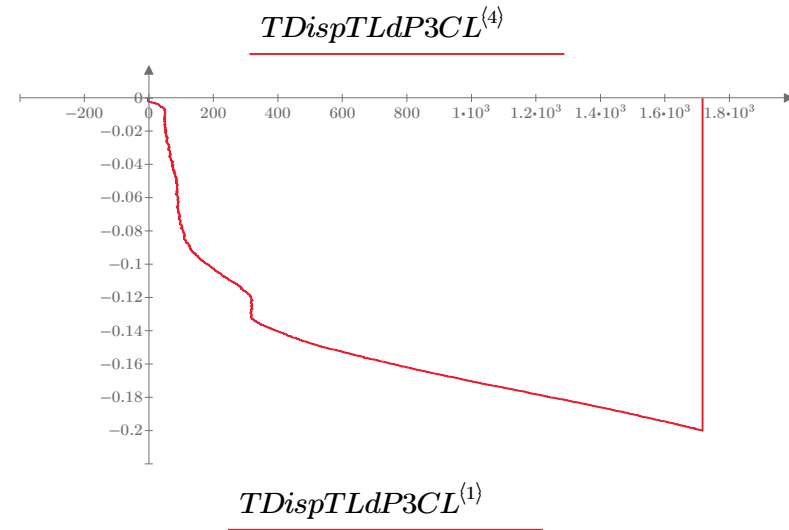


Fig E 30. Load displacement for compression pile P3 CL SG2

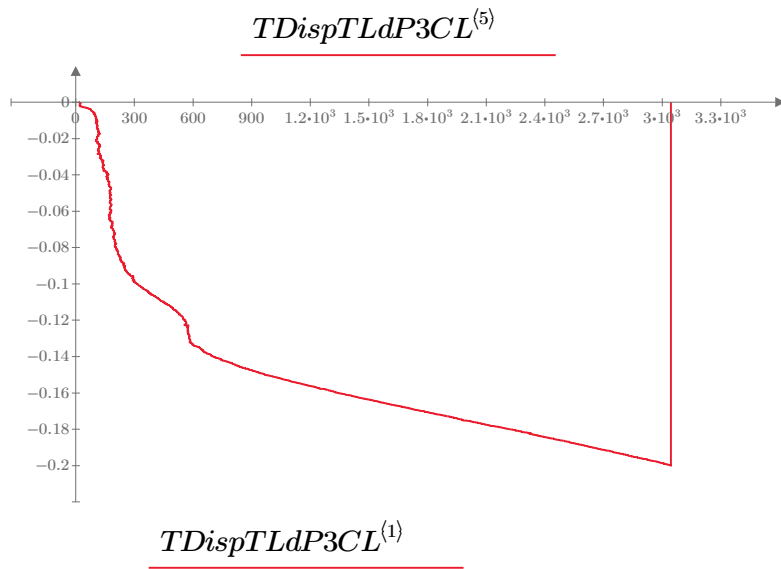


Fig E 31 Load displacement for compression pile P3 CL SG3

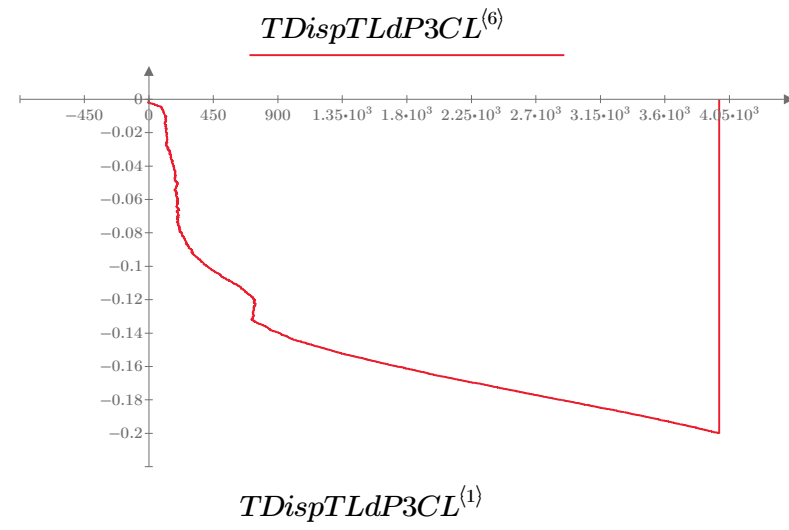


Fig E 32. Load displacement for compression pile P3 CL SG4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

Functions for determining the Qult profile from strain gauge location

TOL := 0.00000001

```
SGplotQP(TDispTLdP0CL, PileNum) :=
  QP0 ← if PileNum = 0
    lookup(-0.15, TDispTLdP0CL(1), TDispTLdP0CL(3), "near")
  else
    lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(3), "near")
  QP1 ← if PileNum = 0
    lookup(-0.15, TDispTLdP0CL(1), TDispTLdP0CL(4), "near")
  else
    lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(4), "near")
  QP2 ← lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(5), "near")
  QP3 ← lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(6), "near")
  combined ← if PileNum = 0
    stack(QP0, QP1, QP1, QP1, QP1, QP1)
  else if PileNum = 1
    stack(QP0, QP1, QP1, QP2, QP2, QP2)
  else
    stack(QP0, QP1, QP1, QP2, QP2, QP3)
  combined
```

$$SGPlotQP3CL := SGplotQP(TDispTLdP3CL, 3) \text{ kN} = \begin{bmatrix} 49.539 \\ 86.596 \\ 86.596 \\ 171.738 \\ 171.738 \\ 196.652 \end{bmatrix} \text{ kN}$$

$$SGEmbDP := \begin{bmatrix} 0.6 + 3.5 & 0.6 + 3.5 & 0.6 + 3.5 & 0.6 + 3.5 & 0.6 + 3.5 \\ 0.6 & 0.6 + 3 & 0.6 + 3 & 0.6 + 2 & 0.6 + 3 \\ 0 & 0.6 + 3 & 0.6 + 3 & 0.6 + 2 & 0.6 + 3 \\ 0 & 0.6 & 0.6 + 2 & 0.6 + 1 & 0.6 + 1 \\ 0 & 0 & 0.6 + 2 & 0.6 + 1 & 0.6 + 1 \\ 0 & 0 & 0.6 & 0.6 & 0.6 \end{bmatrix} \cdot D \cdot Nscale_{0,0}^{sclfac}$$

SG embedment depth in prototype scale. Here, colm 0-4 represents P0 to P4. Row 0 to 5 represents depth to strain SG 1 to 4

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

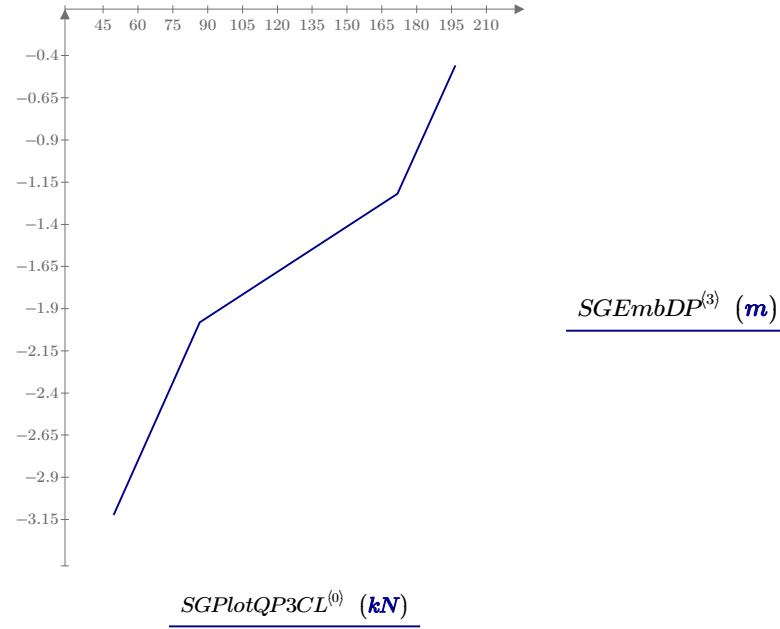


Fig E 33. SG Depth vs Axial Load for P3 pile

Functions for calculating EDR from the load displacement curve for each cycles and each pseudostatic loads

TOL := 0.00000001

```
EDR(TDispTLdP0PL1, Pseu1perS, IniTime, IniDisp, LoopNo, SGNo) :=
||
|| m ← TDispTLdP0PL1
|| o ← TimeCycLoop(Pseu1perS, IniTime, IniDisp) – IniTime
|| w ← -m(1)
|| wmax ← max(-m(1))
||
|| if SGNo = 1
|| || q ← m(3)
|| || qmax ← max(m(3))
|| else if SGNo = 2
|| || q ← m(4)
|| || qmax ← max(m(4))
|| else if SGNo = 3
|| || q ← m(5)
|| || qmax ← max(m(5))
|| else if SGNo = 4
|| || q ← m(6)
|| || qmax ← max(m(6))
||
||
```

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

```

11 LoopNo = 1
    t1 ← m1,0 - IniTime
    t2 ← o1
else if LoopNo = 2
    t1 ← o1
    t2 ← o2
else if LoopNo = 3
    t1 ← o2
    t2 ← o3
else if LoopNo = 4
    t1 ← o3
    t2 ← o4

tstart ← lookup (t1, (m(0) - IniTime), (m(0) - IniTime), "near")
tend ← lookup (t2, (m(0) - IniTime), (m(0) - IniTime), "near")
rowstart ← match (t1, (m(0) - IniTime), "near")
rowend ← match (t2, (m(0) - IniTime), "near")
for i ∈ rowstart0,0 .. rowend0,0
    ri ← ((wi - wi-1) * ((qi + qi-1)) / 2)

area ← ∑ r

EDR ← if qmax = 0
    if wmax = 0
        0
    else
        area / (qmax * wmax)

s ← augment ((tstart + IniTime), (tend + IniTime), rowstart, rowend, qmax, wmax, area, EDR)
EDR

```

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

Functions for combining EDR from the load displacement curve for each cycles and each pseudostatic loads

```

EDRPOPLSG (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, PileNo) :=
q1 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1)
q2 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1)
q3 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1)
q4 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1)
r1 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2)
r2 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2)
r3 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2)
r4 ← EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2)
w1 ← if PileNo = 0
    || 0
    else
    || EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 3)
w2 ← if PileNo = 0
    || 0
    else
    || EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 3)
w3 ← if PileNo = 0
    || 0
    else
    || EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 3)
w4 ← if PileNo = 0
    || 0
    else
    || EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3)
s1 ← if PileNo = 0
    || 0
    ||
    else if PileNo = 1
    || 0
    else
    || EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 4)
s2 ← if PileNo = 0
    || 0
    ||
    else if PileNo = 1
    || 0
    else
    || EDR (TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 4)
s3 ← if PileNo = 0
    || 0
    ||
    else if PileNo = 1
    ||

```

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

$$NoLoop := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

```

|| 0
|| else
|| EDR(TDispTLdP0PL1,PseuPL1S,IniTimePL1S,IniDisp,3,4)
s4 ← if PileNo = 0
|| 0
|| else if PileNo = 1
|| 0
|| else
|| EDR(TDispTLdP0PL1,PseuPL1S,IniTimePL1S,IniDisp,4,4)
augment(stack(q1,q2,q3,q4),stack(r1,r2,r3,r4),stack(w1,w2,w3,w4),stack(s1,s2,s3,s4))

```

$$EDRP3PL1 := EDRPOPLSG(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, 3) = \begin{bmatrix} 0.611 & 0.509 & 0.481 & 0.464 \\ -0.116 & -0.107 & -0.083 & -0.105 \\ -0.158 & -0.1 & -0.116 & -0.116 \\ -0.342 & -0.108 & -0.098 & -0.104 \end{bmatrix}$$

$$EDRP3PL2 := EDRPOPLSG(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, 3) = \begin{bmatrix} 0.786 & 0.907 & 0.857 & 0.852 \\ 0.49 & 0.555 & 0.526 & 0.516 \\ 0.503 & 0.514 & 0.492 & 0.485 \\ 0.527 & 0.55 & 0.535 & 0.538 \end{bmatrix}$$

$$EDRP3PL3 := EDRPOPLSG(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, 3) = \begin{bmatrix} 0.125 & 0.272 & 0.246 & 0.244 \\ 0.115 & 0.189 & 0.198 & 0.196 \\ 0.141 & 0.194 & 0.194 & 0.204 \\ 0.152 & 0.187 & 0.19 & 0.197 \end{bmatrix}$$

$$EDRP3PL4 := EDRPOPLSG(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, 3) = \begin{bmatrix} -0.057 & 0.217 & 0.133 & 0.222 \\ -0.087 & -0.067 & -0.059 & -0.064 \\ -0.107 & -0.08 & -0.071 & -0.078 \\ -0.112 & -0.089 & -0.08 & -0.088 \end{bmatrix}$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

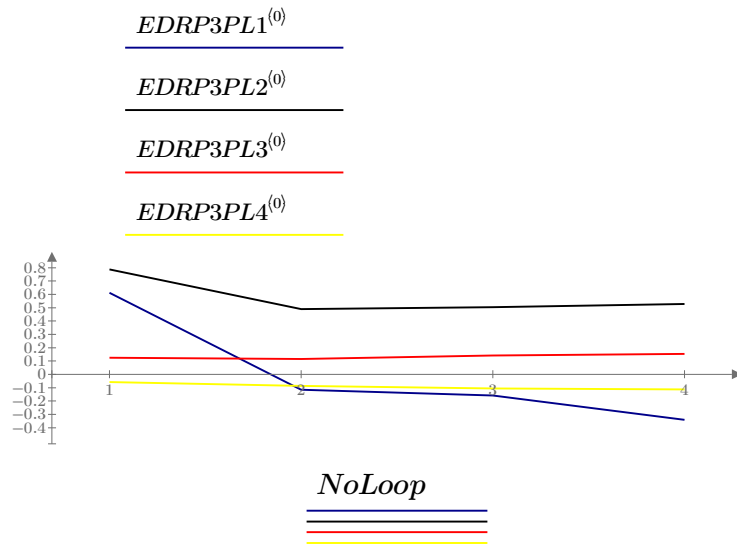


Fig E 34. EDR vs No of loops SG1

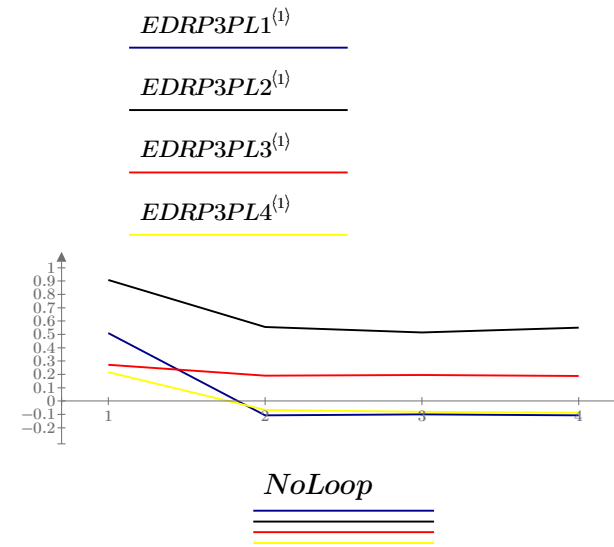


Fig B 35. EDR vs No of loops SG2

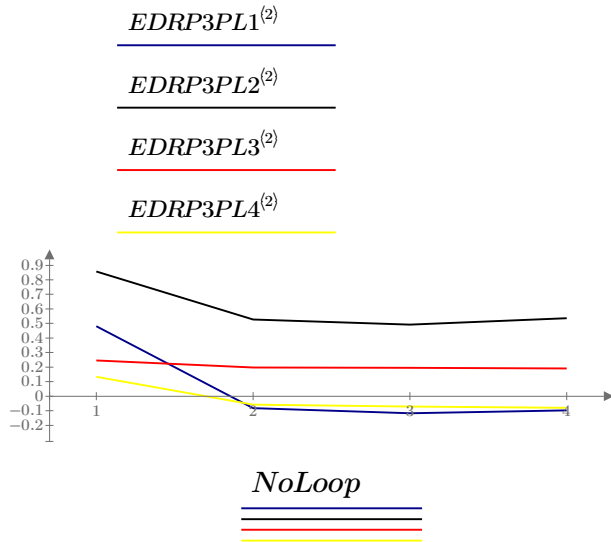


Fig B 36. EDR vs No of loops SG3

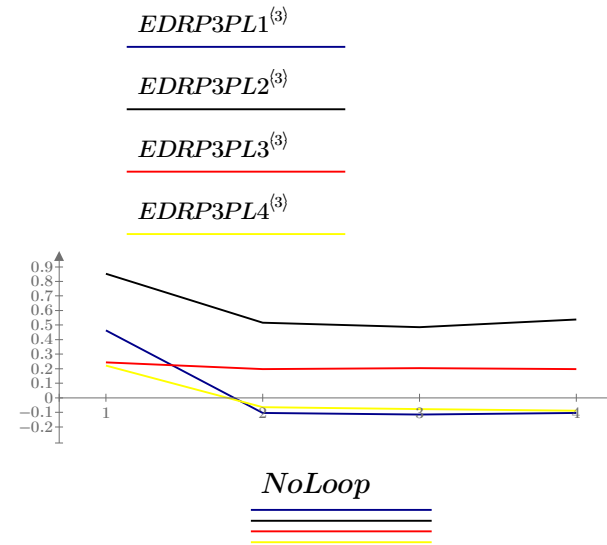


Fig B 37. EDR vs No of loops SG4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

Functions for disintegrating the load-displacement curves into separate cycles

```

DispLd (TDispTLdP0PL1, Pseu1perS, IniTime, IniDisp, LoopNo, SGNo) :=
    m ← TDispTLdP0PL1
    o ← TimeCycLoop(Pseu1perS, IniTime, IniDisp) – IniTime
    w ← –m(1)
    if SGNo = 1
        q ← m(3)
    else if SGNo = 2
        q ← m(4)
    else if SGNo = 3
        q ← m(5)
    else if SGNo = 4
        q ← m(6)
    if LoopNo = 1
        t1 ← o0
        t2 ← o1
    else if LoopNo = 2
        t1 ← o1
        t2 ← o2
    else if LoopNo = 3
        t1 ← o2
        t2 ← o3
    else if LoopNo = 4
        t1 ← o3
        t2 ← o4
    tstart ← lookup(t1, (m(0) – IniTime), (m(0) – IniTime), “near”)
    tend ← lookup(t2, (m(0) – IniTime), (m(0) – IniTime), “near”)
    rowstart ← match(t1, (m(0) – IniTime), “near”)
    rowend ← match(t2, (m(0) – IniTime), “near”)
    for i ∈ rowstart0,0 .. rowend0,0
        di ← wi
        ldi ← qi
    augment(d, ld)

```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

$$DispLdP3PL1L1SG1 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 1, 1)$$

$$DispLdP3PL1L2SG1 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 2, 1)$$

$$DispLdP3PL1L3SG1 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 3, 1)$$

$$DispLdP3PL1L4SG1 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 4, 1)$$

$$DispLdP3PL2L1SG1 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 1, 1)$$

$$DispLdP3PL2L2SG1 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 2, 1)$$

$$DispLdP3PL2L3SG1 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 3, 1)$$

$$DispLdP3PL2L4SG1 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 4, 1)$$

$$DispLdP3PL3L1SG1 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 1, 1)$$

$$DispLdP3PL3L2SG1 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 2, 1)$$

$$DispLdP3PL3L3SG1 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 3, 1)$$

$$DispLdP3PL3L4SG1 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 4, 1)$$

$$DispLdP3PL4L1SG1 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 1, 1)$$

$$DispLdP3PL4L2SG1 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 2, 1)$$

$$DispLdP3PL4L3SG1 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 3, 1)$$

$$DispLdP3PL4L4SG1 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 4, 1)$$

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

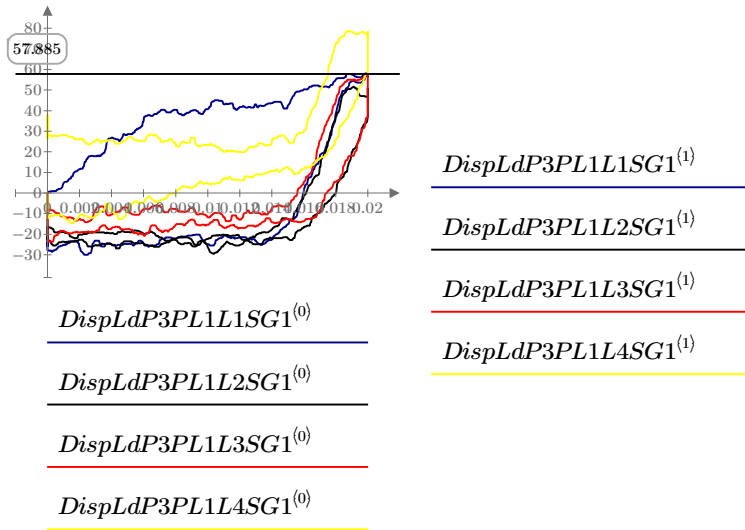


Fig E 38. Load-Displacement for P3 PL1 SG1

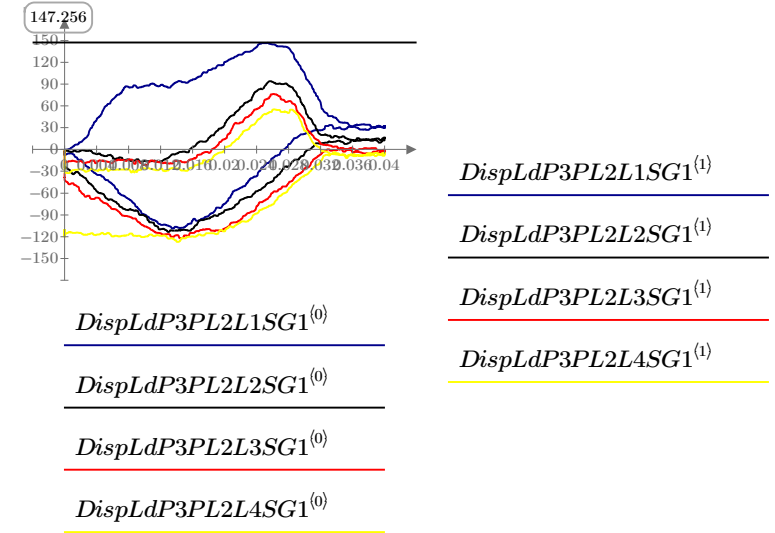


Fig E 39. Load-Displacement for P3 PL2 SG1

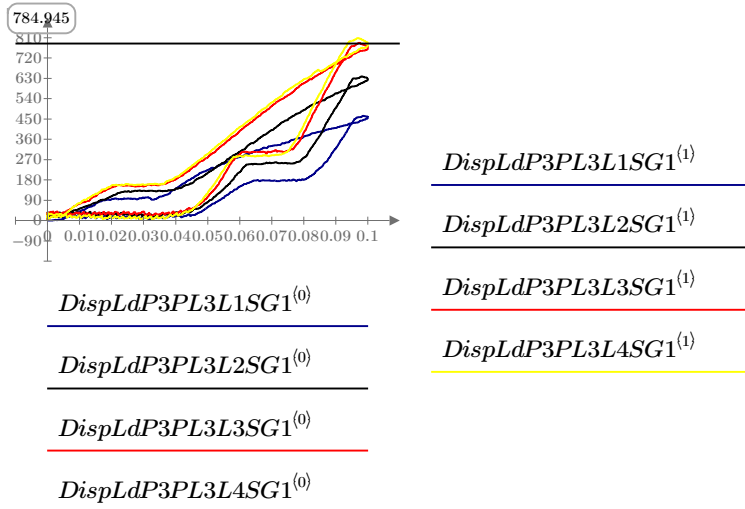


Fig E 40. Load-Displacement for P3 PL3 SG1

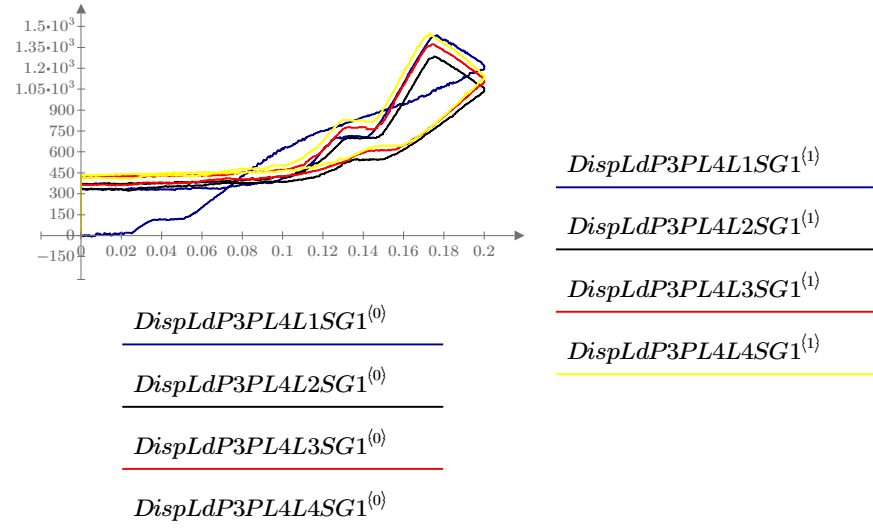


Fig E 41. Load-Displacement for P3 PL4 SG1

Appendix E
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

$DispLdP3PL1L1SG2 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 1, 2)$

$DispLdP3PL1L2SG2 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 2, 2)$

$DispLdP3PL1L3SG2 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 3, 2)$

$DispLdP3PL1L4SG2 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 4, 2)$

$DispLdP3PL2L1SG2 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 1, 2)$

$DispLdP3PL2L2SG2 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 2, 2)$

$DispLdP3PL2L3SG2 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 3, 2)$

$DispLdP3PL2L4SG2 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 4, 2)$

$DispLdP3PL3L1SG2 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 1, 2)$

$DispLdP3PL3L2SG2 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 2, 2)$

$DispLdP3PL3L3SG2 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 3, 2)$

$DispLdP3PL3L4SG2 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 4, 2)$

$DispLdP3PL4L1SG2 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 1, 2)$

$DispLdP3PL4L2SG2 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 2, 2)$

$DispLdP3PL4L3SG2 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 3, 2)$

$DispLdP3PL4L4SG2 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 4, 2)$

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

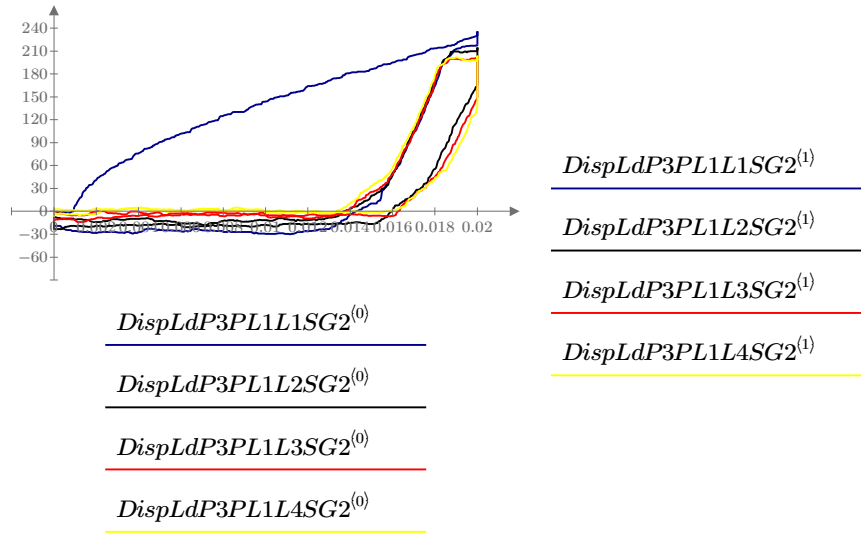


Fig E 42. Load-Displacement for P2 PL1 SG2

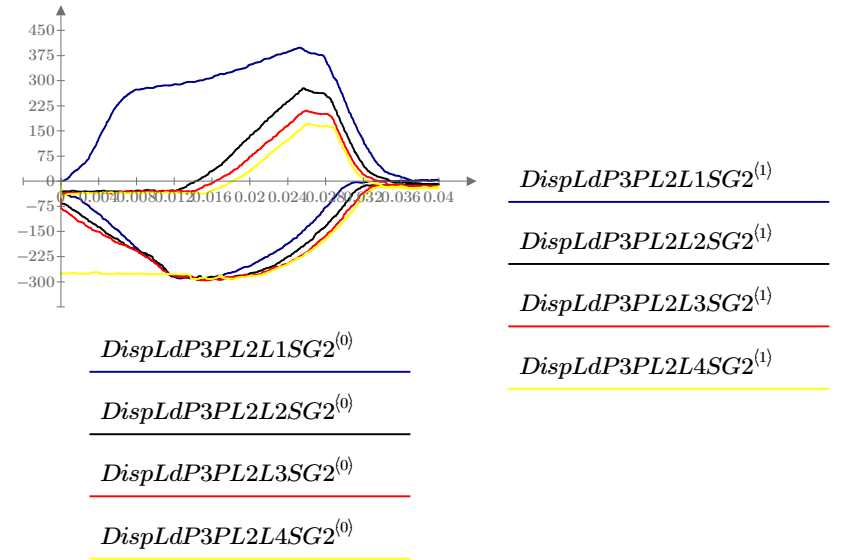


Fig E 43. Load-Displacement for P2 PL2 SG2

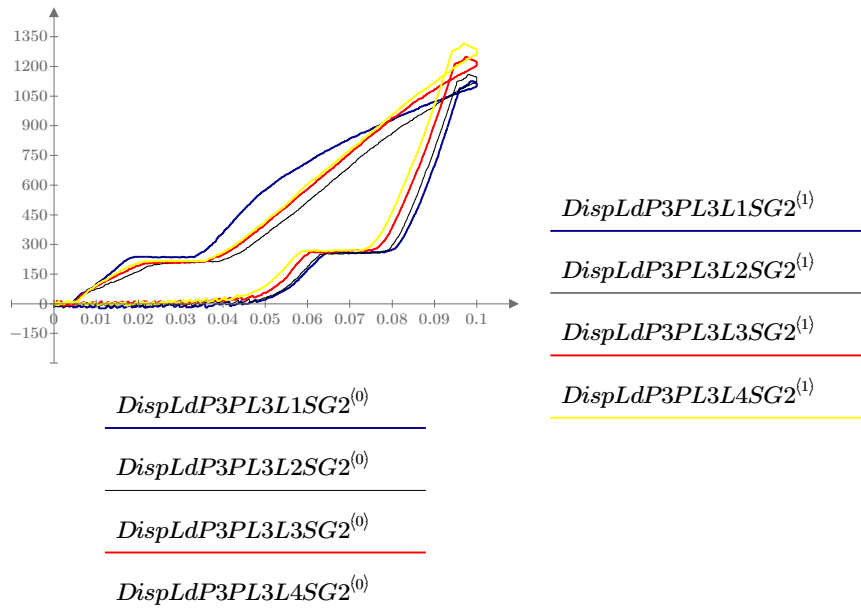


Fig E 44. Load-Displacement for P2 PL3 SG2

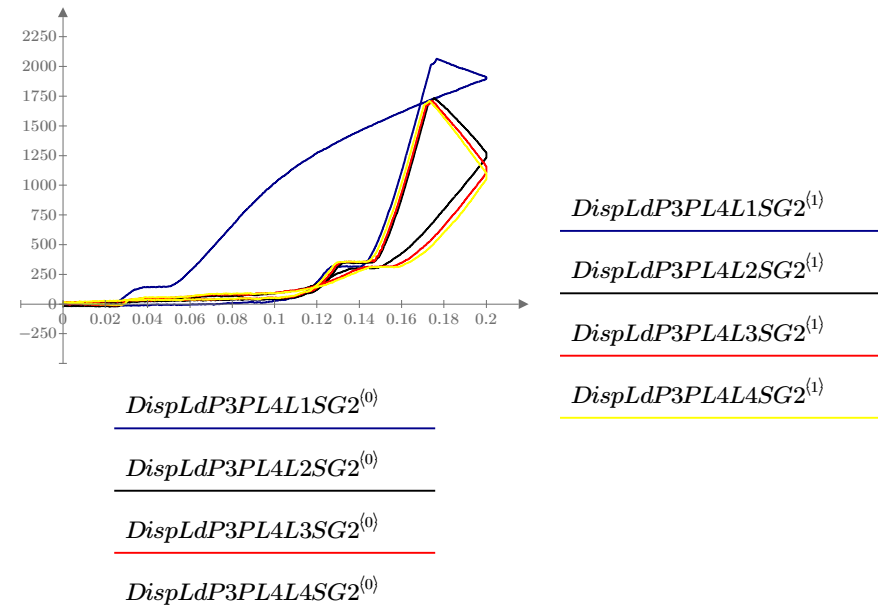


Fig E 45. Load-Displacement for P2 PL4 SG2

Appendix E
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

$DispLdP3PL1L1SG3 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 1, 3)$

$DispLdP3PL1L2SG3 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 2, 3)$

$DispLdP3PL1L3SG3 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 3, 3)$

$DispLdP3PL1L4SG3 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 4, 3)$

$DispLdP3PL2L1SG3 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 1, 3)$

$DispLdP3PL2L2SG3 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 2, 3)$

$DispLdP3PL2L3SG3 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 3, 3)$

$DispLdP3PL2L4SG3 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 4, 3)$

$DispLdP3PL3L1SG3 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 1, 3)$

$DispLdP3PL3L2SG3 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 2, 3)$

$DispLdP3PL3L3SG3 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 3, 3)$

$DispLdP3PL3L4SG3 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 4, 3)$

$DispLdP3PL4L1SG3 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 1, 3)$

$DispLdP3PL4L2SG3 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 2, 3)$

$DispLdP3PL4L3SG3 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 3, 3)$

$DispLdP3PL4L4SG3 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 4, 3)$

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

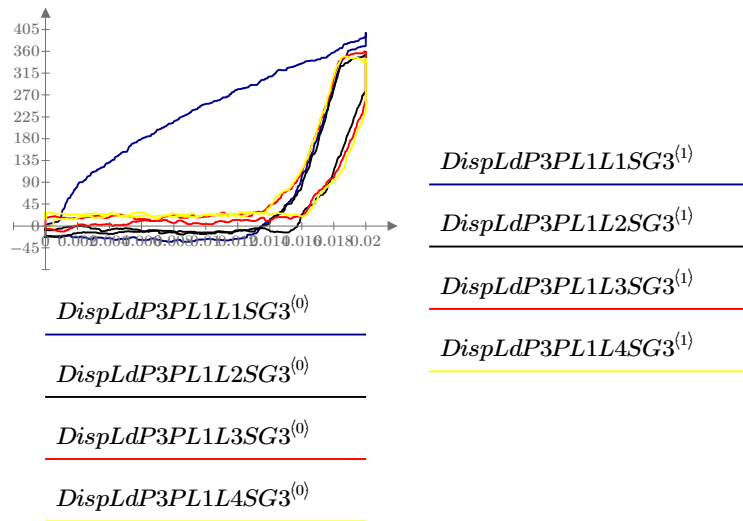


Fig E 46. Load-Displacement for P3 PL1 SG3

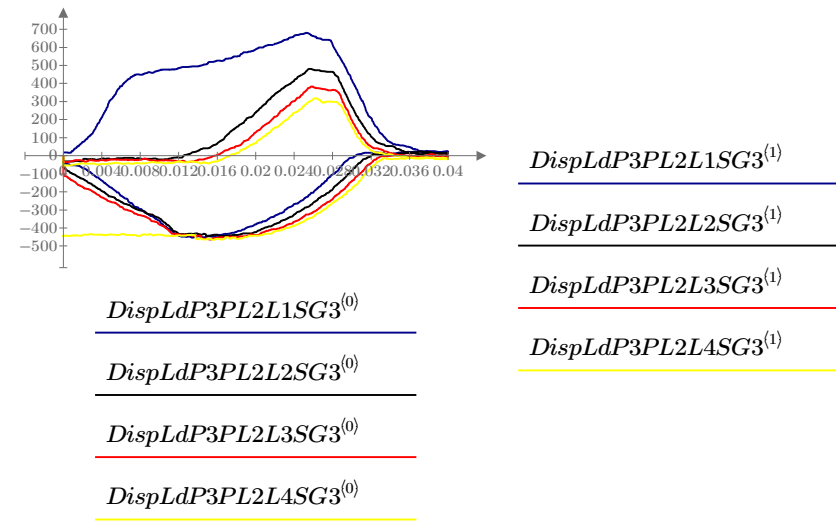


Fig E 47. Load-Displacement for P3 PL2 SG3

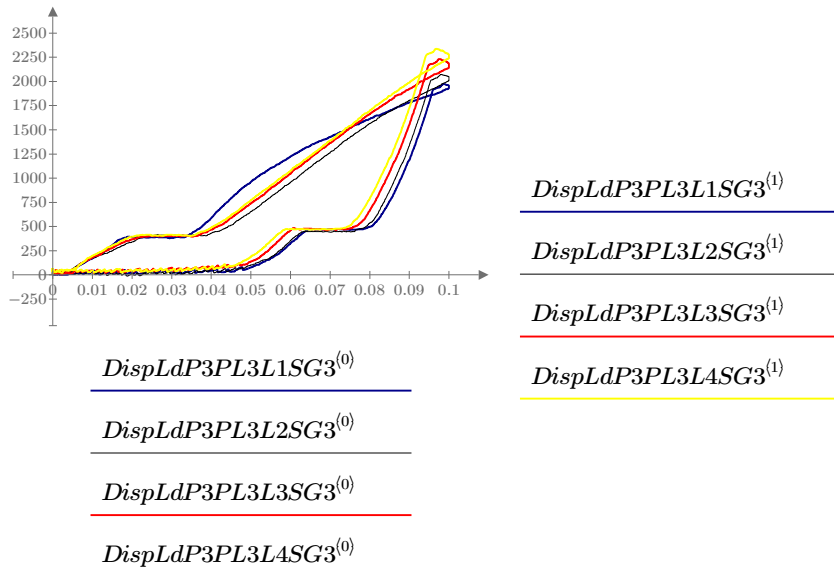


Fig E 48. Load-Displacement for P3 PL3 SG3

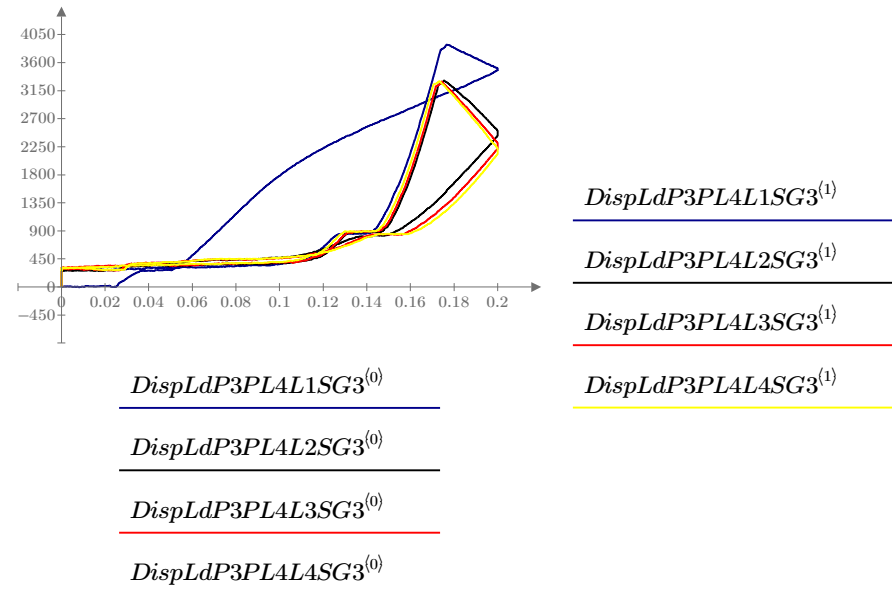


Fig E 49. Load-Displacement for P2 PL4 SG3

Appendix E
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

$DispLdP3PL1L1SG4 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 1, 4)$

$DispLdP3PL1L2SG4 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 2, 4)$

$DispLdP3PL1L3SG4 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 3, 4)$

$DispLdP3PL1L4SG4 := DispLd(TDispTLdP3PL1, PseuPL1H, IniTimePL1H, IniDisp, 4, 4)$

$DispLdP3PL2L1SG4 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 1, 4)$

$DispLdP3PL2L2SG4 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 2, 4)$

$DispLdP3PL2L3SG4 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 3, 4)$

$DispLdP3PL2L4SG4 := DispLd(TDispTLdP3PL2, PseuPL2H, IniTimePL2H, IniDisp, 4, 4)$

$DispLdP3PL3L1SG4 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 1, 4)$

$DispLdP3PL3L2SG4 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 2, 4)$

$DispLdP3PL3L3SG4 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 3, 4)$

$DispLdP3PL3L4SG4 := DispLd(TDispTLdP3PL3, PseuPL3H, IniTimePL3H, IniDisp, 4, 4)$

$DispLdP3PL4L1SG4 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 1, 4)$

$DispLdP3PL4L2SG4 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 2, 4)$

$DispLdP3PL4L3SG4 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 3, 4)$

$DispLdP3PL4L4SG4 := DispLd(TDispTLdP3PL4, PseuPL4H, IniTimePL4H, IniDisp, 4, 4)$

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

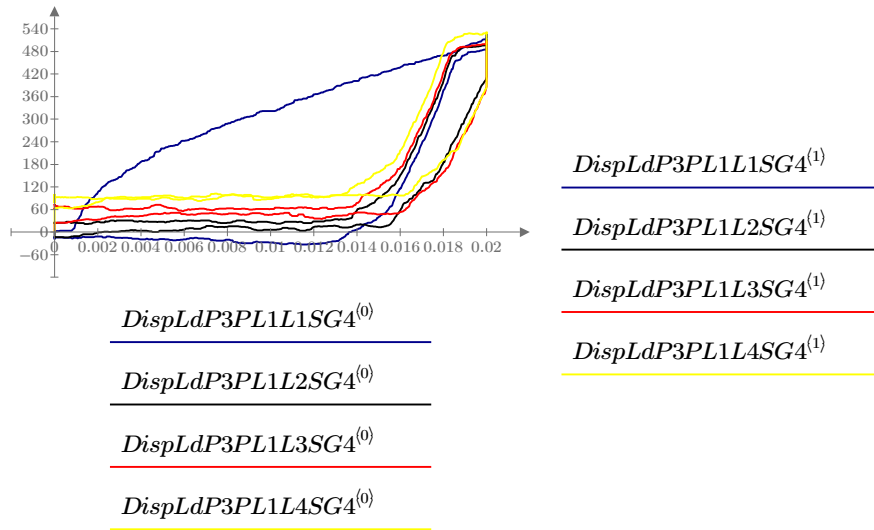


Fig E 50. Load-Displacement for P3 PL1 SG4

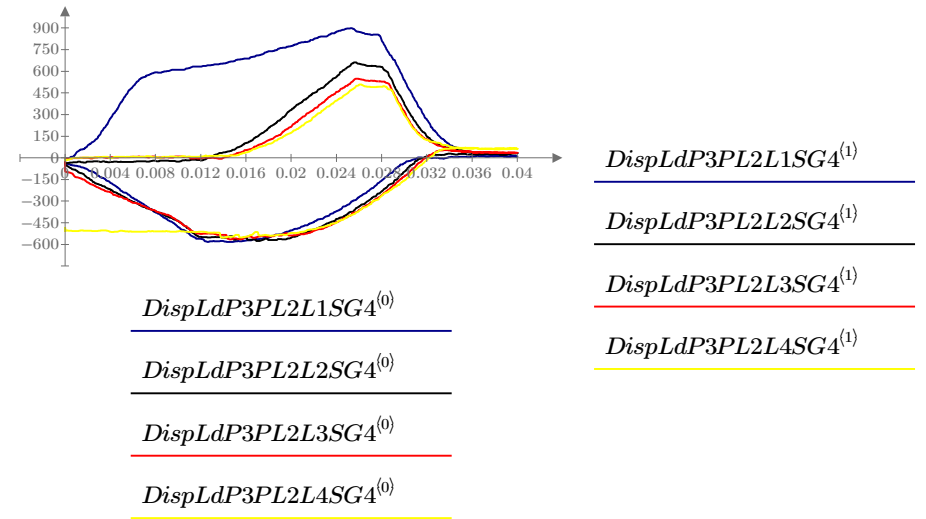


Fig E 51. Load-Displacement for P3 PL2 SG4

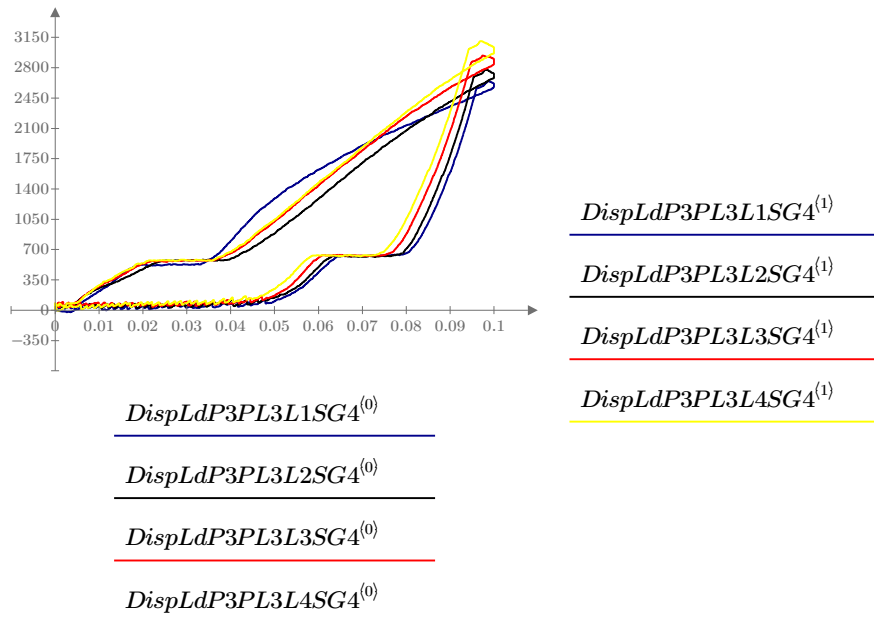


Fig E 52. Load-Displacement for P3 PL3 SG4

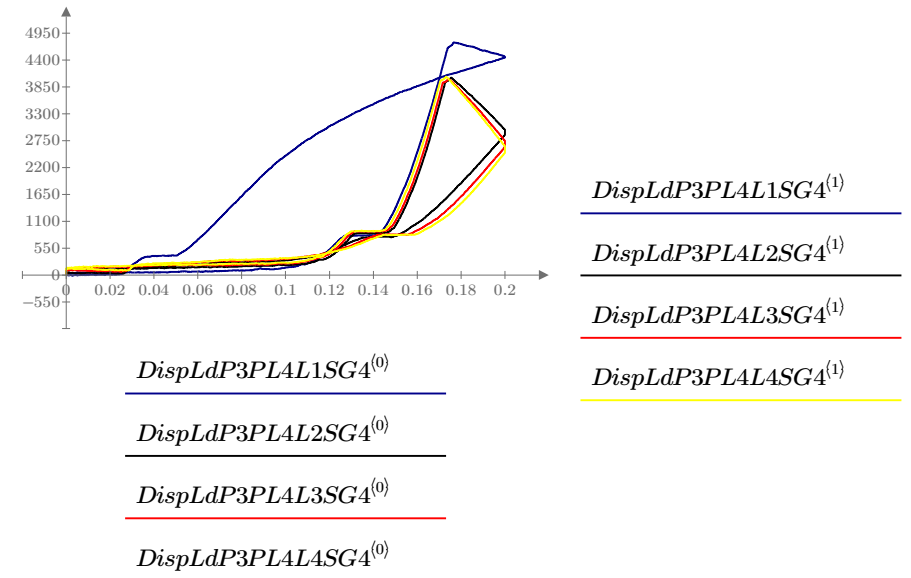


Fig E 53. Load-Displacement for P3 PL4 SG4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

Functions for determining the Q_{max} profile from each loads

TOL := 0.00000001

$$Q_{maxSG}(TDispTLdP2PL1, PileNum) := \begin{cases} QP0 \leftarrow \max(TDispTLdP2PL1^{(3)}) \\ QP1 \leftarrow \max(TDispTLdP2PL1^{(4)}) \\ QP2 \leftarrow \max(TDispTLdP2PL1^{(5)}) \\ QP3 \leftarrow \max(TDispTLdP2PL1^{(6)}) \\ combined \leftarrow \text{if } PileNum = 0 \\ \quad \text{stack}(QP0, QP1, QP1, QP1, QP1, QP1) \\ \text{else if } PileNum = 1 \\ \quad \text{stack}(QP0, QP1, QP1, QP2, QP2, QP2) \\ \text{else} \\ \quad \text{stack}(QP0, QP1, QP1, QP2, QP2, QP3) \\ combined \end{cases}$$

$Q_{maxP3PL1} := Q_{maxSG}(TDispTLdP3PL1, 3) \cdot \mathbf{kN}$

$Q_{maxP3PL2} := Q_{maxSG}(TDispTLdP3PL2, 3) \mathbf{kN}$

$Q_{maxP3PL3} := Q_{maxSG}(TDispTLdP3PL3, 3) \mathbf{kN}$

$Q_{maxP3PL4} := Q_{maxSG}(TDispTLdP3PL4, 3) \mathbf{kN}$

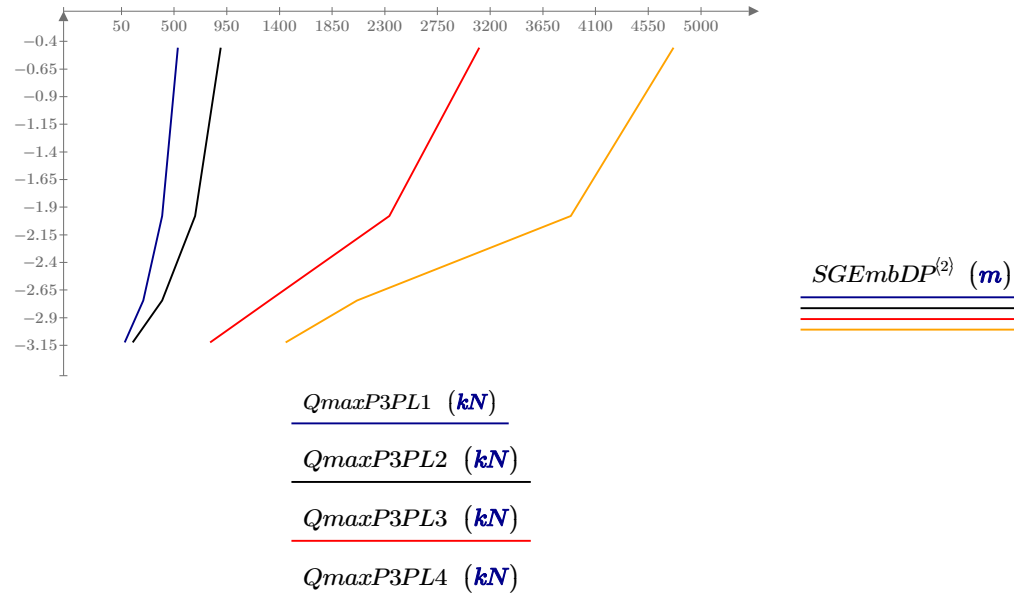
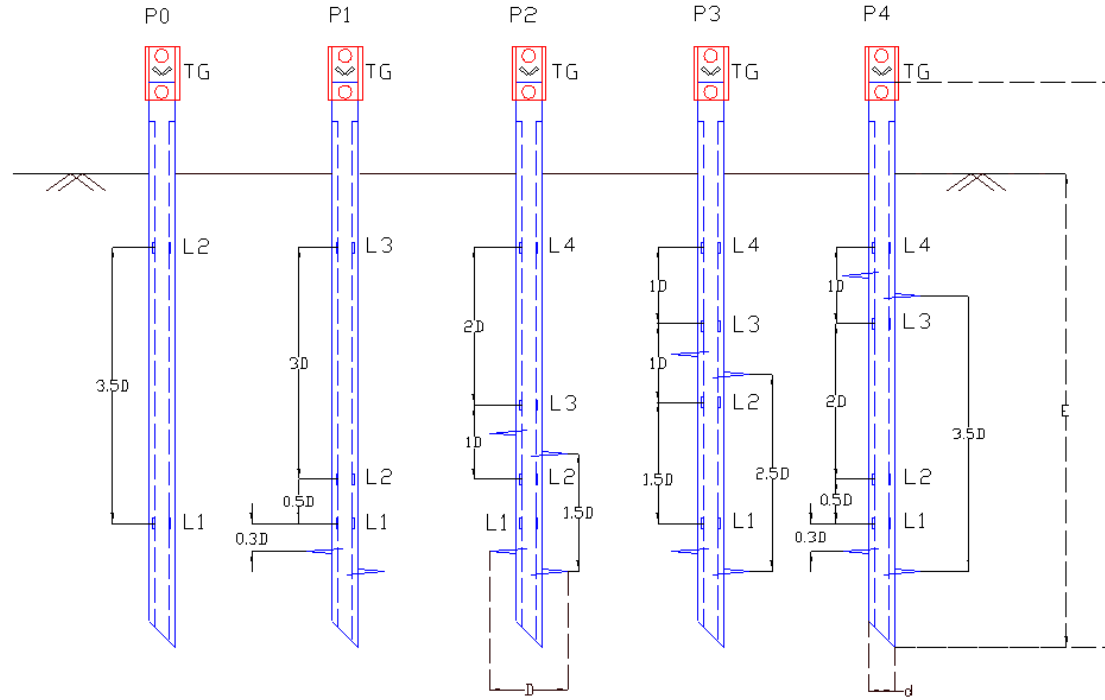


Fig E 54. SG Depth vs Q max from each load amplitude for P3 pile

2.3.3 Skin Friction vs Depth



Strain gauge locations in model piles.

$$HgtShaft := \begin{bmatrix} 3.5 & 0.5 & 0.5 & 1.5 & 0.5 \\ 0 & 3 & 1 & 1 & 2 \\ 0 & 0 & 2 & 1 & 1 \end{bmatrix} \cdot D \cdot Nscale^{sclfac_{0,0}} = \begin{bmatrix} 2.667 & 0.381 & 0.381 & 1.143 & 0.381 \\ 0 & 2.286 & 0.762 & 0.762 & 1.524 \\ 0 & 0 & 1.524 & 0.762 & 0.762 \end{bmatrix} m$$

Height in the shaft segment between two stations in prototype scale. Here, colm 0-4 represents P0 to P4. Row 0 to 2 represents height between SG 1-2, 2-3 & 3-4

$$SurfArea := HgtShaft \cdot \pi \cdot d \cdot Nscale^{sclfac_{0,0}} = \begin{bmatrix} 2.128 & 0.304 & 0.304 & 0.912 & 0.304 \\ 0 & 1.824 & 0.608 & 0.608 & 1.216 \\ 0 & 0 & 1.216 & 0.608 & 0.608 \end{bmatrix} m^2$$

Surface Area of the shaft segment between two stations in prototype scale. Here, colm 0-4 represents P0 to P4. Row 0 to 2 represents surface area between SG 1-2, 2-3 & 3-4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

Function for determining the Unit Shaft Resistance within the shaft segment

```

UntShtRes(LdP, PileNum) :=
  for i ∈ 0, 1..rows(LdP) - 1
    for j ∈ 0, 1..cols(LdP) - 1
      shaft12i,0 ←  $\frac{(LdP_{i,4} - LdP_{i,3}) \text{ kN}}{\text{submatrix}(\text{SurfArea}, 0, 2, \text{PileNum}, \text{PileNum})_{0,0}}$ 
      shaft23i,1 ← if submatrix(SurfArea, 0, 2, PileNum, PileNum)1 = 0
        0
      else
         $\frac{(LdP_{i,5} - LdP_{i,4}) \text{ kN}}{\text{submatrix}(\text{SurfArea}, 0, 2, \text{PileNum}, \text{PileNum})_1}$ 
      shaft34i,2 ← if submatrix(SurfArea, 0, 2, PileNum, PileNum)2 = 0
        0
      else
         $\frac{(LdP_{i,6} - LdP_{i,5}) \text{ kN}}{\text{submatrix}(\text{SurfArea}, 0, 2, \text{PileNum}, \text{PileNum})_2}$ 
    augment(shaft12(0), shaft23(1), shaft34(2))
  
```

$$ShftResP3PL1 := UntShtRes(TDispTLdP3PL1, 3)$$

$$ShftResP3PL2 := UntShtRes(TDispTLdP3PL2, 3)$$

$$ShftResP3PL3 := UntShtRes(TDispTLdP3PL3, 3)$$

$$ShftResP3PL4 := UntShtRes(TDispTLdP3PL4, 3)$$

$$ShftResP3CL := UntShtRes(TDispTLdP3CL, 3)$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

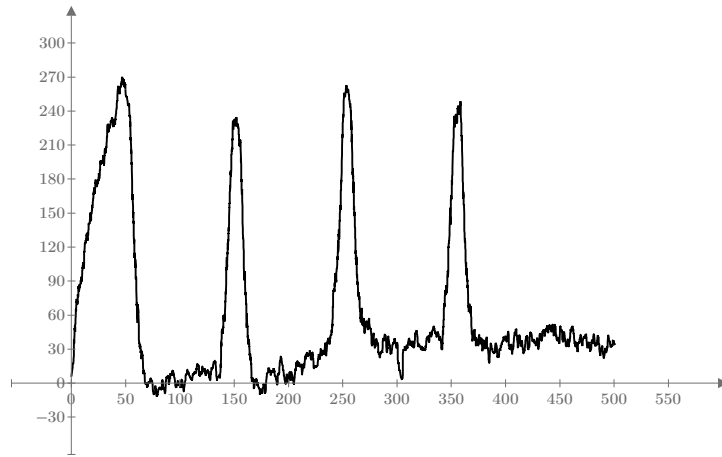
 $TD_{\text{DispTLdP3PL1}}^{(0)}$  $ShftResP3PL1^{(1)}$ (***kPa***)

Fig E 55. Shaft Resistances vs Time, P3 PL1

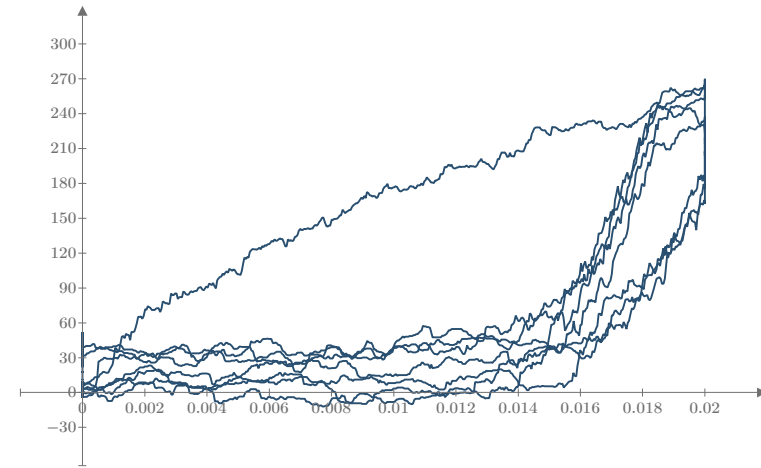
 $-TD_{\text{DispTLdP3PL1}}^{(1)}$  $ShftResP3PL1^{(1)}$ (***kPa***)

Fig E 56. Shaft Resistances vs Displacement, P3 PL1

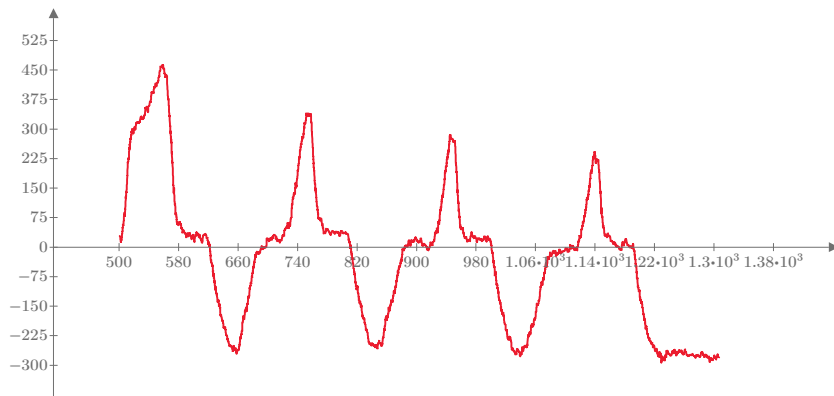
 $TD_{\text{DispTLdP3PL2}}^{(0)}$  $ShftResP3PL2^{(1)}$ (***kPa***)

Fig E 57. Shaft Resistances vs Time, P3 PL2

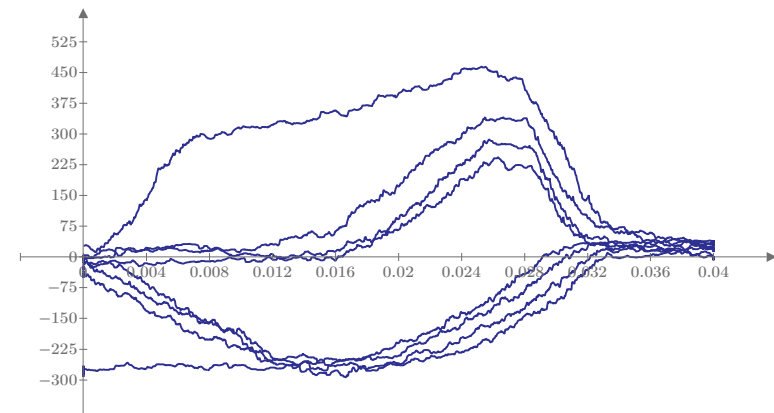
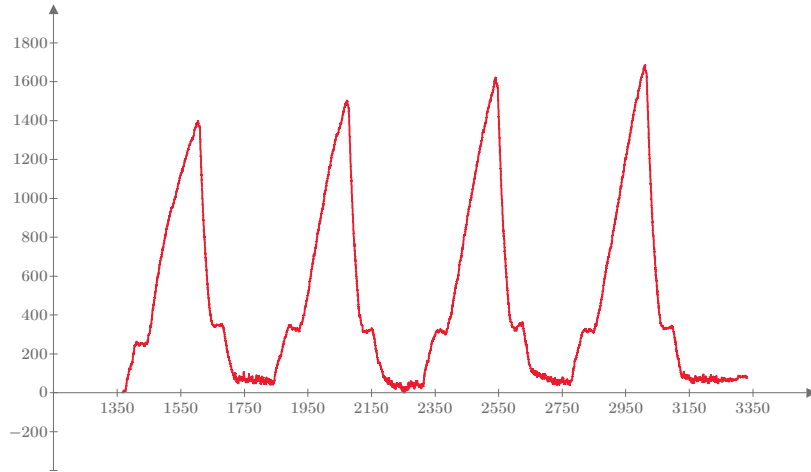
 $-TD_{\text{DispTLdP3PL2}}^{(1)}$  $ShftResP3PL2^{(1)}$ (***kPa***)

Fig E 58. Shaft Resistances vs Displacement, P3 PL2

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

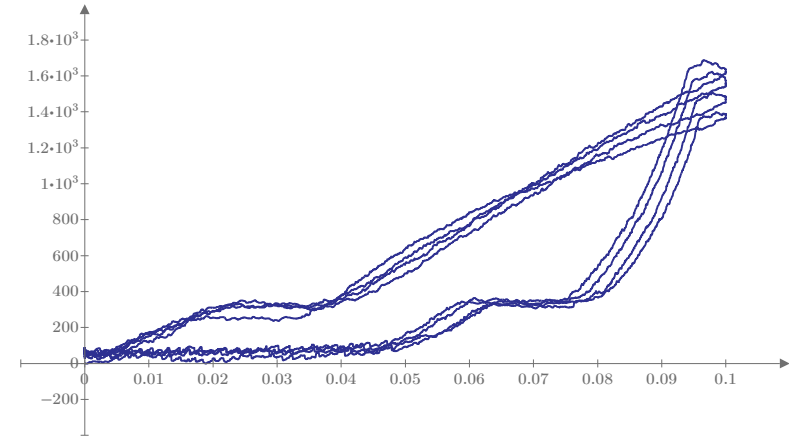
$$\underline{\underline{TDispTLdP3PL3^{(0)}}}$$



$$\underline{\underline{ShftResP3PL3^{(1)}} \text{ (kPa)}}$$

Fig E 59. Shaft Resistances vs Time, P3 PL3

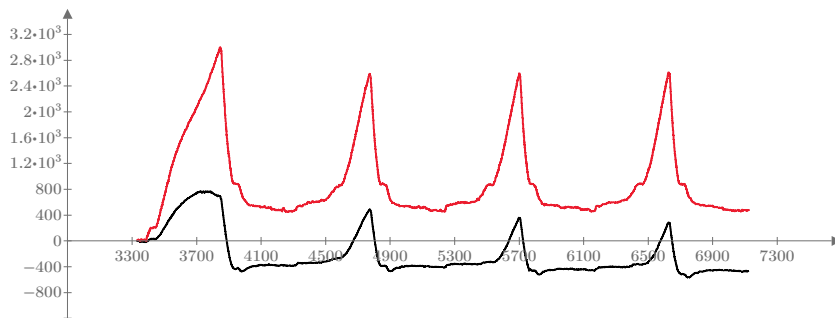
$$\underline{\underline{-TDispTLdP3PL3^{(1)}}}$$



$$\underline{\underline{ShftResP3PL3^{(1)}} \text{ (kPa)}}$$

Fig E 60. Shaft Resistances vs Displacement, P3 PL3

$$\underline{\underline{TDispTLdP3PL4^{(0)}}}$$

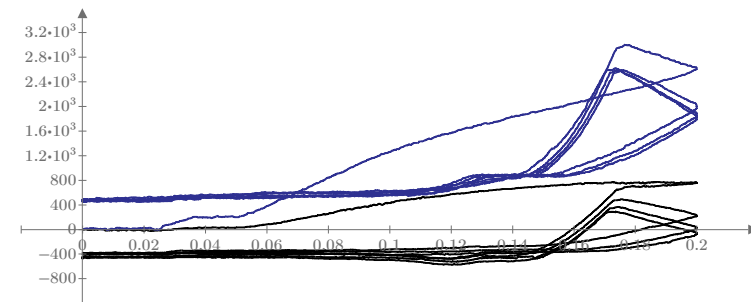


$$\underline{\underline{ShftResP3PL4^{(0)}} \text{ (kPa)}}$$

$$\underline{\underline{ShftResP3PL4^{(1)}} \text{ (kPa)}}$$

Fig E 61. Shaft Resistances vs Time, P3 PL4

$$\underline{\underline{-TDispTLdP3PL4^{(1)}}}$$



$$\underline{\underline{ShftResP3PL4^{(0)}} \text{ (kPa)}}$$

$$\underline{\underline{ShftResP3PL4^{(1)}} \text{ (kPa)}}$$

Fig E 62. Shaft Resistances vs Displacement, P3 PL4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

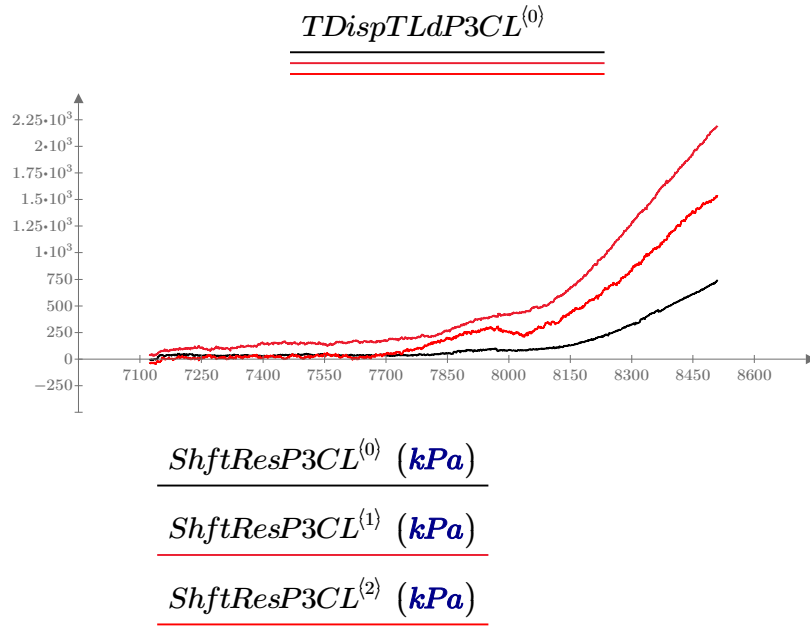


Fig E 63. Shaft Resistances vs Time, P3 CL

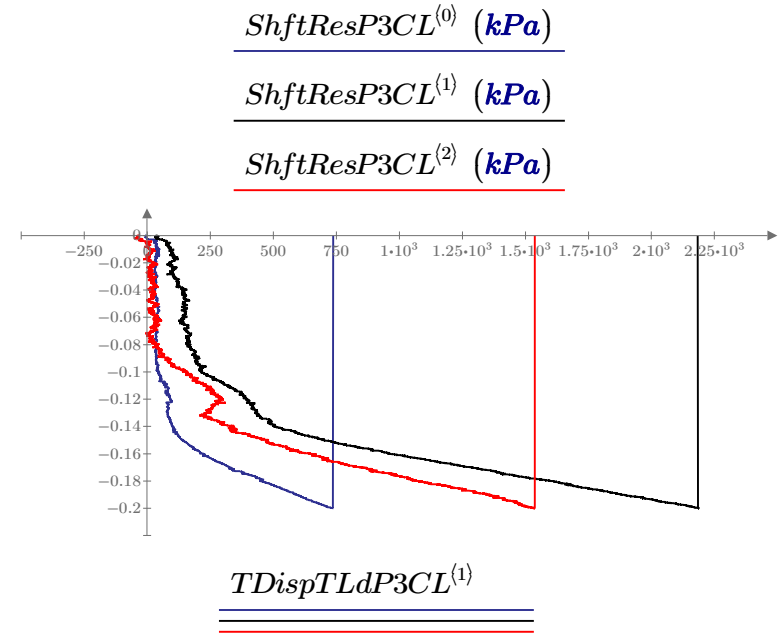


Fig E 64. Shaft Resistances vs Displacement, P3 CL

$$ShftP3CL := \text{augment} \left(TDispTLdP3CL^{(1)}, \frac{ShftResP3CL^{(0)}}{\text{kPa}}, \frac{ShftResP3CL^{(1)}}{\text{kPa}}, \frac{ShftResP3CL^{(2)}}{\text{kPa}} \right)$$

$$UltShReP3_2 := \text{lookup} \left(-0.05, ShftP3CL^{(0)}, ShftP3CL^{(3)}, \text{"near"} \right) = [40.975]$$

$$UltShReP3_1 := \text{lookup} \left(-0.05, ShftP3CL^{(0)}, ShftP3CL^{(2)}, \text{"near"} \right) = [140.024]$$

$$UltShReP3_0 := \text{lookup} \left(-0.05, ShftP3CL^{(0)}, ShftP3CL^{(1)}, \text{"near"} \right) = [40.629]$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

Functions for calculating the ultimate unit shaft resistance along the depth

```

ShftResplot(ShftP0CL, PileNum) := for i ∈ 0, 1 .. cols(ShftP0CL) - 1
    ||
    || UltShReP0 ← if PileNum = 0
    ||     || lookup(-0.15, ShftP0CL(0), ShftP0CL(1), "near")
    ||     || else
    ||     || lookup(-0.05, ShftP0CL(0), ShftP0CL(1), "near")
    ||
    || UltShReP1 ← if PileNum = 0
    ||     || 0
    ||     || else
    ||     || lookup(-0.05, ShftP0CL(0), ShftP0CL(2), "near")
    ||
    || UltShReP2 ← if PileNum = 0
    ||     || 0
    ||     || else if PileNum = 1
    ||     || 0
    ||     || else
    ||     || lookup(-0.05, ShftP0CL(0), ShftP0CL(3), "near")
    ||
    ||
    || combined ← if PileNum = 0
    ||     || stack(UltShReP0, UltShReP0, UltShReP0, UltShReP0, UltShReP0, UltShReP0)
    ||     || else if PileNum = 1
    ||     || stack(UltShReP0, UltShReP0, UltShReP1, UltShReP1, UltShReP1, UltShReP1)
    ||     || else
    ||     || stack(UltShReP0, UltShReP0, UltShReP1, UltShReP1, UltShReP2, UltShReP2)
    ||
    ||

```

$$ShftResPlotP3CL := ShftResplot(ShftP3CL, 3) \text{ kPa} = \begin{bmatrix} 40.629 \\ 40.629 \\ 140.024 \\ 140.024 \\ 40.975 \\ 40.975 \end{bmatrix} \text{ kPa}$$

Appendix E
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

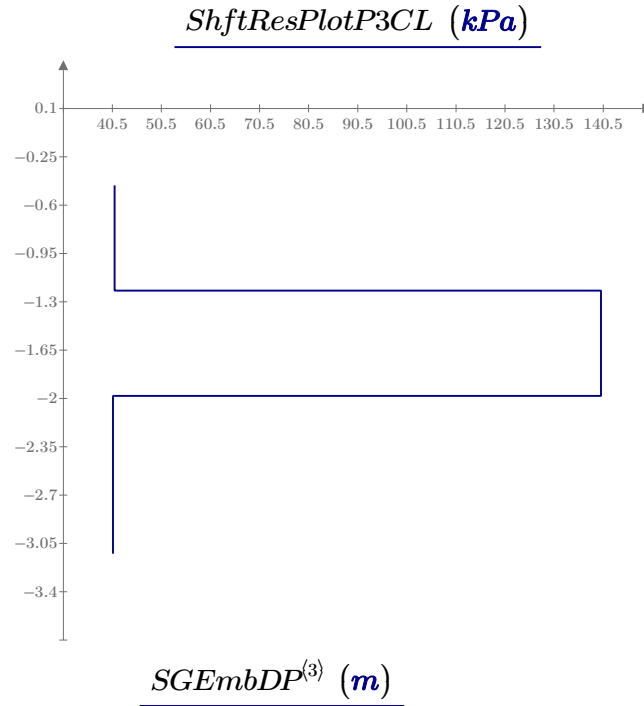


Fig E 65. Strain Gauge Depth vs Unit Shaft Resistance for post cyclic pile P3.

$ShftResplotP_C := \text{augment}(ShftResPlotP3CL, ShftResPlotP3CL, ShftResPlotP3CL, ShftResPlotP3CL, ShftResPlotP3CL)$
Ultimate Shaft resistance on the five compression piles between SGS

Function for estimating Mid depth of SGs on each piles

```
MidDSGsgmt(PileNum) :=
  shaft12 ← mean(submatrix(SGEmbDP, 0, 1, PileNum, PileNum))
  shaft23 ← if mean(submatrix(SGEmbDP, 2, 3, PileNum, PileNum)) = 0
    0
  else
    mean(submatrix(SGEmbDP, 2, 3, PileNum, PileNum))
  shaft34 ← if mean(submatrix(SGEmbDP, 4, 5, PileNum, PileNum)) = 0
    0
  else
    mean(submatrix(SGEmbDP, 4, 5, PileNum, PileNum))
  stack(shaft12, shaft23, shaft34)
```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

Function for estimating Ks of each piles

$$Ks(ShftResplotP, PileNum) := \begin{cases} shaft12 \leftarrow \frac{\text{mean}(\text{submatrix}(ShftResplotP, 0, 1, PileNum, PileNum))}{\text{mean}(\text{submatrix}(SGEmbDP, 0, 1, PileNum, PileNum)) \cdot \gamma \cdot \tan(\delta)} \\ shaft23 \leftarrow \begin{cases} \text{if } PileNum = 2 \\ 0 \\ \text{else if } PileNum = 3 \\ 0 \\ \text{else} \\ \text{if } \text{mean}(\text{submatrix}(SGEmbDP, 2, 3, PileNum, PileNum)) = 0 \\ 0 \\ \text{else} \\ \frac{\text{mean}(\text{submatrix}(ShftResplotP, 2, 3, PileNum, PileNum))}{\text{mean}(\text{submatrix}(SGEmbDP, 2, 3, PileNum, PileNum)) \cdot \gamma \cdot \tan(\delta)} \end{cases} \\ shaft34 \leftarrow \begin{cases} \text{if } PileNum = 4 \\ 0 \\ \text{else} \\ \text{if } \text{mean}(\text{submatrix}(SGEmbDP, 4, 5, PileNum, PileNum)) = 0 \\ 0 \\ \text{else} \\ \frac{\text{mean}(\text{submatrix}(ShftResplotP, 4, 5, PileNum, PileNum))}{\text{mean}(\text{submatrix}(SGEmbDP, 4, 5, PileNum, PileNum)) \cdot \gamma \cdot \tan(\delta)} \end{cases} \\ \text{stack}(-shaft12, -shaft23, -shaft34) \end{cases}$$

$$KsP_C := Ks(ShftResplotP_C, 3)$$

$$MidDSGsgmtP := \text{augment}(MidDSGsgmt(0), MidDSGsgmt(1), MidDSGsgmt(2), MidDSGsgmt(3), MidDSGsgmt(4))$$

$$Ko := \begin{bmatrix} 1 - \sin(\varphi) & 1 - \sin(\varphi) \end{bmatrix} \quad Kp := \begin{bmatrix} \frac{1 + \sin(\varphi)}{1 - \sin(\varphi)} & \frac{1 + \sin(\varphi)}{1 - \sin(\varphi)} \end{bmatrix} \quad Ka := \begin{bmatrix} \frac{1 - \sin(\varphi)}{1 + \sin(\varphi)} & \frac{1 - \sin(\varphi)}{1 + \sin(\varphi)} \end{bmatrix} = \begin{bmatrix} 0.317 & 0.317 \end{bmatrix}$$

$$K := \begin{bmatrix} 0.09 \cdot e^{0.08 \cdot \left(\varphi \cdot \frac{180}{\pi}\right)} & 0.09 \cdot e^{0.08 \cdot \left(\varphi \cdot \frac{180}{\pi}\right)} \end{bmatrix} \quad \text{Mitsch and Clemence 1985}$$

$$ProtEmbed := \begin{bmatrix} 0 & -E \cdot Nscale^{sclfac}_{0,0} \end{bmatrix} = \begin{bmatrix} 0 & -3.382 \end{bmatrix} \text{ m} \quad \text{Pile Embedment in prototype scale unit}$$

$$KsP_C = \begin{bmatrix} 2.284 \\ 0 \\ 7.016 \end{bmatrix}$$

$$MidDSGsgmtP = \begin{bmatrix} -1.791 & -2.934 & -2.934 & -2.553 & -2.934 \\ 0 & -1.6 & -2.362 & -1.6 & -1.981 \\ 0 & 0 & -1.219 & -0.838 & -0.838 \end{bmatrix} \text{ m}$$

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

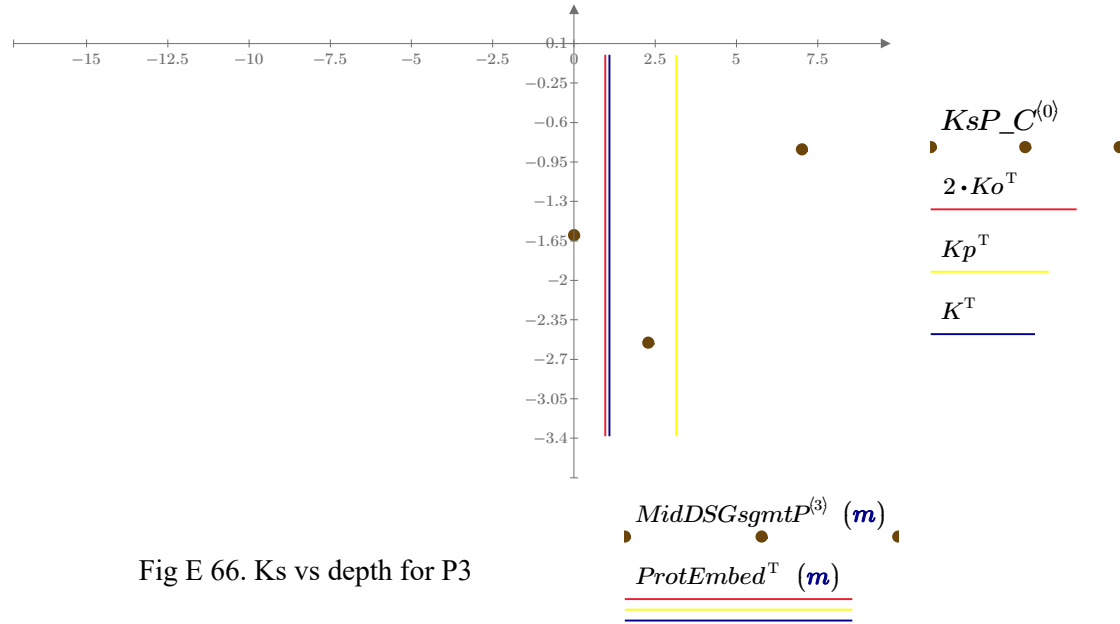


Fig E 66. Ks vs depth for P3

Function for estimating the shaft resistance EDR

```

ShftEDR (TDispTLdP0PL1, ShftResP2PL1, Pseu1perS, IniTime, IniDisp, LoopNo, ShftNo) :=
    m ← TDispTLdP0PL1
    n ← ShftResP2PL1
    n ← kPa
    o ← TimeCycLoop (Pseu1perS, IniTime, IniDisp) - IniTime
    w ← -m(1)
    wmax ← max (-m(1))
    if ShftNo = 1
        q ← n(0)
        qmax ← max (n(0))
    else if ShftNo = 2
        q ← n(1)
        qmax ← max (n(1))
    else if ShftNo = 3
        q ← n(2)
        qmax ← max (n(2))
    if LoopNo = 1
        t1 ← m1,0 - IniTime
        t2 ← o1
    else if LoopNo = 2
        t1 ← o1
        t2 ← on

```

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

```

else if LoopNo = 3
    t1 ← o2
    t2 ← o3
else if LoopNo = 4
    t1 ← o3
    t2 ← o4

tstart ← lookup (t1, (m(0) - IniTime), (m(0) - IniTime), "near")
tend ← lookup (t2, (m(0) - IniTime), (m(0) - IniTime), "near")
rowstart ← match (t1, (m(0) - IniTime), "near")
rowend ← match (t2, (m(0) - IniTime), "near")
for i ∈ rowstart0,0 .. rowend0,0
    ri ← ((wi - wi-1) * ((qi + qi-1) / 2))

area ← ∑ r

EDR ← if qmax = 0
    0
    else if wmax = 0
    0
    else if area = 0
    0
    else
    area / (qmax * wmax)

s ← augment ((tstart + IniTime), (tend + IniTime), rowstart, rowend, qmax, wmax, area, EDR)
EDR

```

Function for combining the shaft resistance EDR

```

ShftEDRPOPLSG (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, PileNo) :=
q1 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1)
q2 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1)
q3 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1)
q4 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1)
r1 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2)
r2 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2)
r3 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2)
r4 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2)
w1 ← if PileNo = 0
    0
    else
    ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 3)
w2 ← if PileNo = 0
    0
    else
    ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 3)
w3 ← if PileNo = 0
    0
    else
    ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 3)

```

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

$$NoLoop := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

$$\begin{aligned} & w4 \leftarrow \text{if } PileNo = 0 \\ & \quad 0 \\ & \quad \text{else} \\ & \quad \quad ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3) \\ & \text{augment}(\text{stack}(q1, q2, q3, q4), \text{stack}(r1, r2, r3, r4), \text{stack}(w1, w2, w3, w4)) \end{aligned}$$

$$ShftEDRP3PL1 := ShftEDRPOPLSG(TDispTLdP3PL1, ShftResP3PL1, PseuPL1H, IniTimePL1H, 3) = \begin{bmatrix} 0.4 & 0.438 & 0.288 \\ -0.09 & -0.048 & -0.118 \\ -0.061 & -0.14 & -0.08 \\ 0.008 & -0.083 & -0.084 \end{bmatrix}$$

$$ShftEDRP3PL2 := ShftEDRPOPLSG(TDispTLdP3PL2, ShftResP3PL2, PseuPL2H, IniTimePL2H, 3) = \begin{bmatrix} 0.975 & 0.787 & 0.821 \\ 0.593 & 0.485 & 0.474 \\ 0.52 & 0.461 & 0.452 \\ 0.562 & 0.514 & 0.536 \end{bmatrix}$$

$$ShftEDRP3PL3 := ShftEDRPOPLSG(TDispTLdP3PL3, ShftResP3PL3, PseuPL3H, IniTimePL3H, 3) = \begin{bmatrix} 0.386 & 0.212 & 0.237 \\ 0.235 & 0.209 & 0.19 \\ 0.212 & 0.194 & 0.234 \\ 0.184 & 0.193 & 0.218 \end{bmatrix}$$

$$ShftEDRP3PL4 := ShftEDRPOPLSG(TDispTLdP3PL4, ShftResP3PL4, PseuPL4H, IniTimePL4H, 3) = \begin{bmatrix} 0.752 & 0.039 & 0.525 \\ -0.018 & -0.048 & -0.076 \\ -0.015 & -0.061 & -0.091 \\ -0.029 & -0.07 & -0.104 \end{bmatrix}$$

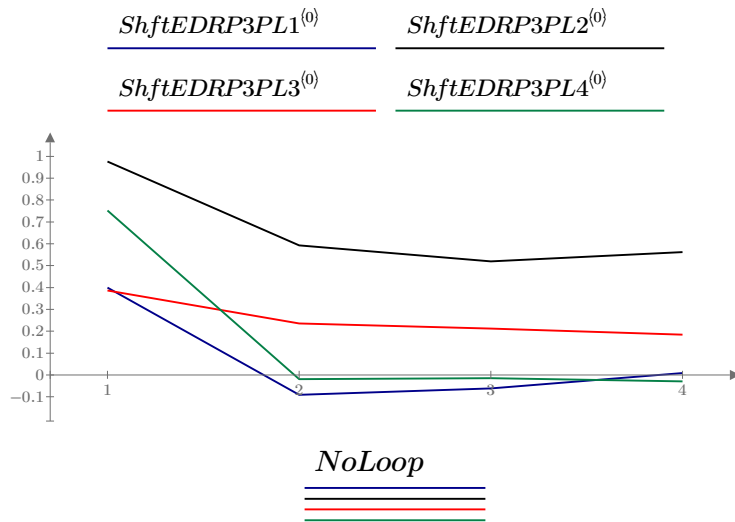


Fig E 67. Shaft EDR vs No of loops Seg1

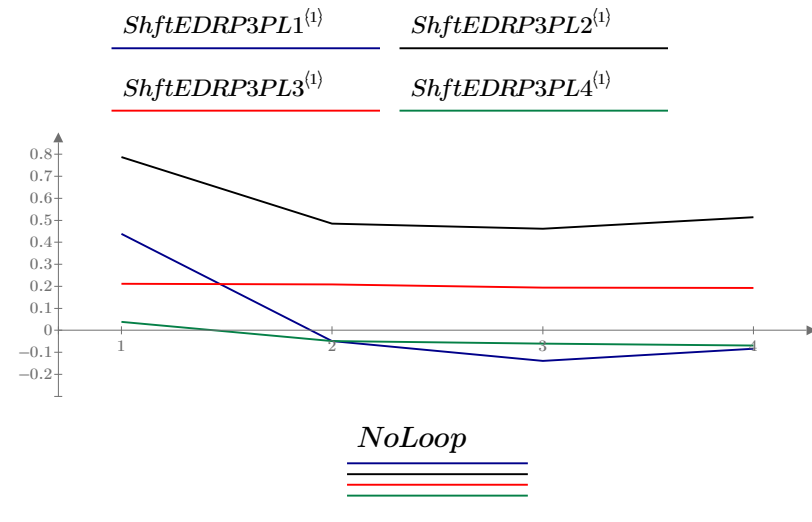


Fig E 68. Shaft EDR vs No of loops Seg 2

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

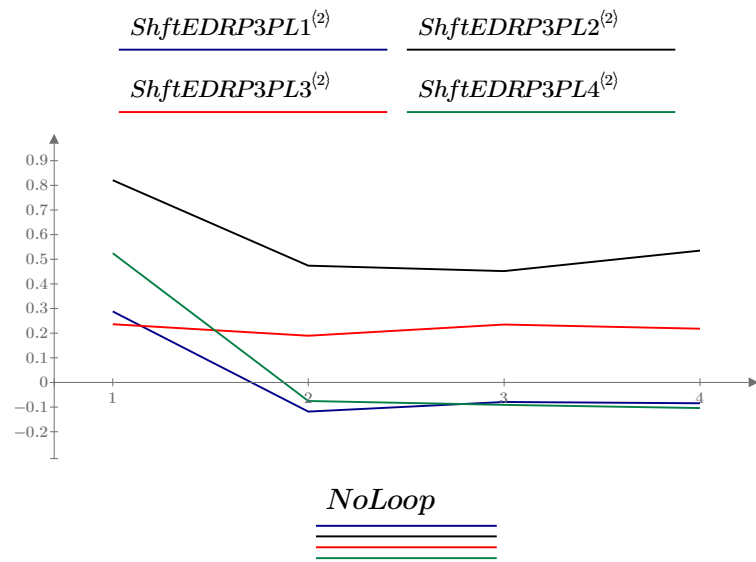
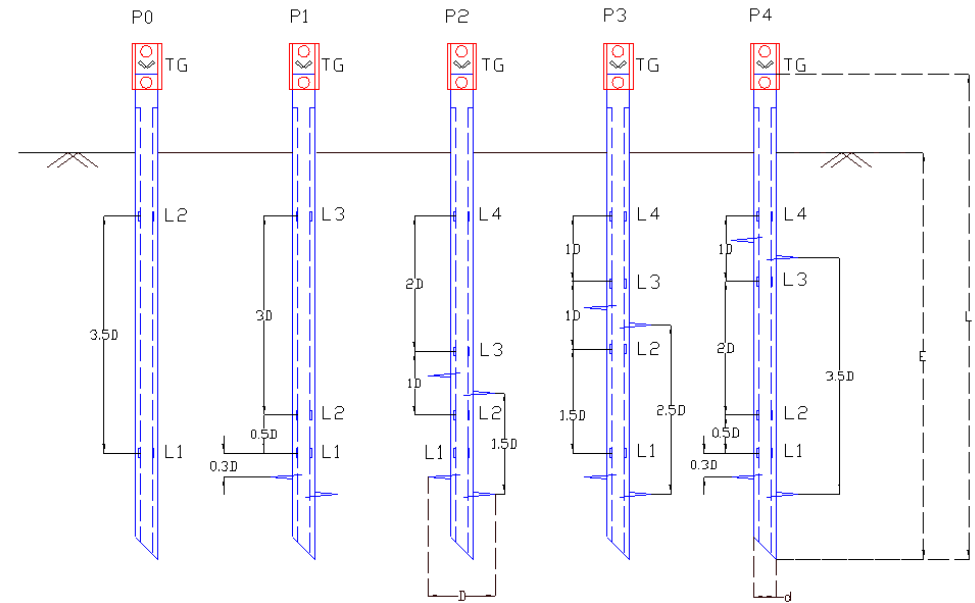


Fig E 69. EDR vs No of loops Seg 3



2.3.4 End Bearing vs Depth

$$A_b := \pi \cdot \frac{\left(D \cdot Nscale^{sclfac_{0,0}}\right)^2}{4} = 0.456 \text{ m}^2$$

Total area at the helix in prototype scale

$$A_d := \pi \cdot \frac{\left(d \cdot Nscale^{sclfac_{0,0}}\right)^2}{4} = 0.051 \text{ m}^2$$

Total area at the shaft in prototype scale

Function for determining the end bearing

```

EndBrng(TDispTLdP0CL, PileNum) :=
  for i ∈ 0, 1..rows(TDispTLdP0CL) - 1
    for j ∈ 0, 1..cols(TDispTLdP0CL) - 1
      qb1_{i,0} ← if PileNum = 0
                  (TDispTLdP0CL_{i,3}) kN
                  A_d
                else
                  (TDispTLdP0CL_{i,3}) kN
                  A_b - A_d
      qb23_{i,1} ← if PileNum = 2
                   (TDispTLdP0CL_{i,5} - TDispTLdP0CL_{i,4}) kN
                   A_b - A_d
                 else if PileNum = 3
                   (TDispTLdP0CL_{i,5} - TDispTLdP0CL_{i,4}) kN
                   A_b - A_d
                 else
                   0
      qb34_{i,2} ← if PileNum = 4
                   (TDispTLdP0CL_{i,6} - TDispTLdP0CL_{i,5}) kN
                   A_b - A_d
                 else
                   0
    augment(qb1^{(0)}, qb23^{(1)}, qb34^{(2)})
  
```


Appendix E
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

$$EndBrng(TDispTLdP3CL, 3) = \begin{matrix} 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ \vdots \\ 13855 \end{matrix} \begin{bmatrix} 1.551 & 49.849 & 0 \\ 2.481 & 51.095 & 0 \\ 3.412 & 52.498 & 0 \\ 4.342 & 53.901 & 0 \\ 5.273 & 55.537 & 0 \\ 4.342 & 57.173 & 0 \\ 4.342 & 57.173 & 0 \\ 4.342 & 59.978 & 0 \\ 4.342 & 59.978 & 0 \\ 4.342 & 59.978 & 0 \\ 2.481 & 59.978 & 0 \\ 2.481 & 62.47 & 0 \\ \vdots & \vdots & \vdots \end{bmatrix} \text{ kPa}$$

$$\frac{EndBrng(TDispTLdP3CL, 3)^{(1)} \text{ (kPa)}}{EndBrng(TDispTLdP3CL, 3)^{(0)} \text{ (kPa)}}$$

$$\frac{EndBrng(TDispTLdP3CL, 3)^{(0)} \text{ (kPa)}}{EndBrng(TDispTLdP3CL, 3)^{(0)} \text{ (kPa)}}$$

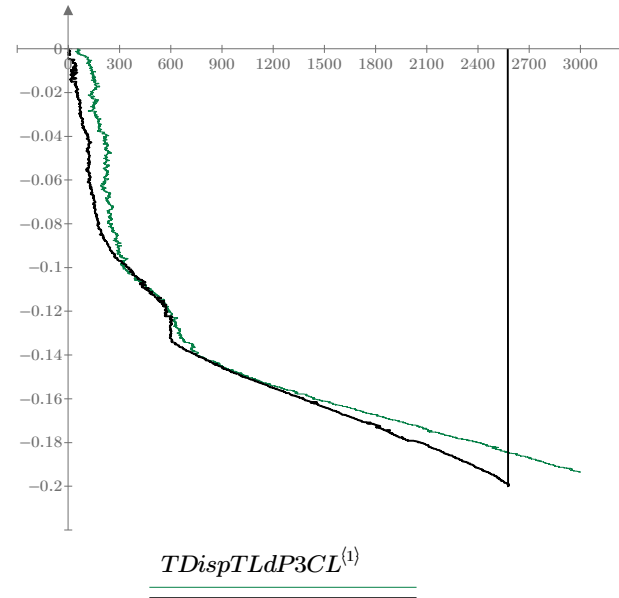


Fig E 70. Depth vs End Bearing for compression pile P3

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

$$UltEndBrngP3_1 := \text{lookup}\left(-0.05, TDispTLdP3CL^{(1)}, EndBrng(TDispTLdP3CL, 3)^{(1)}, \text{"near"}\right) = [210.037] \text{ } \mathbf{kPa}$$

$$UltEndBrngP3_0 := \text{lookup}\left(-0.05, TDispTLdP3CL^{(1)}, EndBrng(TDispTLdP3CL, 3)^{(0)}, \text{"near"}\right) = [122.209] \text{ } \mathbf{kPa}$$

$$HelixLoc := - \begin{bmatrix} 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 \\ 0 & 0 & 0.6 + 2 + 0.3 + 0.17 & 0.6 + 1 + 0.3 + 0.17 & 0.6 + 0.3 + 0.17 \end{bmatrix} \cdot D \cdot Nscale^{sclfac_{0,0}}$$

$$\text{stack}\left(\frac{UltEndBrngP3_0}{-HelixLoc_{0,3} \cdot \gamma}, \frac{UltEndBrngP3_1}{-HelixLoc_{1,3} \cdot \gamma}\right) = \begin{bmatrix} 2.18 \\ 8.271 \end{bmatrix}$$

$$HelixLoc = \begin{bmatrix} -3.482 & -3.482 & -3.482 & -3.482 & -3.482 \\ 0 & 0 & -2.339 & -1.577 & -0.815 \end{bmatrix} \text{ } \mathbf{m}$$

$$BrngP3PL1 := EndBrng(TDispTLdP3PL1, 3)$$

$$BrngP3PL2 := EndBrng(TDispTLdP3PL2, 3)$$

$$BrngP3PL3 := EndBrng(TDispTLdP3PL3, 3)$$

$$BrngP3PL4 := EndBrng(TDispTLdP3PL4, 3)$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

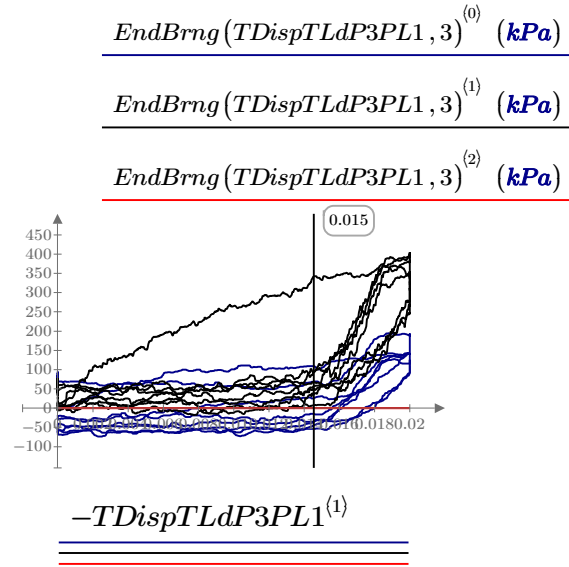


Fig E 71. End Bearing vs Depth for P2 PL1

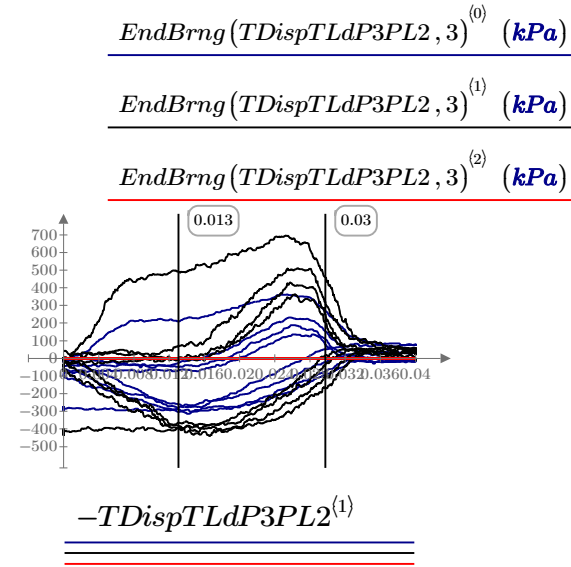


Fig E 72. End Bearing vs Depth for P2 PL2

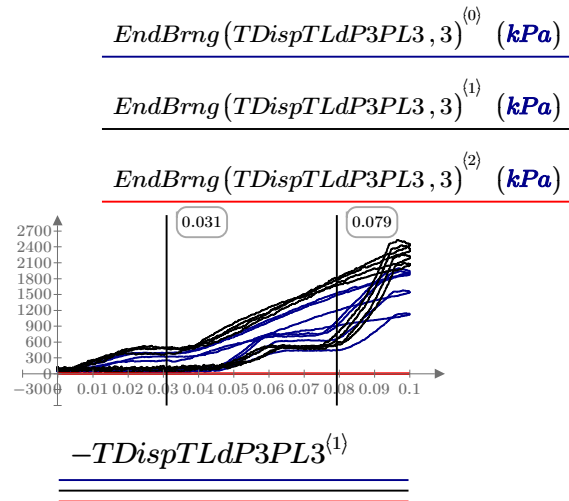


Fig E 73. End Bearing vs Depth for P2 PL3

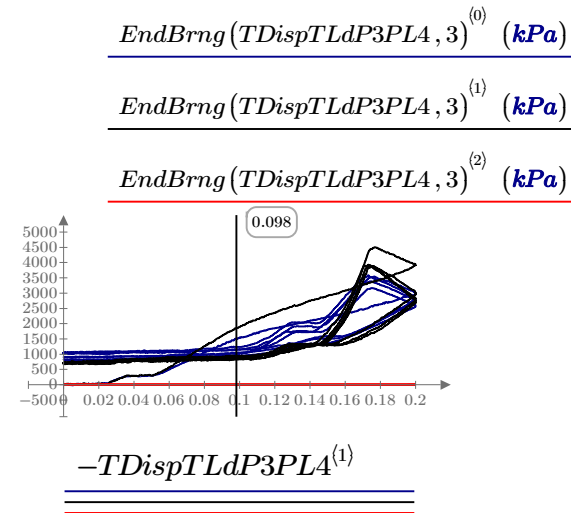


Fig E 74. End Bearing vs Depth for P2 PL4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

Functions for calculating the EDR from the bearing resistances

```

BrngEDR (TDispTLdP0PL1 , BrngP2PL1 , Pseu1perS , IniTime , IniDisp , LoopNo , ShftNo) :=
  m ← TDispTLdP0PL1
  n ←  $\frac{BrngP2PL1}{kPa}$ 
  o ← TimeCyclLoop (Pseu1perS , IniTime , IniDisp) - IniTime
  w ←  $-m^{(1)}$ 
  wmax ← max ( $-m^{(1)}$ )
  if ShftNo = 1
  ||
  || q ←  $n^{(0)}$ 
  || qmax ← max ( $n^{(0)}$ )
  else if ShftNo = 2
  ||
  || q ←  $n^{(1)}$ 
  || qmax ← max ( $n^{(1)}$ )
  else if ShftNo = 3
  ||
  || q ←  $n^{(2)}$ 
  || qmax ← max ( $n^{(2)}$ )
  if LoopNo = 1
  ||
  || t1 ←  $m_{1,0} - IniTime$ 
  || t2 ←  $o_1$ 
  else if LoopNo = 2
  ||
  || t1 ←  $o_1$ 
  || t2 ←  $o_2$ 
  else if LoopNo = 3
  ||
  || t1 ←  $o_2$ 
  || t2 ←  $o_3$ 
  else if LoopNo = 4
  ||
  || t1 ←  $o_3$ 
  || t2 ←  $o_4$ 
  tstart ← lookup (t1 , ( $m^{(0)} - IniTime$ ) , ( $m^{(0)} - IniTime$ ) , "near")
  tend ← lookup (t2 , ( $m^{(0)} - IniTime$ ) , ( $m^{(0)} - IniTime$ ) , "near")
  rowstart ← match (t1 , ( $m^{(0)} - IniTime$ ) , "near")
  rowend ← match (t2 , ( $m^{(0)} - IniTime$ ) , "near")
  for i ∈ rowstart0,0 .. rowend0,0
  ||
  ||  $r_i \leftarrow \left( (w_i - w_{i-1}) \cdot \left( \frac{(q_i + q_{i-1})}{2} \right) \right)$ 
  area ←  $\sum r$ 
  EDR ← if qmax = 0
  ||
  || 0
  else if wmax = 0
  ||
  || 0
  else if area = 0
  ||
  || 0
  else
  ||
  ||  $\frac{area}{qmax \cdot wmax}$ 
  s ← augment ((tstart + IniTime) , (tend + IniTime) , rowstart , rowend , qmax , wmax , area , EDR)
  EDR

```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

Function for compiling EDR for the end bearing in loading cycles

$$BrngEDRPOPLSG(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, PileNo) := \begin{cases} q1 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1) \\ q2 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1) \\ q3 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1) \\ q4 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1) \\ r1 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2) \\ r2 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2) \\ r3 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2) \\ r4 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2) \\ w1 \leftarrow \text{if } PileNo = 0 \\ \quad \begin{cases} 0 \\ \text{else} \\ BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 3) \end{cases} \\ w2 \leftarrow \text{if } PileNo = 0 \\ \quad \begin{cases} 0 \\ \text{else} \\ BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 3) \end{cases} \\ w3 \leftarrow \text{if } PileNo = 0 \\ \quad \begin{cases} 0 \\ \text{else} \\ BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 3) \end{cases} \\ w4 \leftarrow \text{if } PileNo = 0 \\ \quad \begin{cases} 0 \\ \text{else} \\ BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3) \end{cases} \\ \text{augment}(\text{stack}(q1, q2, q3, q4), \text{stack}(r1, r2, r3, r4), \text{stack}(w1, w2, w3, w4)) \end{cases}$$

$$NoLoop := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

$$BrngEDRP3PL1 := BrngEDRPOPLSG(TDispTLdP3PL1, BrngP3PL1, PseuPL1H, IniTimePL1H, 3) = \begin{bmatrix} 0.611 & 0.438 & 0 \\ -0.116 & -0.048 & 0 \\ -0.158 & -0.14 & 0 \\ -0.342 & -0.083 & 0 \end{bmatrix}$$

$$BrngEDRP3PL2 := BrngEDRPOPLSG(TDispTLdP3PL2, BrngP3PL2, PseuPL2H, IniTimePL2H, 3) = \begin{bmatrix} 0.786 & 0.787 & 0 \\ 0.49 & 0.485 & 0 \\ 0.503 & 0.461 & 0 \\ 0.527 & 0.514 & 0 \end{bmatrix}$$

$$BrngEDRP3PL3 := BrngEDRPOPLSG(TDispTLdP3PL3, BrngP3PL3, PseuPL3H, IniTimePL3H, 3) = \begin{bmatrix} 0.125 & 0.212 & 0 \\ 0.115 & 0.209 & 0 \\ 0.141 & 0.194 & 0 \\ 0.152 & 0.193 & 0 \end{bmatrix}$$

$$BrngEDRP3PL4 := BrngEDRPOPLSG(TDispTLdP3PL4, BrngP3PL4, PseuPL4H, IniTimePL4H, 3) = \begin{bmatrix} -0.057 & 0.039 & 0 \\ -0.087 & -0.048 & 0 \\ -0.107 & -0.061 & 0 \\ -0.112 & -0.07 & 0 \end{bmatrix}$$

Appendix E

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P3 Helix Pile

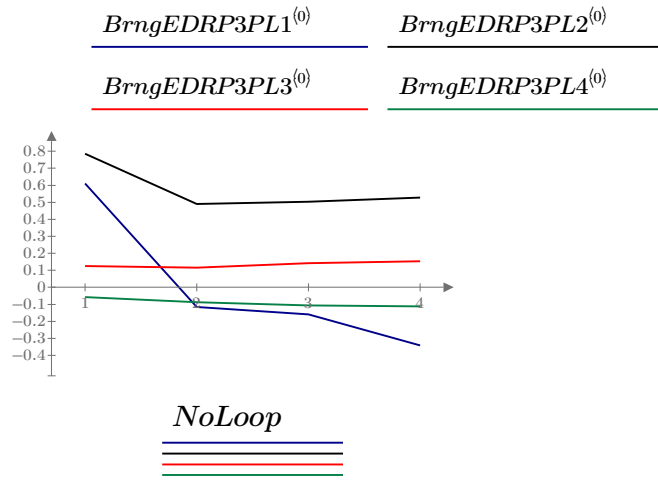


Fig E 75. Shaft EDR vs No of loops Helix Location 1 SG 1

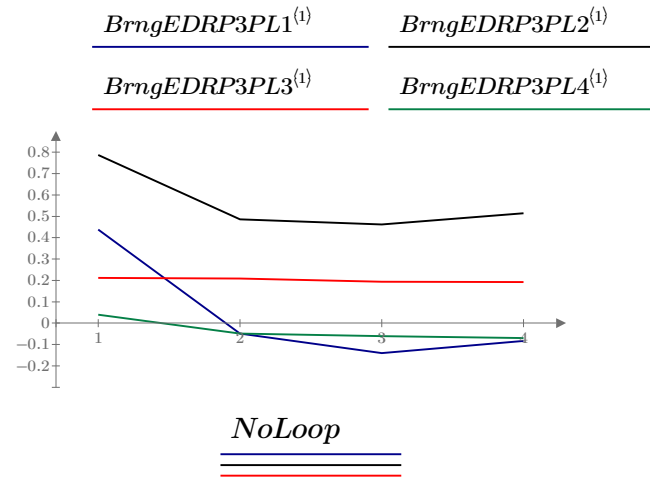


Fig E 76. Shaft EDR vs No of loops Helix Location 2 SG 2-3

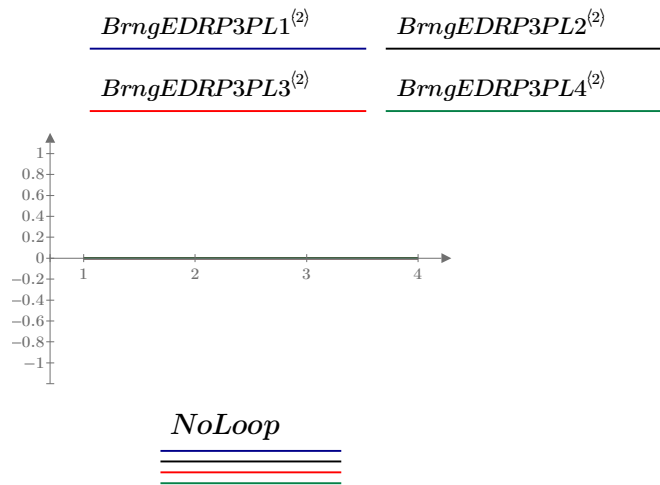
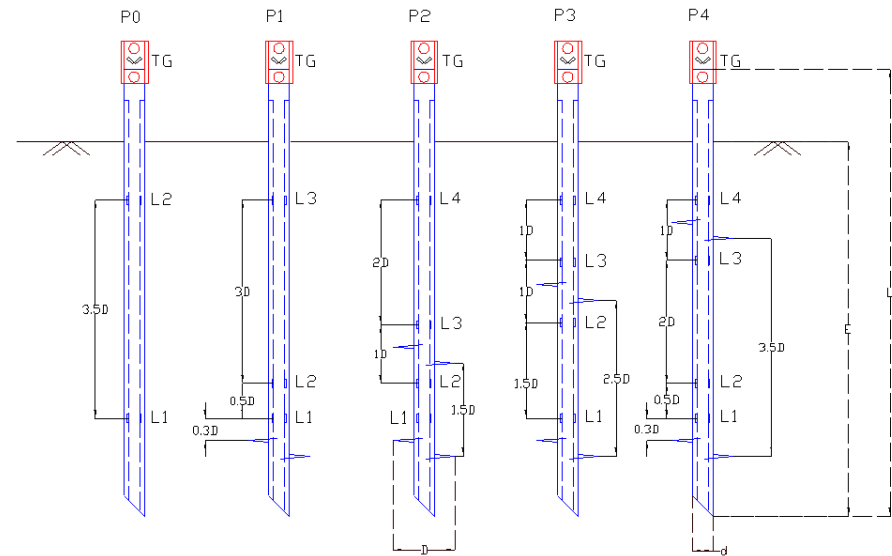


Fig E 77. EDR vs No of loops Helix Location 3 SG 3-4



Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

1. Introduction

The series of sheets in Appendix B contains the data conversion and processing procedures specifically for the NI02 centrifuge test series on P4 Helix Pile. For the data conversion procedures, the raw data files were first corrected by subtracting the initial value of pre spin data depending on file index. The data were then converted into engineering units through recalibrations of the strain gauges in the centrifuge data logger.

2. HBM Data Conversion

HBM data were recorded by the HBM Data Logger connected to the main computer unit of the GeoCerf centrifuge.

2.1 General Information

2.1.1 Model Pile Dimensions

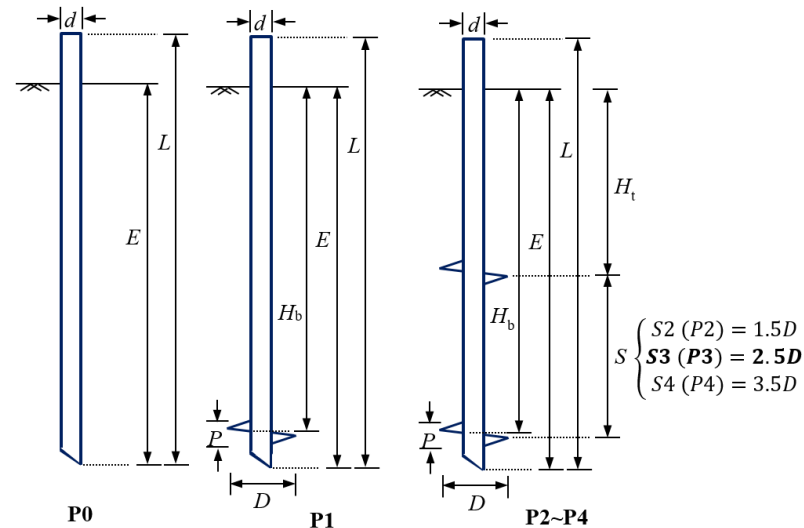
$L := 271.8 \text{ mm}$	Length of the Pile
$d := 12.7 \text{ mm}$	Diameter of the shaft
$D := 38.1 \text{ mm}$	Diameter of the helix
$E := 169.1 \text{ mm}$	Embedment depth of pile
$H_b := 150 \text{ mm}$	Depth to bottom helix
$H_t := [150] \text{ mm}$	Depth to top helix
$P_s := \pi \cdot D = 0.12 \text{ m}$	Perimeter of the Helical Pile Shaft
$H_{eff} := (H_b - D)$	Effective Shaft Length
$P := 12.7 \text{ mm}$	Pitch of the helix

2.1.2 Properties of Sand

$\gamma := 16.1 \frac{\text{kN}}{\text{m}^3}$	Unit Weight
$\varphi := 31.2 \text{ deg}$	CV Friction Angle
$\delta := \left(\frac{3}{4} \cdot \varphi\right) = 23.4 \text{ deg}$	CV Dilation Angle

2.1.3 Centrifuge Scale

$NoSGages := 4$	1 refers to the Strain Gage at the bottom and 4 the Strain Gage at the top of the pile; Total No of Strain Gages: P0=2, P1=3, P2 to P4= 4
$Nscale := 20$	Centrifuge g-level



Schematic of the model piles

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

$$sclfac := [1 \ 2 \ 3]$$

Centrifuge scale factor N^{scale} , 1 for displacement, 2 for force, 3 for Torque

2.1.4 Pseudostatic Loading Stages

2.1.4.1 Actuator Scale Factors

$$RateScale := \frac{8}{\frac{mm}{sec}} \quad \leq 1V8 = 1mm/sec$$

$$DistanScale := \frac{64000}{mm} \quad \leq 1D64000 = 1mm$$

2.1.4.2 Pseudostatic Loading Stages for Helix Piles (P1 to P4)

$$LDisp := \begin{bmatrix} 0.01 \\ 0.02 \\ 0.05 \\ 0.10 \\ 0.10 \end{bmatrix} \quad LNoLoop := \begin{bmatrix} 8 \\ 8 \\ 8 \\ 8 \\ 1 \end{bmatrix} \quad PsdoTLag := 5 \text{ s} \quad LRate := \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 0.33 \end{bmatrix} \frac{mm}{min}$$

$$LTime(Dia) := \left\| \begin{array}{l} \text{for } i \in 0, 1 \dots \text{rows}(LDisp) - 1 \\ \left\| \begin{array}{l} 2 \cdot LDisp_i \cdot Dia \cdot LNoLoop_i \\ k_i \leftarrow \frac{\quad}{LRate_i} + (PsdoTLag \cdot (LNoLoop_i - 1)) \end{array} \right\| \\ k \end{array} \right\|$$

$$LTime(D) = \begin{bmatrix} 400.76 \\ 766.52 \\ 1863.8 \\ 3692.6 \\ 1385.455 \end{bmatrix} \text{ s} \quad LTime(d) = \begin{bmatrix} 156.92 \\ 278.84 \\ 644.6 \\ 1254.2 \\ 461.818 \end{bmatrix} \text{ s}$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

2.2 Calibration of the Strain Gages in HBM Data Logger

2.2.1 Calibration of Axial Strain Gages

RawDataCalib := READEXCEL (“..\Finalized NI01\Calibration SGages HBM Centrifuge Corrected.xlsx”, “Sheet1!A1:G12”)

$$\text{RawDataCalib} = \begin{bmatrix} 4.427 & 1 & 0.076 & 0.104 & 0.149 & 0.098 & 0.132 \\ 7.97 & 1 & 0.152 & 0.171 & 0.23 & 0.195 & 0.244 \\ 13.606 & 1 & 0.391 & 0.295 & 0.343 & 0.287 & 0.336 \\ 4.427 & 2 & 0.048 & 0.06 & 0.078 & 0.091 & 0.1 \\ 7.97 & 2 & 0.053 & 0.114 & 0.114 & 0.136 & 0.194 \\ 13.606 & 2 & 0.088 & 0.214 & 0.161 & 0.225 & 0.231 \\ 4.427 & 3 & 0 & 0.043 & 0.028 & 0.052 & 0.037 \\ 7.97 & 3 & 0 & 0.063 & 0.151 & 0.087 & 0.078 \\ 13.606 & 3 & 0 & 0.127 & 0.199 & 0.149 & 0.112 \\ 4.427 & 4 & 0 & 0 & 0.089 & 0.035 & 0.028 \\ 7.97 & 4 & 0 & 0 & 0.109 & 0.067 & 0.055 \\ 13.606 & 4 & 0 & 0 & 0.145 & 0.127 & 0.141 \end{bmatrix}$$

Colm 0 represents calibration loads in kg, Colm 1 represents Strain Gage Number, Colm 2-6 represents Strain Gage HBM readings for piles P0,P1,P2,P3 and P4 respectively

CmbLdAx := RawDataCalib⁽⁰⁾ **kg · g** Load Combinations

CalibdataPile := submatrix (RawDataCalib, 0, rows (RawDataCalib) - 1, 2, 6) · 10⁻³ · $\frac{mV}{V}$ HBM Strain Gage Data

Function for Calibration factor for all strain gages in each pile

$$CF := \begin{bmatrix} \text{for } i \in 0, 1 \dots \text{rows}(\text{CalibdataPile}) - 1 \\ \text{for } j \in 0, 1 \dots \text{cols}(\text{CalibdataPile}) - 1 \\ k_{i,j} \leftarrow \text{CmbLdAx}_{i,0} \\ q_{i,j} \leftarrow \text{CalibdataPile}_{i,j} \\ m_{i,j} \leftarrow \text{if } q_{i,j} = 0 \\ \quad 0 \\ \text{else} \\ \quad \frac{k_{i,j}}{q_{i,j}} \end{bmatrix} = \begin{bmatrix} 571.237 & 417.443 & 291.369 & 443 & 328.894 \\ 514.204 & 457.07 & 339.822 & 400.815 & 320.324 \\ 341.251 & 452.303 & 389.007 & 464.91 & 397.111 \\ 904.459 & 723.567 & 556.59 & 477.077 & 434.14 \\ 1474.698 & 685.605 & 685.605 & 574.699 & 402.881 \\ 1516.242 & 623.501 & 828.753 & 593.019 & 577.616 \\ 0 & 1009.629 & 1550.501 & 834.885 & 1173.352 \\ 0 & 1240.619 & 517.609 & 898.379 & 1002.038 \\ 0 & 1050.624 & 670.499 & 895.499 & 1191.333 \\ 0 & 0 & 487.798 & 1240.401 & 1550.501 \\ 0 & 0 & 717.055 & 1166.552 & 1421.073 \\ 0 & 0 & 920.202 & 1050.624 & 946.307 \end{bmatrix} \frac{kN}{\frac{mV}{V}}$$

Calibration Factor: Here, the columns represents the Piles from P0 to P4 (left to right) and the rows represents the Strain Gage readings SG1 to SG4 (top to bottom) for three load combinations

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

2.2.1 Calibration of Torque Strain Gages

RawDataTorque := READEXCEL (“..\Finalized NI01\Calibration Torque S Gages HBM Centrifuge .xlsx”, “Sheet1!J34:K36”)

$$\text{RawDataTorque} = \begin{bmatrix} 0.144 & 0.022 \\ 0.206 & 0.03 \\ 0.35 & 0.052 \end{bmatrix} \quad \text{CmbLdTr} := \text{RawDataTorque}^{(0)} \mathbf{N} \cdot \mathbf{m} \quad \text{CalibdataTr} := \text{RawDataTorque}^{(1)} \cdot 10^{-3} \cdot \frac{\mathbf{mV}}{\mathbf{V}}$$

Function for Calibration factor for all torsional load on strain gages in each pile

$$\text{CFTr} := \left\| \begin{array}{l} \text{for } i \in 0, 1 \dots \text{rows}(\text{CalibdataTr}) - 1 \\ \quad \left\| \begin{array}{l} \text{for } j \in 0, 1 \dots \text{cols}(\text{CalibdataTr}) - 1 \\ \quad \left\| \begin{array}{l} k_{i,j} \leftarrow \text{CmbLdTr}_{i,0} \\ q_{i,j} \leftarrow \text{CalibdataTr}_{i,j} \\ m_{i,j} \leftarrow \text{if } q_{i,j} = 0 \\ \quad \left\| 0 \\ \quad \text{else} \\ \quad \quad \left\| \frac{k_{i,j}}{q_{i,j}} \end{array} \right\| \end{array} \right\| \end{array} \right\| \end{array} \right\| = \begin{bmatrix} 6.674 \\ 6.813 \\ 6.763 \end{bmatrix} \mathbf{m} \cdot \frac{\mathbf{kN}}{\frac{\mathbf{mV}}{\mathbf{V}}}$$

2.3 Pseudostatic Cyclic Centrifuge Test on Piles

Five piles were tested in compression and four piles were tested in tension in two separate model boxes two ascertain the axial load transfer mechanism within the pile.

2.3.1 Pseudostatic Cyclic Displacement Time History

$$\text{Lag} := 5 \quad \text{LagCyc} := 100 \quad \text{LoadCycRate} := 1 \frac{\mathbf{mm}}{\mathbf{min}} = 0.017 \frac{\mathbf{mm}}{\mathbf{s}} \quad \text{LoadCompRate} := 0.33 \frac{\mathbf{mm}}{\mathbf{min}} = 0.006 \frac{\mathbf{mm}}{\mathbf{s}}$$

Actuator Loading rate in cyclic Actuator Loading rate in compression

$$\text{NormDisp} := \begin{bmatrix} 0.01 \\ 0.02 \\ 0.05 \\ 0.1 \\ 0.2 \end{bmatrix} \quad \text{NormDispPeakCycles} := 2 \cdot \begin{bmatrix} \text{NormDisp}_0 \\ \text{NormDisp}_1 \\ \text{NormDisp}_2 \\ \text{NormDisp}_3 \end{bmatrix} = \begin{bmatrix} 0.02 \\ 0.04 \\ 0.1 \\ 0.2 \end{bmatrix}$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

Function for calculating time required for each pseudostatic load

```

Time(Dia) := for j ∈ 0,1..3
  for i ∈ 0,1..4
    k ← NormDisp
    p ←  $\frac{Dia}{m}$ 
    z ←  $\frac{LoadCycRate}{s}$ 
    x ←  $\frac{LoadCompRate}{m}$ 
     $q_{0,0} \leftarrow k_{0,0} \cdot \frac{p}{z}$ 
     $q_{1,0} \leftarrow k_{1,0} \cdot \frac{p}{z}$ 
     $q_{2,0} \leftarrow k_{2,0} \cdot \frac{p}{z}$ 
     $q_{3,0} \leftarrow k_{3,0} \cdot \frac{p}{z}$ 
     $q_{4,0} \leftarrow k_{4,0} \cdot \frac{p}{x}$ 
  end for
end for
q

```

$$TimeHelix := Time(D) = \begin{bmatrix} 22.86 \\ 45.72 \\ 114.3 \\ 228.6 \\ 1385.455 \end{bmatrix}$$

$$TimeShaft := Time(d) = \begin{bmatrix} 7.62 \\ 15.24 \\ 38.1 \\ 76.2 \\ 461.818 \end{bmatrix}$$

Function for calculating initial time required for each pseudostatic load

```

DispIniTime(DispHelixShaft) := for j ∈ 0,1..3
  for i ∈ 0,1..5
     $q_{0,0} \leftarrow 0$ 
     $q_{1,0} \leftarrow \left( (16 \cdot DispHelixShaft_{0,0}) + (7 \cdot Lag) + LagCyc \right)$ 
     $q_{2,0} \leftarrow q_{1,0} + \left( (16 \cdot DispHelixShaft_{1,0}) + (7 \cdot Lag) + (LagCyc) \right)$ 
     $q_{3,0} \leftarrow q_{2,0} + \left( (16 \cdot DispHelixShaft_{2,0}) + (7 \cdot Lag) + (LagCyc) \right)$ 
     $q_{4,0} \leftarrow q_{3,0} + \left( (16 \cdot DispHelixShaft_{3,0}) + (7 \cdot Lag) + (LagCyc) \right)$ 
  end for
end for
q

```

$$IniTimeHelix := DispIniTime(TimeHelix) = \begin{bmatrix} 0 \\ 500.76 \\ 1367.28 \\ 3331.08 \\ 7123.68 \end{bmatrix}$$

$$IniTimeShaft := DispIniTime(TimeShaft) = \begin{bmatrix} 0 \\ 256.92 \\ 635.76 \\ 1380.36 \\ 2734.56 \end{bmatrix}$$

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

$PseuPL1H := \begin{bmatrix} TimeHelix_{0,0} & NormDisp_{0,0} \end{bmatrix}$	$IniTimePL1H := DispIniTime(TimeHelix)_{0,0} = 0$	$IniDisp := 0$
$PseuPL2H := \begin{bmatrix} TimeHelix_{1,0} & NormDisp_{1,0} \end{bmatrix}$	$IniTimePL2H := DispIniTime(TimeHelix)_{1,0} = 500.76$	
$PseuPL3H := \begin{bmatrix} TimeHelix_{2,0} & NormDisp_{2,0} \end{bmatrix}$	$IniTimePL3H := DispIniTime(TimeHelix)_{2,0} = 1.367 \cdot 10^3$	
$PseuPL4H := \begin{bmatrix} TimeHelix_{3,0} & NormDisp_{3,0} \end{bmatrix}$	$IniTimePL4H := DispIniTime(TimeHelix)_{3,0} = 3.331 \cdot 10^3$	
$PseuCLH := \begin{bmatrix} TimeHelix_{4,0} & NormDisp_{4,0} \end{bmatrix}$	$IniTimeCLH := DispIniTime(TimeHelix)_{4,0} = 7.124 \cdot 10^3$	
$PseuPL1S := \begin{bmatrix} TimeShaft_{0,0} & NormDisp_{0,0} \end{bmatrix}$	$IniTimePL1S := DispIniTime(TimeShaft)_{0,0} = 0$	$IniDisp := 0$
$PseuPL2S := \begin{bmatrix} TimeShaft_{1,0} & NormDisp_{1,0} \end{bmatrix}$	$IniTimePL2S := DispIniTime(TimeShaft)_{1,0} = 256.92$	
$PseuPL3S := \begin{bmatrix} TimeShaft_{2,0} & NormDisp_{2,0} \end{bmatrix}$	$IniTimePL3S := DispIniTime(TimeShaft)_{2,0} = 635.76$	
$PseuPL4S := \begin{bmatrix} TimeShaft_{3,0} & NormDisp_{3,0} \end{bmatrix}$	$IniTimePL4S := DispIniTime(TimeShaft)_{3,0} = 1.38 \cdot 10^3$	
$PseuCLS := \begin{bmatrix} TimeShaft_{4,0} & NormDisp_{4,0} \end{bmatrix}$	$IniTimeCLS := DispIniTime(TimeShaft)_{4,0} = 2.735 \cdot 10^3$	

Function for calculating time required for each cycle of the pseudostatic loads

```

TimeCycLoop(Pseu1per, IniTimeHelix, IniDisp) :=
  for j ∈ 0, 1 .. 3
    for i ∈ 0, 1 .. 40000
      q0,0 ← IniTimeHelix
      diff ← 0.1
      qi+1,0 ← qi,0 + diff
      q0,1 ← IniDisp
      Lag ← 5
      LagCyc ← 100
      k0,0 ← q0,0
      k1,0 ← ((q0,0 + 4 • Pseu1per0,0) + (2 • Lag))
      k2,0 ← ((q0,0 + 8 • Pseu1per0,0) + (4 • Lag))
      k3,0 ← ((q0,0 + 12 • Pseu1per0,0) + (6 • Lag))
      k4,0 ← ((q0,0 + 16 • Pseu1per0,0) + (7 • Lag) + LagCyc)
    k
  
```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

Function for calculating displacement increments for each cycles of the pseudostatic loads

```

DispCyc(Pseu1per, IniTimeHelix, IniDisp) :=
  for j ∈ 0, 1..3
  for i ∈ 0, 1..40000
    q0,0 ← IniTimeHelix
    diff ← 0.1
    qi+1,0 ← qi,0 + diff
    q0,1 ← IniDisp
    Lag ← 5
    LagCyc ← 100
    qi+1,0 ← if qi+1,0 ≤ ((q0,0 + 16 • Pseu1per0,0) + (7 • Lag) + LagCyc)
      || qi+1,0
    else if qi+1,0 > ((q0,0 + 16 • Pseu1per0,0) + (7 • Lag) + LagCyc)
      || break
    qi+1,1 ← if (qi+1,0) ≤ (q0,0 + 2 • Pseu1per0,0)
      ||  $\frac{(q_{i+1,0} - q_{0,0})}{((q_{0,0} + 2 \cdot Pseu1per_{0,0}) - q_{0,0})} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if (q0,0 + 2 • Pseu1per0,0) < qi+1,0 ≤ ((q0,0 + 2 • Pseu1per0,0) + Lag)
      || 2 • Pseu1per0,1
    else if ((q0,0 + 2 • Pseu1per0,0) + Lag) < qi+1,0 ≤ ((q0,0 + 4 • Pseu1per0,0) + Lag)
      ||  $\frac{(((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + Lag) - q_{i+1,0})}{(((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + Lag) - ((q_{0,0} + 2 \cdot Pseu1per_{0,0}) + Lag))} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if ((q0,0 + 4 • Pseu1per0,0) + Lag) < qi+1,0 ≤ ((q0,0 + 4 • Pseu1per0,0) + (2 • Lag))
      || q0,1
    else if ((q0,0 + 4 • Pseu1per0,0) + (2 • Lag)) < qi+1,0 ≤ ((q0,0 + 6 • Pseu1per0,0) + (2 • Lag))
      ||  $\frac{(q_{i+1,0} - ((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + (2 \cdot Lag)))}{(((q_{0,0} + 6 \cdot Pseu1per_{0,0}) + 2 \cdot Lag) - ((q_{0,0} + 4 \cdot Pseu1per_{0,0}) + (2 \cdot Lag)))} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if ((q0,0 + 6 • Pseu1per0,0) + (2 • Lag)) < qi+1,0 ≤ ((q0,0 + 6 • Pseu1per0,0) + (3 • Lag))
      || 2 • Pseu1per0,1
    else if ((q0,0 + 6 • Pseu1per0,0) + (3 • Lag)) < qi+1,0 ≤ ((q0,0 + 8 • Pseu1per0,0) + (3 • Lag))
      ||  $\frac{(((q_{0,0} + 8 \cdot Pseu1per_{0,0}) + (3 \cdot Lag)) - q_{i+1,0})}{(((q_{0,0} + 8 \cdot Pseu1per_{0,0}) + (3 \cdot Lag)) - ((q_{0,0} + 6 \cdot Pseu1per_{0,0}) + (3 \cdot Lag)))} \cdot (2 \cdot Pseu1per_{0,1})$ 
    else if ((q0,0 + 8 • Pseu1per0,0) + (3 • Lag)) < qi+1,0 ≤ ((q0,0 + 8 • Pseu1per0,0) + (4 • Lag))
      || q0,1
    else if ((q0,0 + 8 • Pseu1per0,0) + (4 • Lag)) < qi+1,0 ≤ ((q0,0 + 10 • Pseu1per0,0) + (4 • Lag))

```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

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Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

Function for calculating displacement for the monotonic loads

```

DispComp(Pseu1per,IniTime,IniDisp):=
  for j ∈ 0,1..3
  for i ∈ 0,1..40000
    q0,0 ← IniTime
    diff ← 0.1
    qi+1,0 ← qi,0 + diff
    qi+1,0 ← if (qi+1,0) ≤ (q0,0 + Pseu1per0,0)
              qi+1,0
              else if qi+1,0 > (q0,0 + Pseu1per0,0)
              break
    q0,1 ← IniDisp
    qi+1,1 ← if (qi+1,0) ≤ (q0,0 + Pseu1per0,0)
              (qi+1,0 - q0,0) / ((q0,0 + Pseu1per0,0) - q0,0) · (Pseu1per0,1)
              else
              qi+1,1
  q

```

$LdTimePL1H := DispCyc(PseuPL1H, IniTimePL1H, IniDisp)$

$LdTimePL2H := DispCyc(PseuPL2H, IniTimePL2H, IniDisp)$

$LdTimePL3H := DispCyc(PseuPL3H, IniTimePL3H, IniDisp)$

$LdTimePL4H := DispCyc(PseuPL4H, IniTimePL4H, IniDisp)$

$LdTimeCLH := DispComp(PseuCLH, IniTimeCLH, IniDisp)$

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

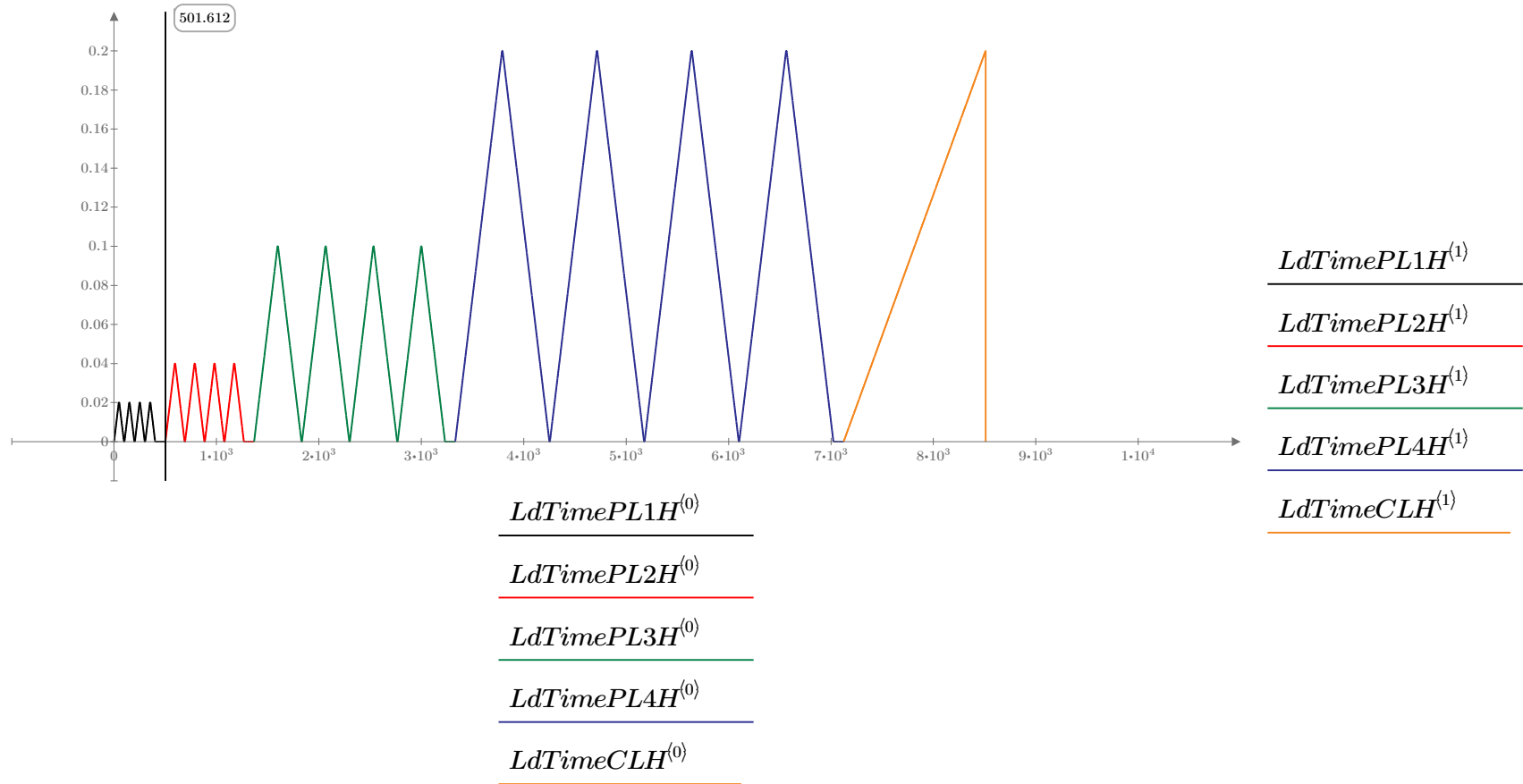


Fig F 1. DisplacementTime History for the Helix Piles

$$LdTimePL1S := DispCyc(PseuPL1S, IniTimePL1S, IniDisp)$$

$$LdTimePL2S := DispCyc(PseuPL2S, IniTimePL2S, IniDisp)$$

$$LdTimePL3S := DispCyc(PseuPL3S, IniTimePL3S, IniDisp)$$

$$LdTimePL4S := DispCyc(PseuPL4S, IniTimePL4S, IniDisp)$$

$$LdTimeCLS := DispComp(PseuCLS, IniTimeCLS, IniDisp)$$

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

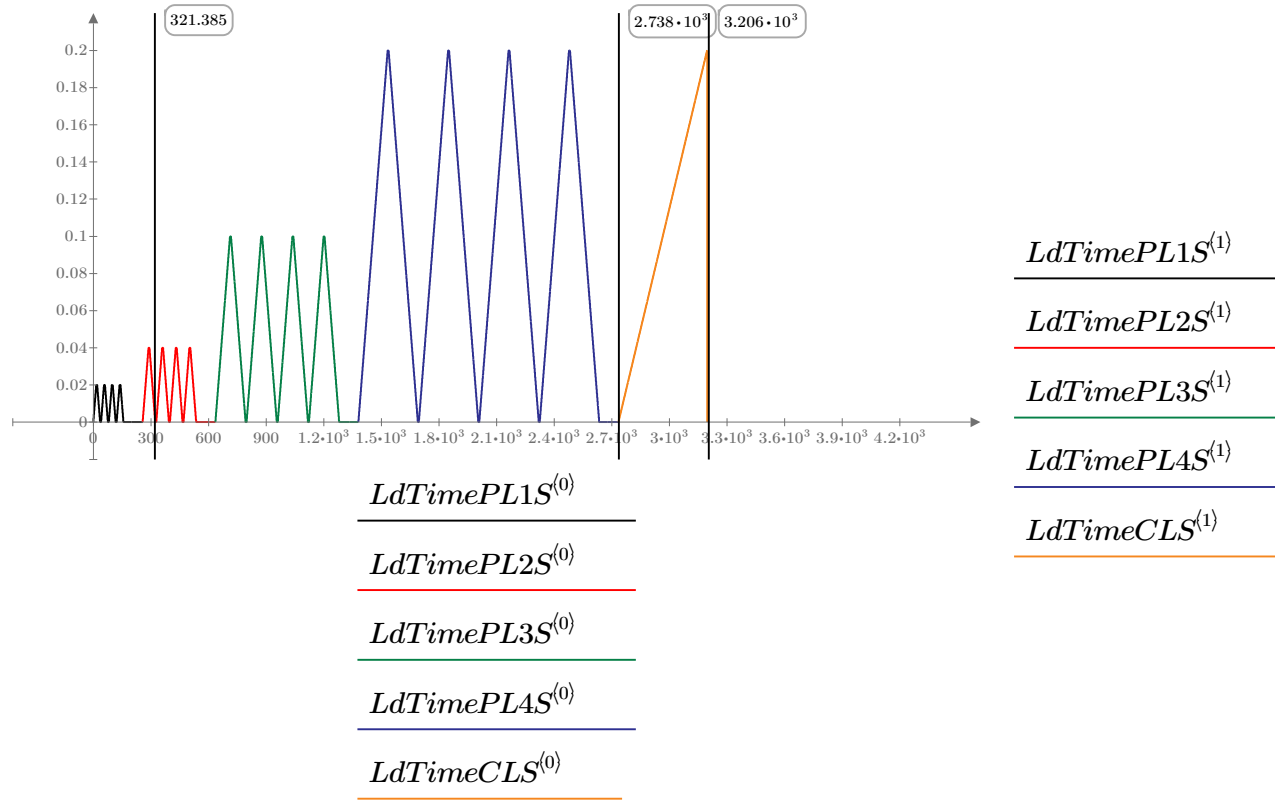


Fig F 2. DisplacementTime History for the smooth pile.

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

2.3.2 Axial Load vs Time

Function for determining the Axial Load Distribution in each pile

```

AxlLd (Rawdata , PileNum) :=
  for i ∈ 0, 1 .. rows (Rawdata) - 1
    for j ∈ 0, 1 .. cols (Rawdata) - 1
      qi,j ← Rawdatai,j - Rawdata0,j

      SG1i,0 ← qi,0 • mean (submatrix (CF, 0, 2, PileNum, PileNum)) • Nscalesclfac0,1

      SG2i,1 ← qi,1 • mean (submatrix (CF, 3, 5, PileNum, PileNum)) • Nscalesclfac0,1

      SG3i,2 ← qi,2 • mean (submatrix (CF, 6, 8, PileNum, PileNum)) • Nscalesclfac0,1

      SG4i,3 ← qi,3 • mean (submatrix (CF, 9, 11, PileNum, PileNum)) • Nscalesclfac0,1

  augment (SG1(0), SG2(1), SG3(2), SG4(3))

```

Function for determining the Time, Displacement Input to Time Axial Load Distribution output in each pile

```

TDispTLd (LdTime1perS, TimeP0, AxLdP0, LdNo) :=
  m ← TimeP0
  n ← AxLdP0
  p ← LdTime1perS
  q ← if LdNo = 1
    m0
  else if LdNo = 2
    m1
  else if LdNo = 3
    m2
  else if LdNo = 4
    m3
  else if LdNo = 5
    m4

  k ← if LdNo = 1
    n0
  else if LdNo = 2
    n1
  else if LdNo = 3
    n2
  else if LdNo = 4
    n3
  else if LdNo = 5
    n

```

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

$$\begin{aligned}
 & \text{if } \text{rows}(p) > \text{rows}(q) \\
 & \quad q \\
 & \text{else if } \text{rows}(p) < \text{rows}(q) \\
 & \quad p \\
 & tdisp \leftarrow \text{submatrix}(LdTime1perS^{(0)}, 0, \text{rows}(o) - 1, 0, 0) \\
 & disp \leftarrow \text{submatrix}(-LdTime1perS^{(1)}, 0, \text{rows}(o) - 1, 0, 0) \\
 & tld \leftarrow \text{submatrix}\left(\frac{q}{s}, 0, \text{rows}(o) - 1, 0, 0\right) \\
 & ld1 \leftarrow \text{medsmooth}\left(\text{submatrix}\left(\frac{k^{(0)}}{kN}, 0, \text{rows}(o) - 1, 0, 0\right), 11\right) \\
 & ld2 \leftarrow \text{medsmooth}\left(\text{submatrix}\left(\frac{k^{(1)}}{kN}, 0, \text{rows}(o) - 1, 0, 0\right), 11\right) \\
 & ld3 \leftarrow \text{medsmooth}\left(\text{submatrix}\left(\frac{k^{(2)}}{kN}, 0, \text{rows}(o) - 1, 0, 0\right), 11\right) \\
 & ld4 \leftarrow \text{medsmooth}\left(\text{submatrix}\left(\frac{k^{(3)}}{kN}, 0, \text{rows}(o) - 1, 0, 0\right), 11\right) \\
 & \text{augment}(tdisp, disp, tld, ld1, ld2, ld3, ld4)
 \end{aligned}$$

There were four strain gages placed within the P4 pile. The following sub sections provides the details on the load distributions:

$$P4HBM := \begin{bmatrix} \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P4_PL1!A1:E6666"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P4_PL2!A1:E9159"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P4_PL3!A1:E20464"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P4_PL4!A1:E37876"}) \\ \text{READExcel}(\text{".\NI02 HBM Data.xlsx"}, \text{"P4_CL!A1:E15419"}) \end{bmatrix} = \begin{bmatrix} [6666 \times 5] \\ [9159 \times 5] \\ [20464 \times 5] \\ [37876 \times 5] \\ [15419 \times 5] \end{bmatrix}$$

$$TimeP4 := \begin{bmatrix} \text{for } i \in 0, 1..4 \\ \quad q_i \leftarrow \text{submatrix}(P4HBM_i, 0, \text{rows}(P4HBM_i) - 1, 0, 0) \\ \quad s \end{bmatrix} = \begin{bmatrix} [6666 \times 1] \ s \\ [9159 \times 1] \ s \\ [20464 \times 1] \ s \\ [37876 \times 1] \ s \\ [15419 \times 1] \ s \end{bmatrix}$$

$$RawdataP4 := \begin{bmatrix} \text{for } i \in 0, 1..4 \\ \quad q_i \leftarrow \text{submatrix}(P4HBM_i, 0, \text{rows}(P4HBM_i) - 1, 1, 4) \\ \quad \frac{mV}{V} \end{bmatrix} = \begin{bmatrix} [6666 \times 4] \\ [9159 \times 4] \\ [20464 \times 4] \\ [37876 \times 4] \\ [15419 \times 4] \end{bmatrix}$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

$$AxLdP4 := \left\| \begin{array}{l} \text{for } i \in 0, 1 \dots 4 \\ \left\| q_i \leftarrow AxLd(RawdataP4_i, 4) \right\| \\ q \end{array} \right\| = \begin{bmatrix} [6666 \times 4] \\ [9159 \times 4] \\ [20464 \times 4] \\ [37876 \times 4] \\ [15419 \times 4] \end{bmatrix} \text{ kN}$$

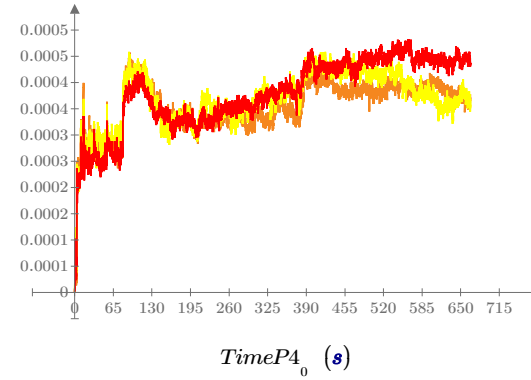
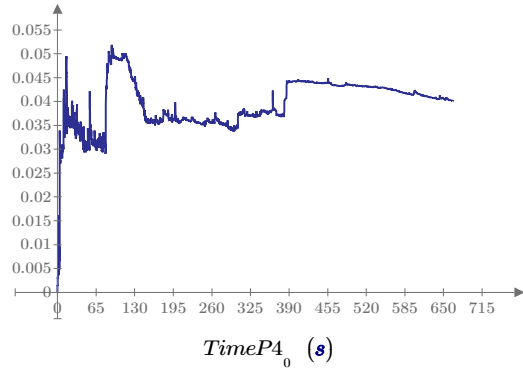


Fig F 3. Rawdata time history for compression pile P4 PL1

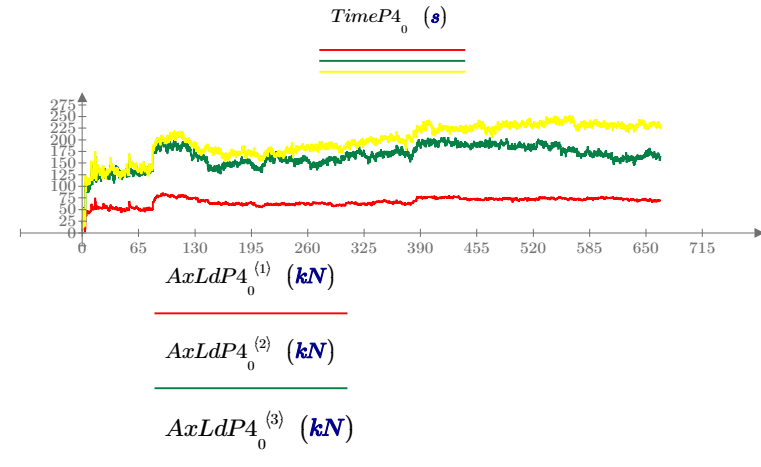
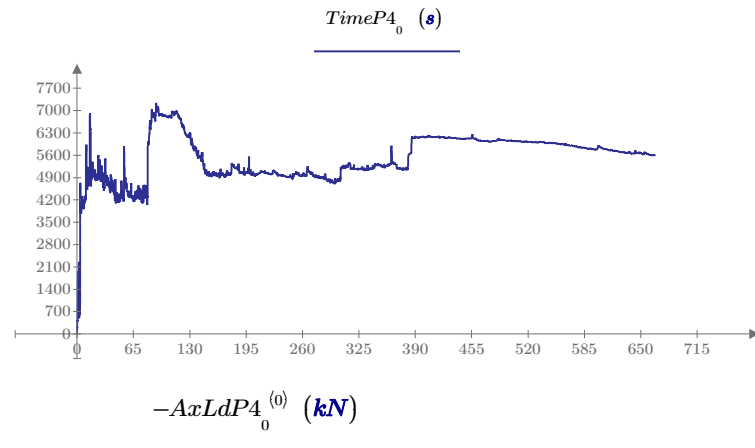


Fig F 4. Load time history for compression pile P4 PL1

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

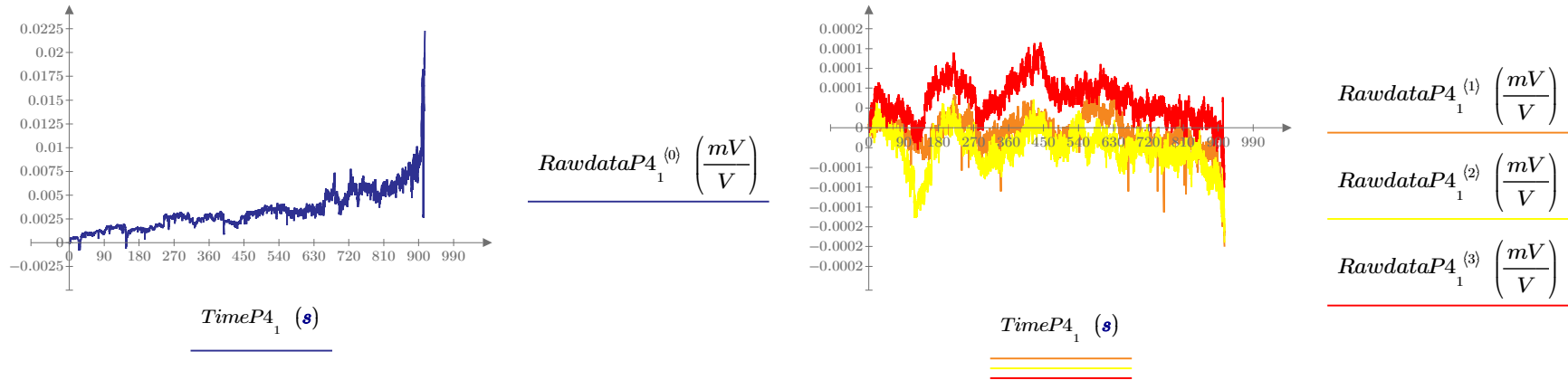


Fig F 5. Rawdata time history for compression pile P4 PL2

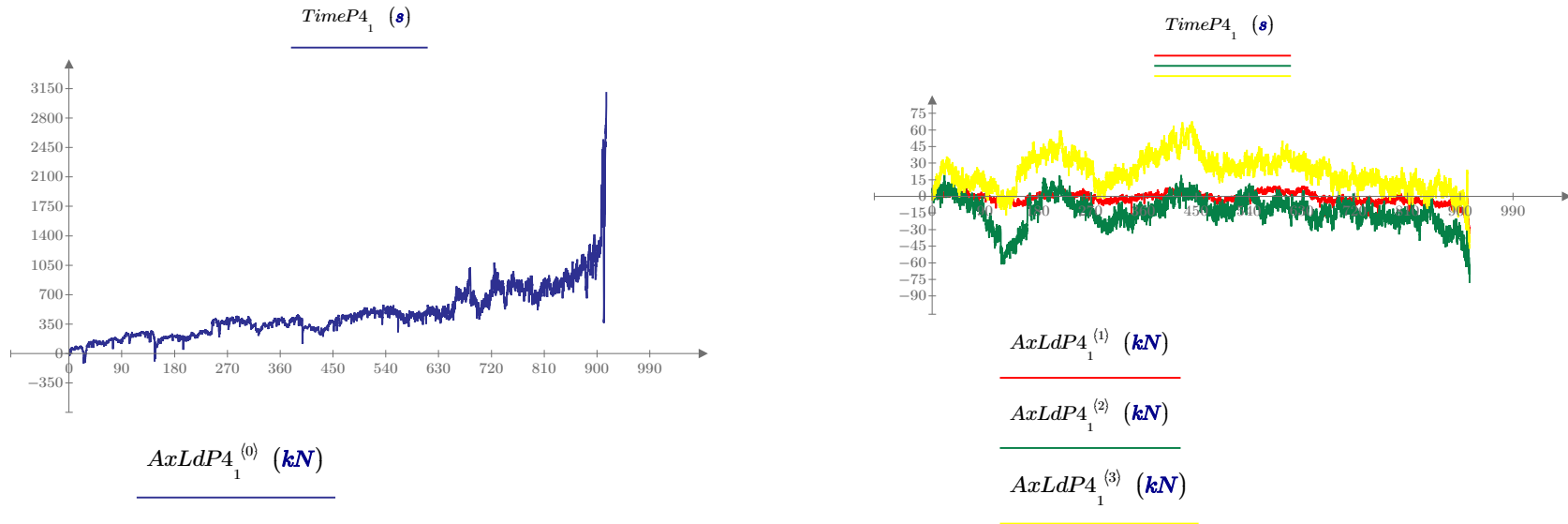


Fig F 6. Load time history for compression pile P4 PL2

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

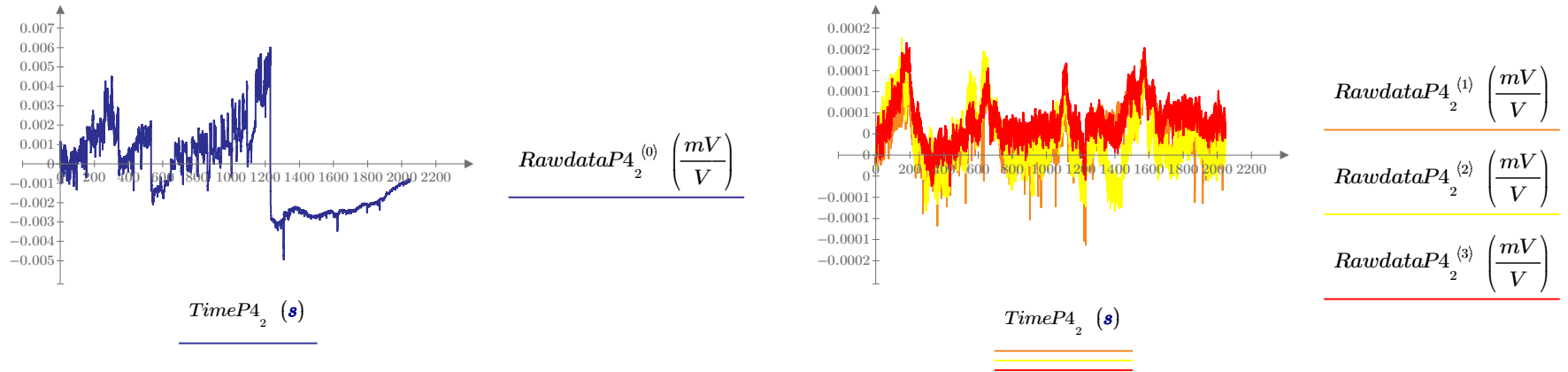


Fig F 7. Rawdata time history for compression pile P4 PL3

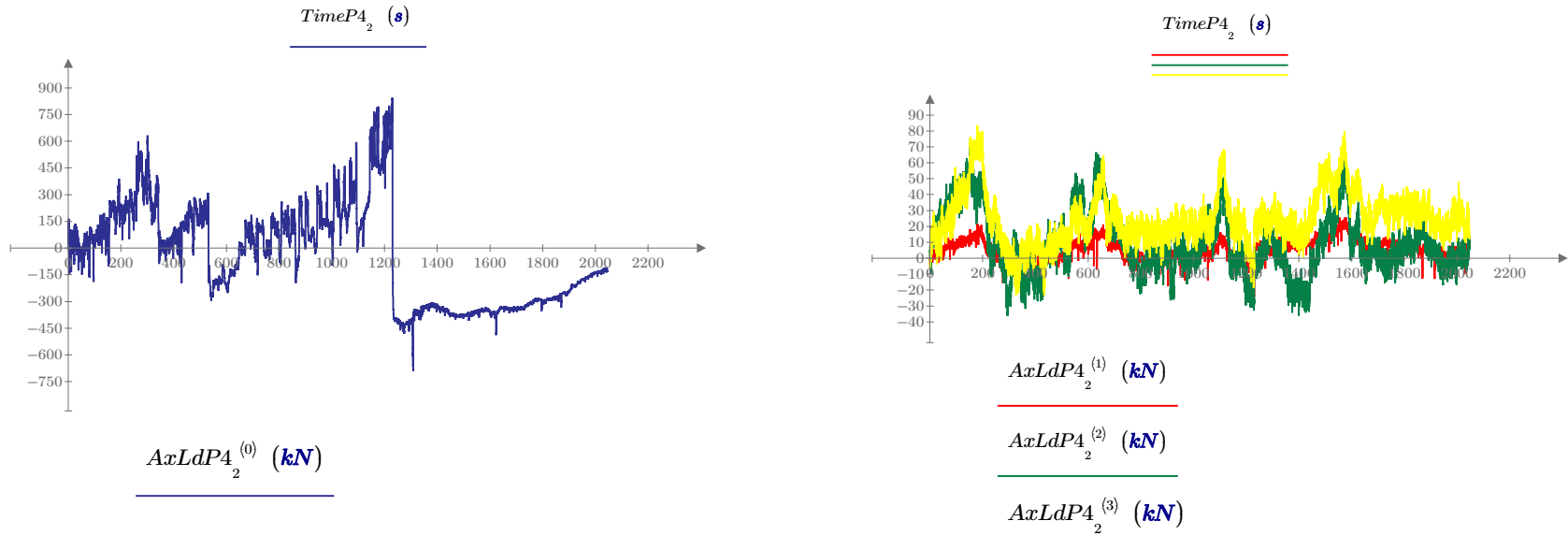


Fig F 8. Load time history for compression pile P4 PL3

Appendix F Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

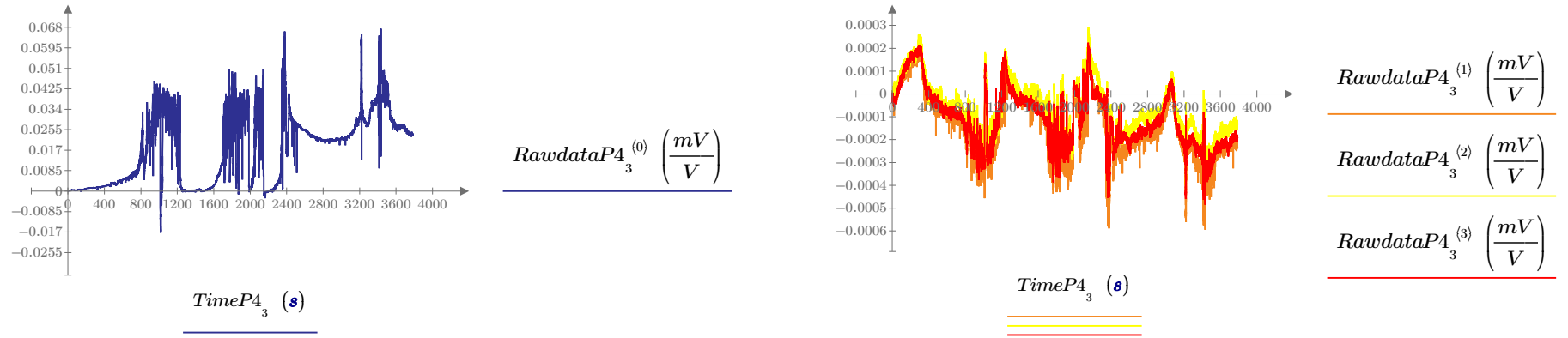


Fig F 9. Rawdata time history for compression pile P4 PL4

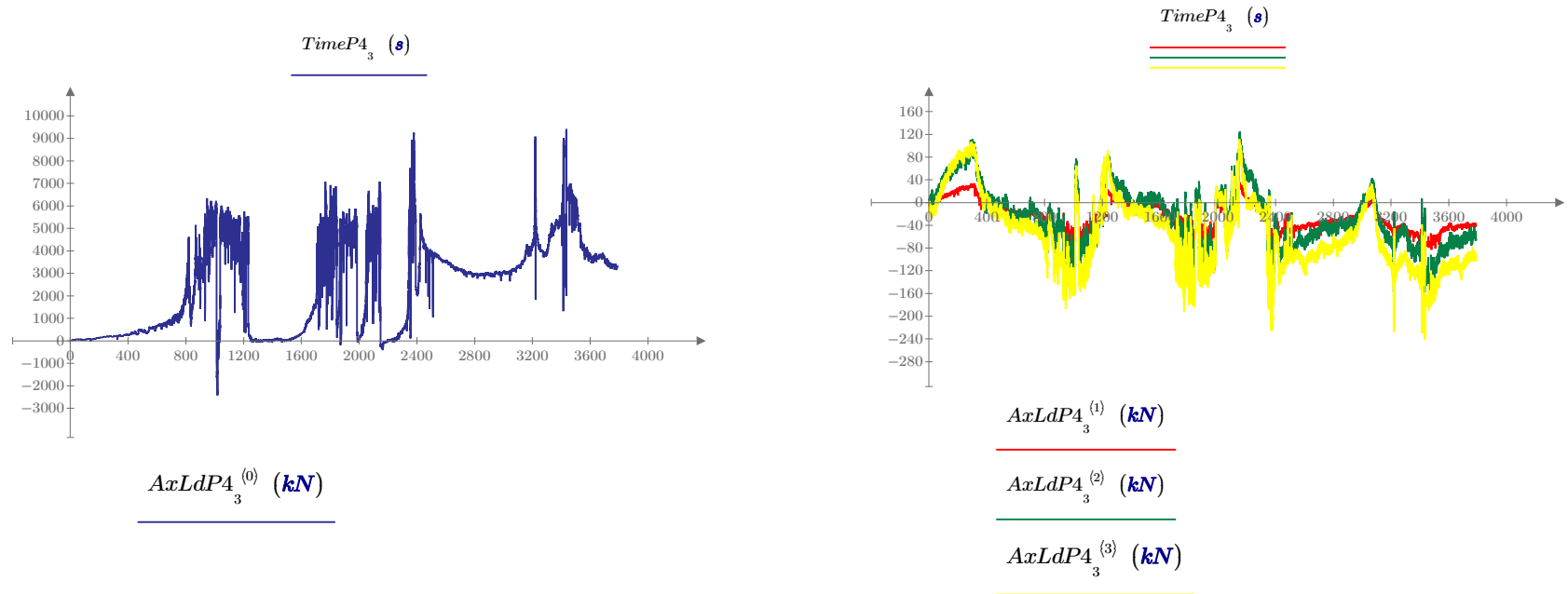


Fig F 10. Load time history for compression pile P4 PL4

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

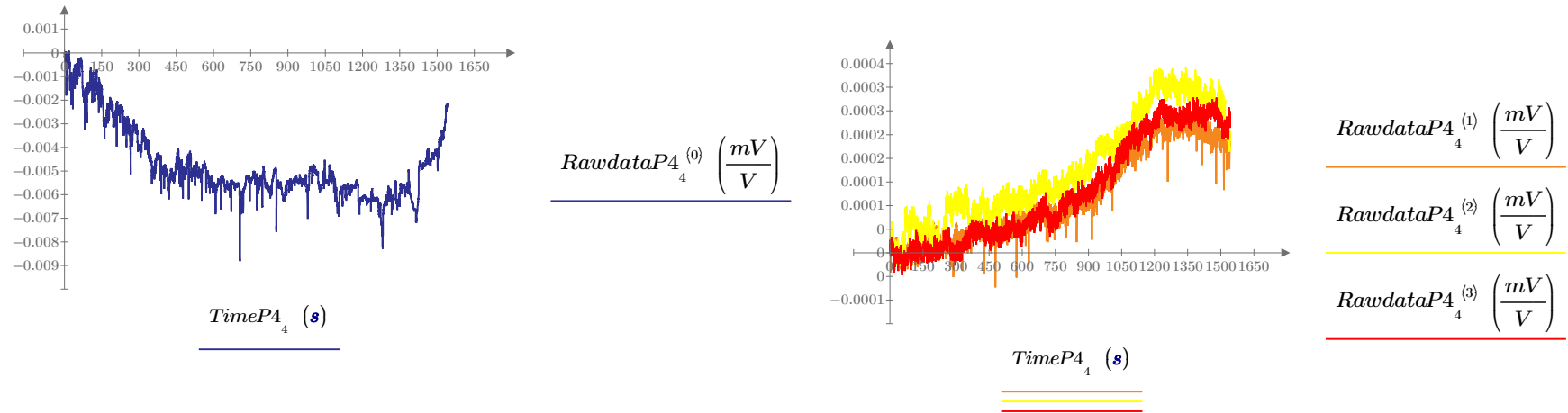


Fig F 11. Rawdata time history for compression pile P4 CL

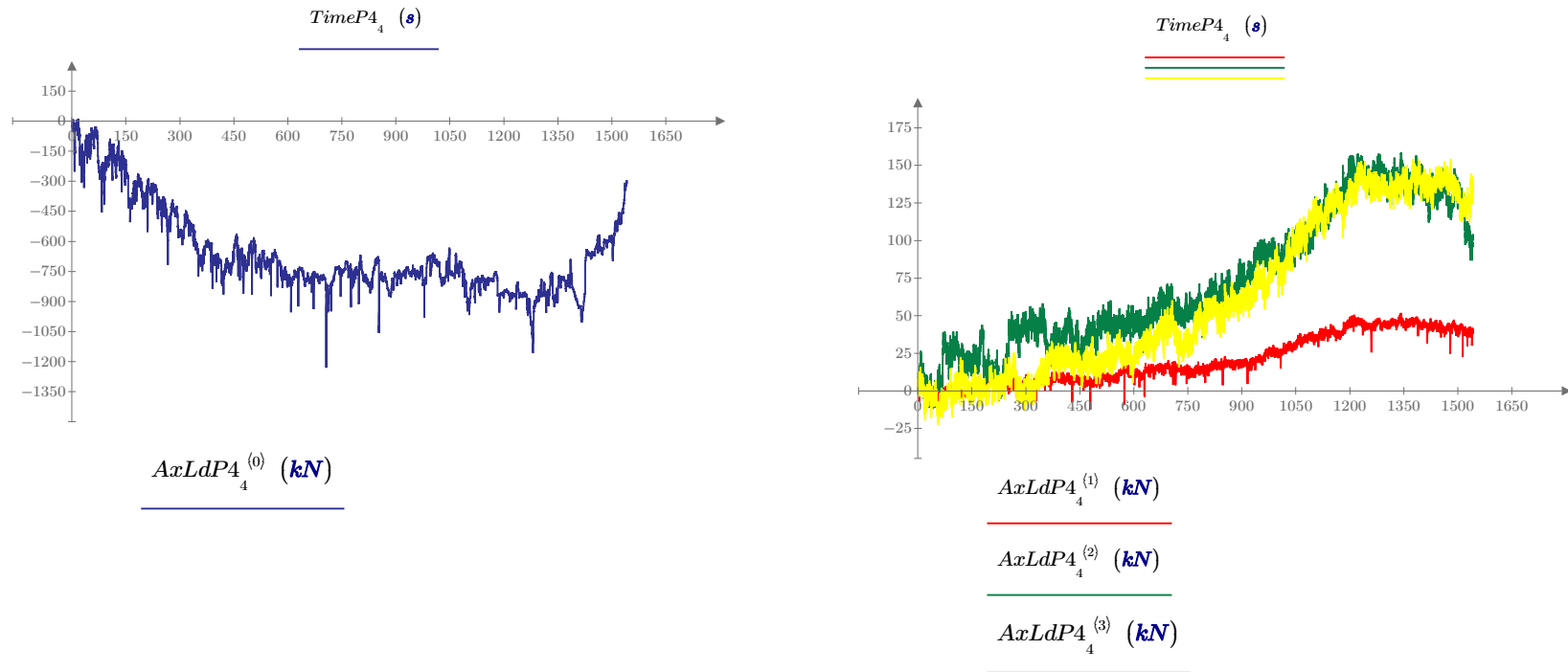


Fig F 12. Load time history for compression pile P4 CL

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for psuedostatic load PL1

$$TDispTLdP4PL1 := TDispTLd(LdTimePL1H, TimeP4, AxLdP4, 1) =$$

0	0	0	-258.148	0.408	13.262	2.258
1	0.1	$-4.374 \cdot 10^{-5}$	0.1	-308.008	0.544	18.113
2	0.2	$-8.749 \cdot 10^{-5}$	0.2	-352.139	0.544	19.084
3	0.3	$-1.312 \cdot 10^{-4}$	0.3	-396.269	0.544	20.054
4	0.4	$-1.75 \cdot 10^{-4}$	0.4	-403.507	0.815	20.701
5	0.5	$-2.187 \cdot 10^{-4}$	0.5	-410.744	1.087	21.348
6	0.6	$-2.625 \cdot 10^{-4}$	0.6	-433.865	2.446	23.289
7	0.7	$-3.062 \cdot 10^{-4}$	0.7	-594.102	5.165	23.289
8	0.8	$-3.5 \cdot 10^{-4}$	0.8	-668.892	6.524	23.936
9	0.9	$-3.937 \cdot 10^{-4}$	0.9	-668.892	7.067	24.583
10	1	$-4.374 \cdot 10^{-4}$	1	-668.892	7.067	23.936
11	1.1	$-4.812 \cdot 10^{-4}$	1.1	-768.613	7.067	23.936
$\vdots$						$\vdots$
5008						

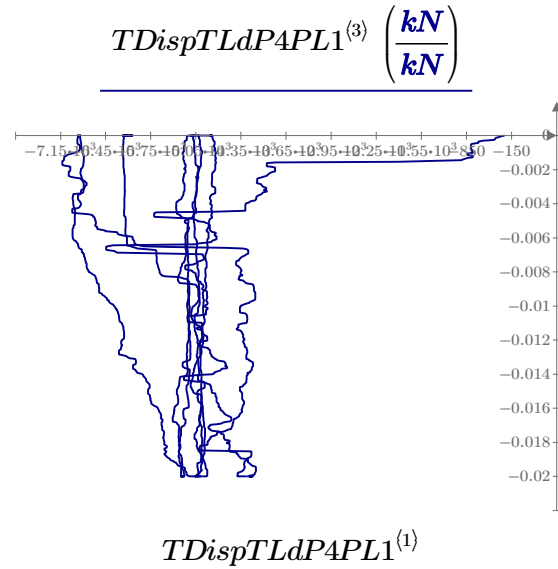


Fig F 13. Load displacement for compression pile P4 PL1 SG1

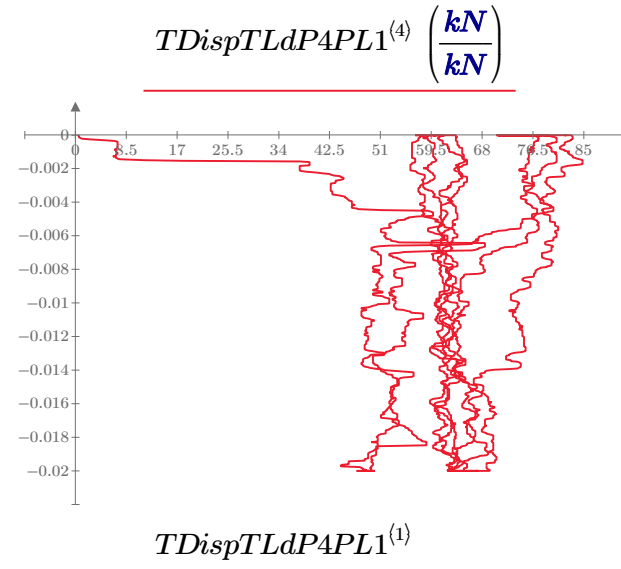


Fig F 14. Load displacement for compression pile P4 PL1 SG2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

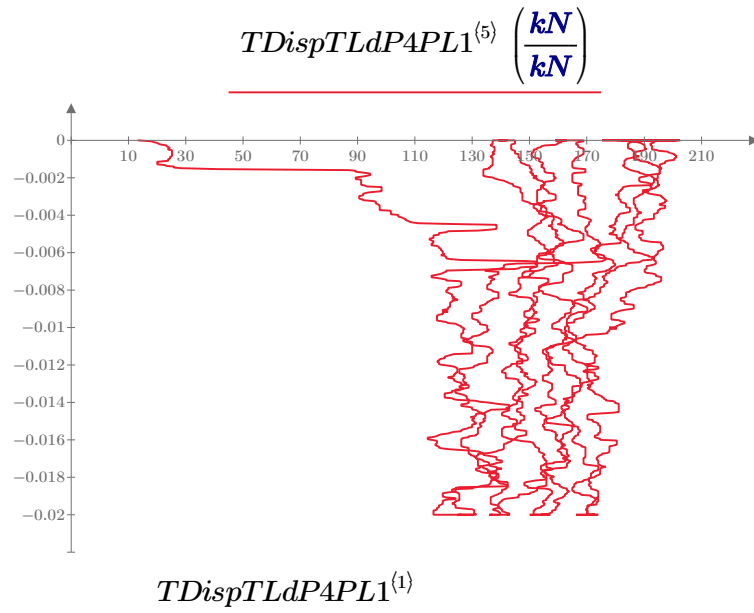


Fig F 15. Load displacement for compression pile P4 PL1 SG3

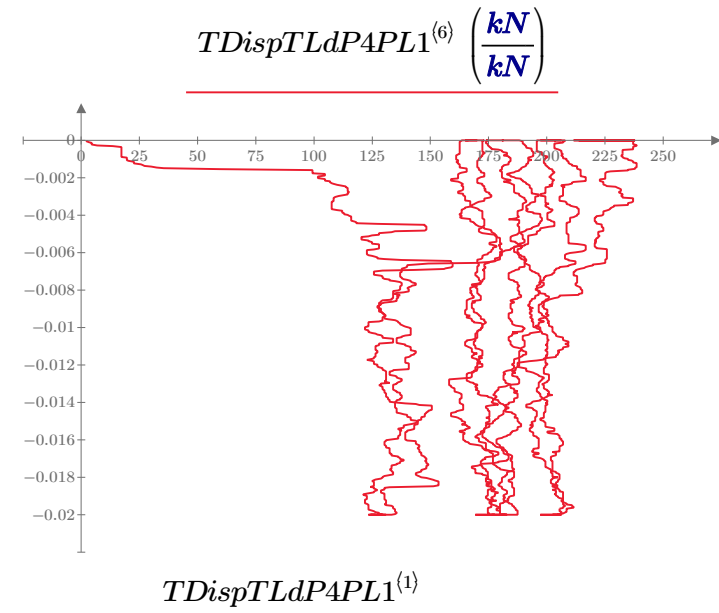


Fig F 16. Load displacement for compression pile P4 PL1 SG4

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for psuedostatic load PL2

$$TDispTLdP4PL2 := TDispTLd(LdTimePL2H, TimeP4, AxLdP4, 2) =$$

0	500.76	0	0	-1.508	-0.272	3.235	0.753
1	500.86	$-4.374 \cdot 10^{-5}$	0.1	-2.01	0	2.588	0.753
2	500.96	$-8.749 \cdot 10^{-5}$	0.2	-3.518	0	2.588	0.753
3	501.06	$-1.312 \cdot 10^{-4}$	0.3	-5.026	0	2.588	0.753
4	501.16	$-1.75 \cdot 10^{-4}$	0.4	-7.137	0.136	2.264	0.753
5	501.26	$-2.187 \cdot 10^{-4}$	0.5	-9.248	0.272	2.588	0.753
6	501.36	$-2.625 \cdot 10^{-4}$	0.6	-9.65	1.903	2.588	1.506
7	501.46	$-3.062 \cdot 10^{-4}$	0.7	-11.058	2.175	2.588	2.258
8	501.56	$-3.5 \cdot 10^{-4}$	0.8	-12.063	2.175	1.941	1.506
9	501.66	$-3.937 \cdot 10^{-4}$	0.9	-12.063	2.175	1.941	1.506
10	501.76	$-4.374 \cdot 10^{-4}$	1	-12.063	2.446	0.647	2.258
11	501.86	$-4.812 \cdot 10^{-4}$	1.1	-12.063	2.446	0.647	2.258
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

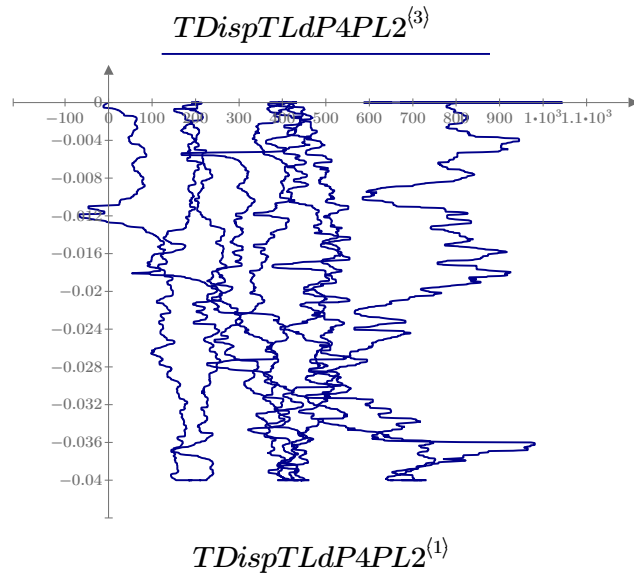


Fig F 17. Load displacement for compression pile P4 PL2 SG1

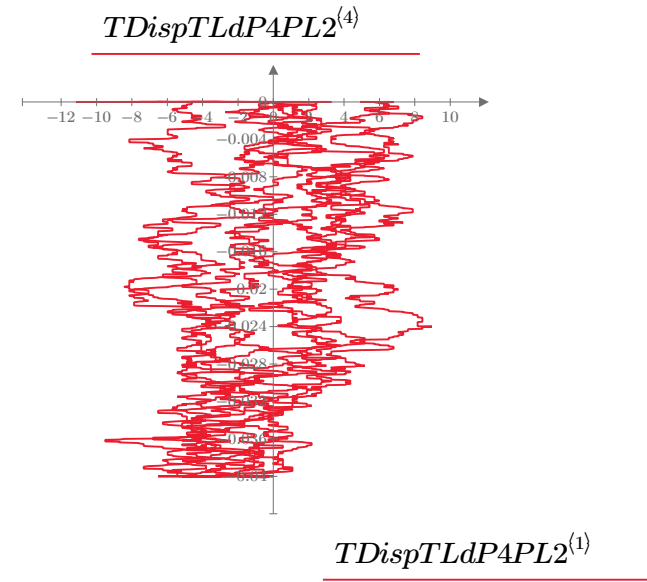


Fig F 18. Load displacement for compression pile P4 PL2 SG2

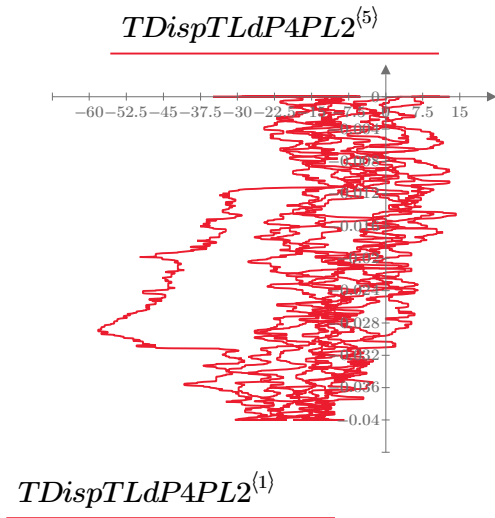


Fig F 19. Load displacement for compression pile P4 PL2 SG3

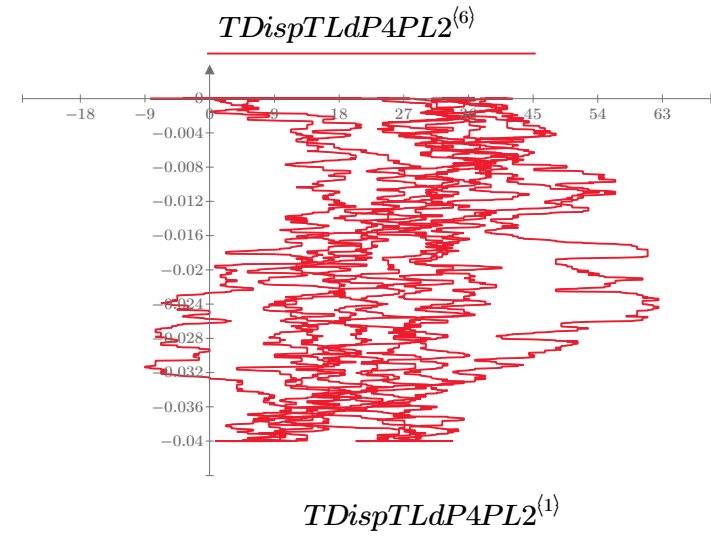


Fig F 20. Load displacement for compression pile P4 PL2 SG4

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for pseudostatic load PL3

$$TDispTLdP4PL3 := TDispTLd(LdTimePL3H, TimeP4, AxLdP4, 3) =$$

0	$1.367 \cdot 10^3$	0	0	25.734	-1.631	4.528	-3.764
1	$1.367 \cdot 10^3$	$-4.374 \cdot 10^{-5}$	0.1	26.338	-1.359	4.528	-3.764
2	$1.367 \cdot 10^3$	$-8.749 \cdot 10^{-5}$	0.2	27.343	-1.087	4.528	-3.388
3	$1.368 \cdot 10^3$	$-1.312 \cdot 10^{-4}$	0.3	28.348	-1.359	4.528	-3.011
4	$1.368 \cdot 10^3$	$-1.75 \cdot 10^{-4}$	0.4	32.57	-1.495	4.528	-2.635
5	$1.368 \cdot 10^3$	$-2.187 \cdot 10^{-4}$	0.5	36.792	-1.631	4.528	-2.258
6	$1.368 \cdot 10^3$	$-2.625 \cdot 10^{-4}$	0.6	47.85	-1.903	4.528	-2.258
7	$1.368 \cdot 10^3$	$-3.062 \cdot 10^{-4}$	0.7	47.85	-1.903	4.528	2.258
8	$1.368 \cdot 10^3$	$-3.5 \cdot 10^{-4}$	0.8	54.283	-2.175	4.528	2.258
9	$1.368 \cdot 10^3$	$-3.937 \cdot 10^{-4}$	0.9	57.299	-2.175	4.528	2.258
10	$1.368 \cdot 10^3$	$-4.374 \cdot 10^{-4}$	1	57.299	-1.903	4.528	3.011
11	$1.368 \cdot 10^3$	$-4.812 \cdot 10^{-4}$	1.1	64.135	-1.903	4.528	3.011
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
10630	⋮	⋮	⋮	⋮	⋮	⋮	⋮

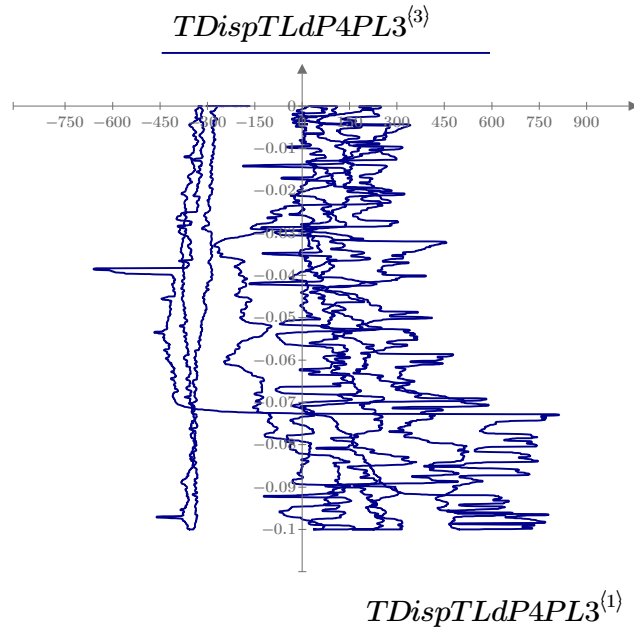


Fig F 21. Load displacement for compression pile P4 PL3 SG1

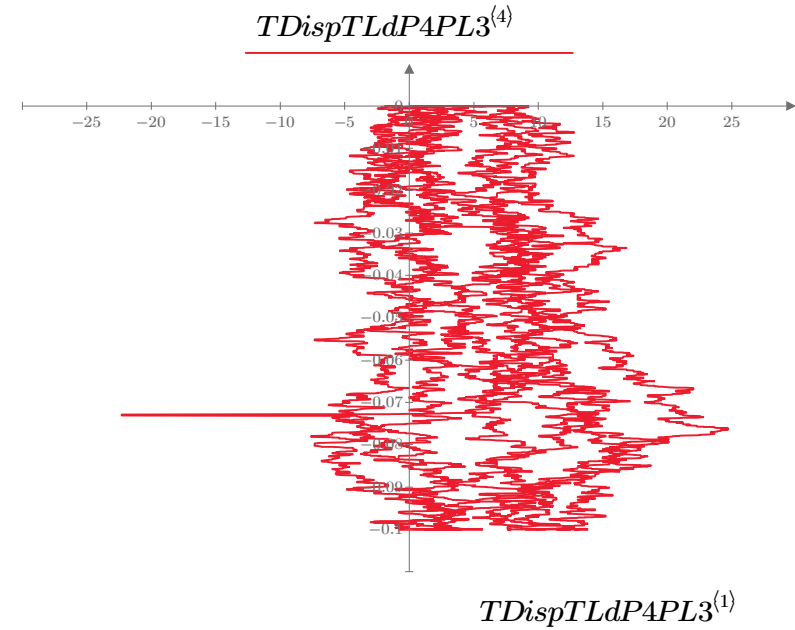


Fig F 22. Load displacement for compression pile P4 PL3 SG2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

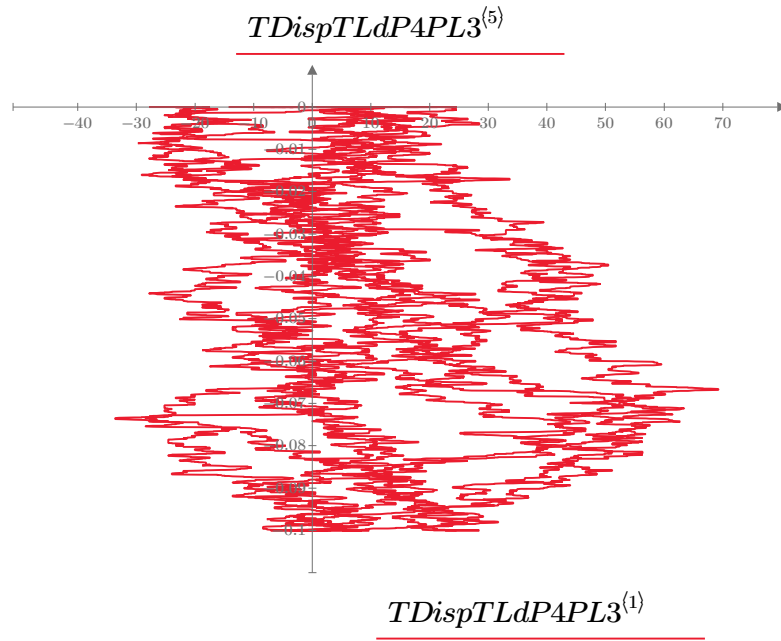


Fig F 23. Load displacement for compression pile P4 PL3 SG3

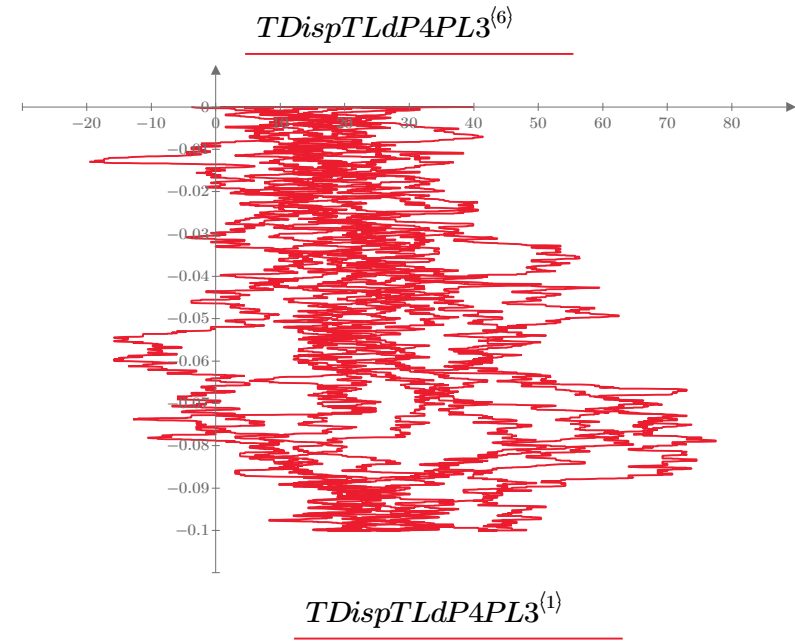


Fig F 24. Load displacement for compression pile P4 PL3 SG4

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for psuedostatic load PL4

$$TDispTLdP4PL4 := TDispTLd(LdTimePL4H, TimeP4, AxLdP4, 4) =$$

0	$3.331 \cdot 10^3$	0	0	2.312	-0.272	1.941	-4.14
1	$3.331 \cdot 10^3$	$-4.374 \cdot 10^{-5}$	0.1	2.614	-0.272	2.588	-5.27
2	$3.331 \cdot 10^3$	$-8.749 \cdot 10^{-5}$	0.2	3.418	-0.544	2.588	-4.14
3	$3.331 \cdot 10^3$	$-1.312 \cdot 10^{-4}$	0.3	2.614	-0.815	2.588	-3.011
4	$3.331 \cdot 10^3$	$-1.75 \cdot 10^{-4}$	0.4	3.418	-0.544	1.941	-1.882
5	$3.332 \cdot 10^3$	$-2.187 \cdot 10^{-4}$	0.5	4.222	-0.272	1.294	-0.753
6	$3.332 \cdot 10^3$	$-2.625 \cdot 10^{-4}$	0.6	5.83	-0.815	1.294	-0.753
7	$3.332 \cdot 10^3$	$-3.062 \cdot 10^{-4}$	0.7	5.83	-0.544	0.647	-1.506
8	$3.332 \cdot 10^3$	$-3.5 \cdot 10^{-4}$	0.8	5.83	-0.272	1.294	0.753
9	$3.332 \cdot 10^3$	$-3.937 \cdot 10^{-4}$	0.9	5.83	-0.272	2.588	1.506
10	$3.332 \cdot 10^3$	$-4.374 \cdot 10^{-4}$	1	5.83	-0.272	0.647	1.506
11	$3.332 \cdot 10^3$	$-4.812 \cdot 10^{-4}$	1.1	5.83	-0.272	0.647	1.506
⋮							⋮

37875

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

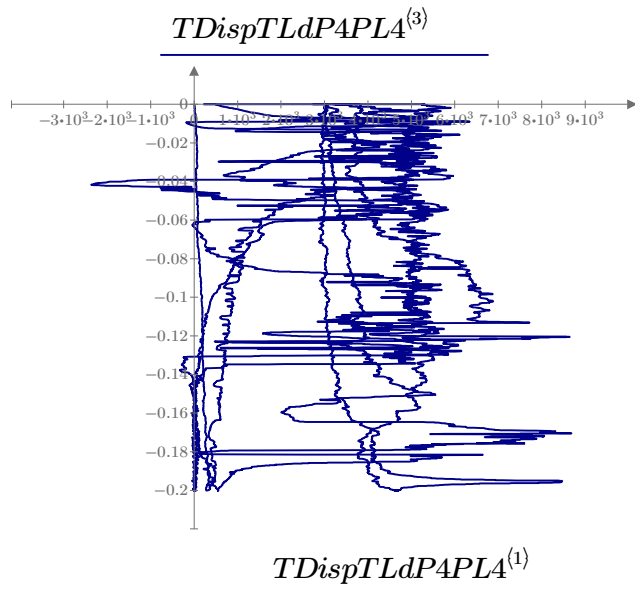


Fig F 25. Load displacement for compression pile P4 PL4 SG1

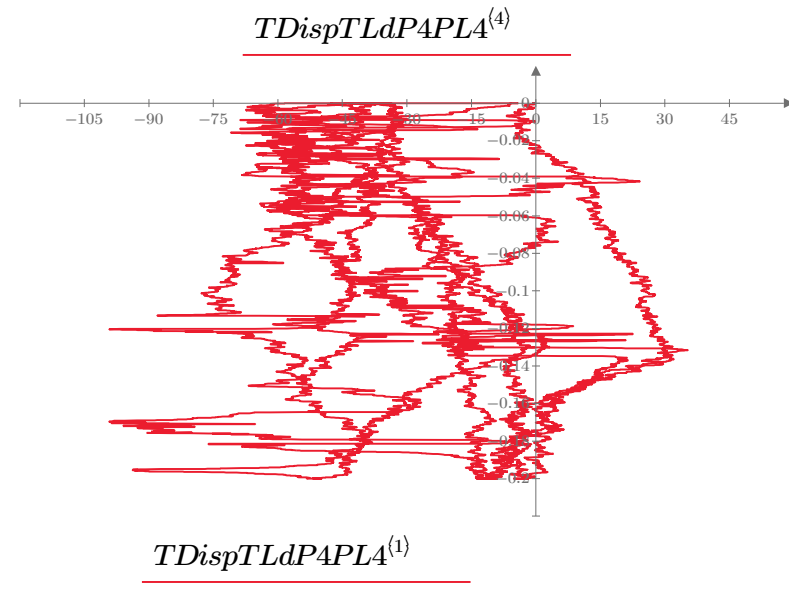


Fig F 26. Load displacement for compression pile P4 PL4 SG2

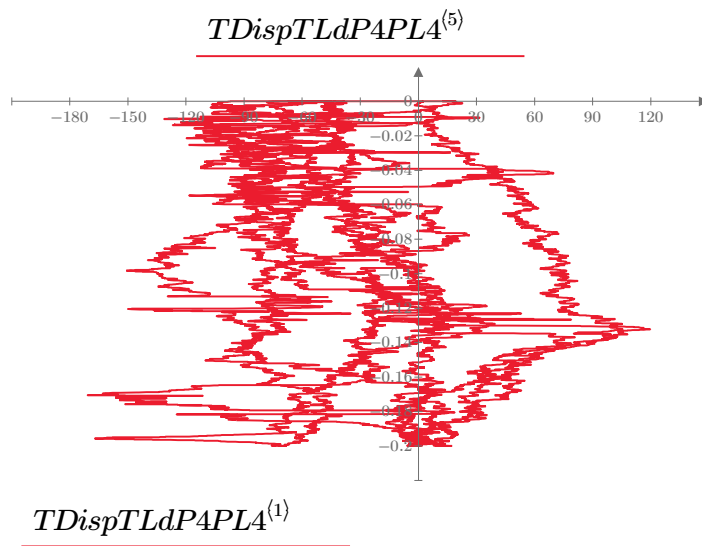


Fig F 27 3. Load displacement for compression pile P4 PL4 SG3

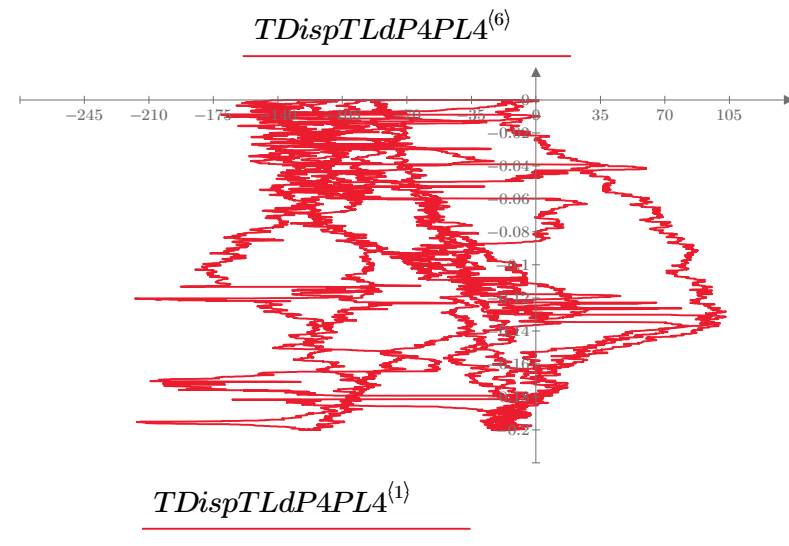


Fig F 28. Load displacement for compression pile P4 PL4 SG4

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

Matrix with input and output data. Here first two columns are for input time and displacement and last four columns are for time and obtained loads in kN from the strain gauges for compressive load CL

$$TDispTLdP4CL := TDispTLd(LdTimeCLH, TimeP4, AxLdP4, 5) =$$

0	$7.124 \cdot 10^3$	0	0	-11.359	2.31	4.528	3.011
1	$7.124 \cdot 10^3$	$-1.444 \cdot 10^{-5}$	0.1	-14.677	2.718	5.822	3.764
2	$7.124 \cdot 10^3$	$-2.887 \cdot 10^{-5}$	0.2	-16.084	2.718	5.822	5.27
3	$7.124 \cdot 10^3$	$-4.331 \cdot 10^{-5}$	0.3	-17.491	2.718	5.822	3.764
4	$7.124 \cdot 10^3$	$-5.774 \cdot 10^{-5}$	0.4	-18.195	2.582	5.499	3.011
5	$7.124 \cdot 10^3$	$-7.218 \cdot 10^{-5}$	0.5	-18.899	2.718	5.175	3.764
6	$7.124 \cdot 10^3$	$-8.661 \cdot 10^{-5}$	0.6	-19.904	2.718	5.822	3.764
7	$7.124 \cdot 10^3$	$-1.01 \cdot 10^{-4}$	0.7	-28.348	2.718	5.822	3.764
8	$7.124 \cdot 10^3$	$-1.155 \cdot 10^{-4}$	0.8	-28.75	3.262	5.175	2.258
9	$7.125 \cdot 10^3$	$-1.299 \cdot 10^{-4}$	0.9	-28.75	3.262	5.175	6.022
10	$7.125 \cdot 10^3$	$-1.444 \cdot 10^{-4}$	1	-28.75	4.077	5.822	6.022
11	$7.125 \cdot 10^3$	$-1.588 \cdot 10^{-4}$	1.1	-28.75	4.077	5.822	3.764
⋮							⋮
13855							

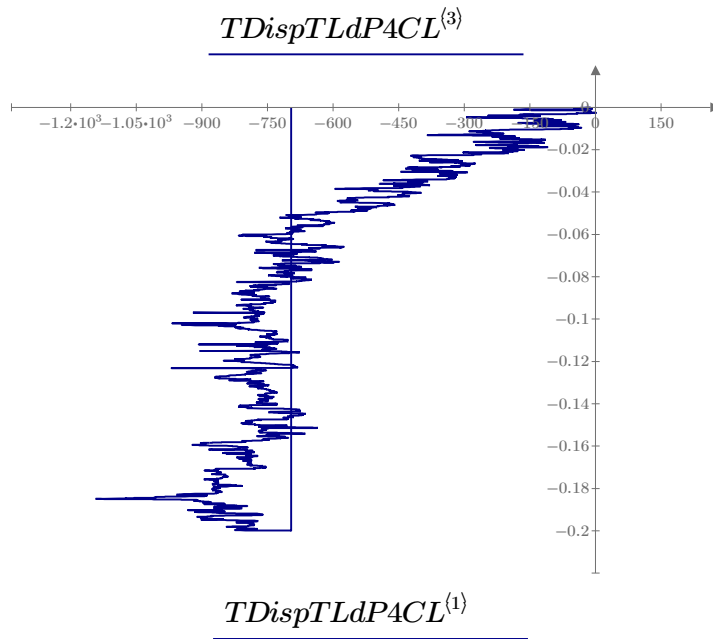


Fig F 29. Load displacement for compression pile P4 CL SG1

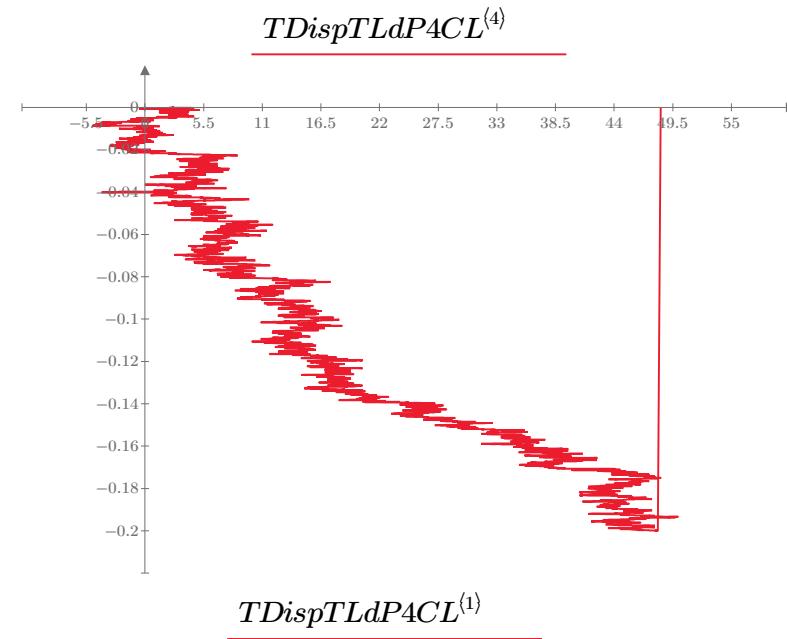


Fig F 30. Load displacement for compression pile P4 CL SG2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

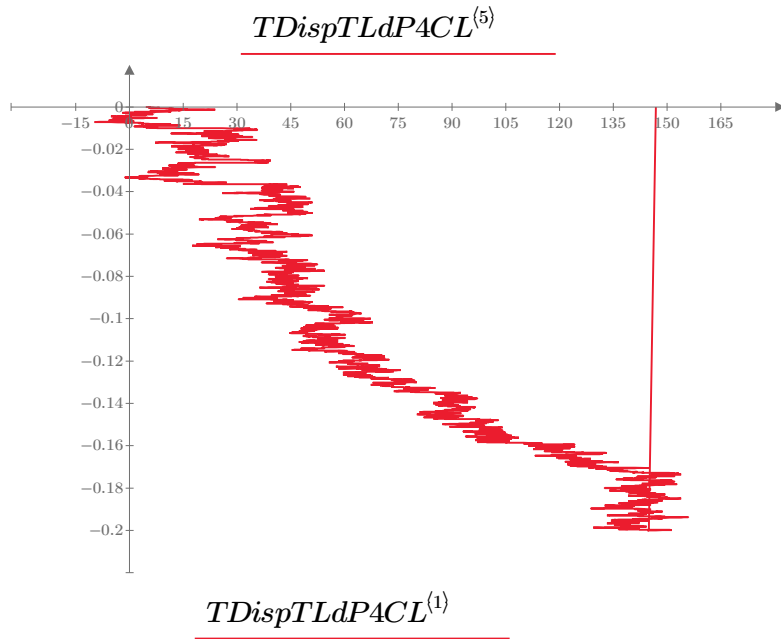


Fig F 31. Load displacement for compression pile P4 CL SG3

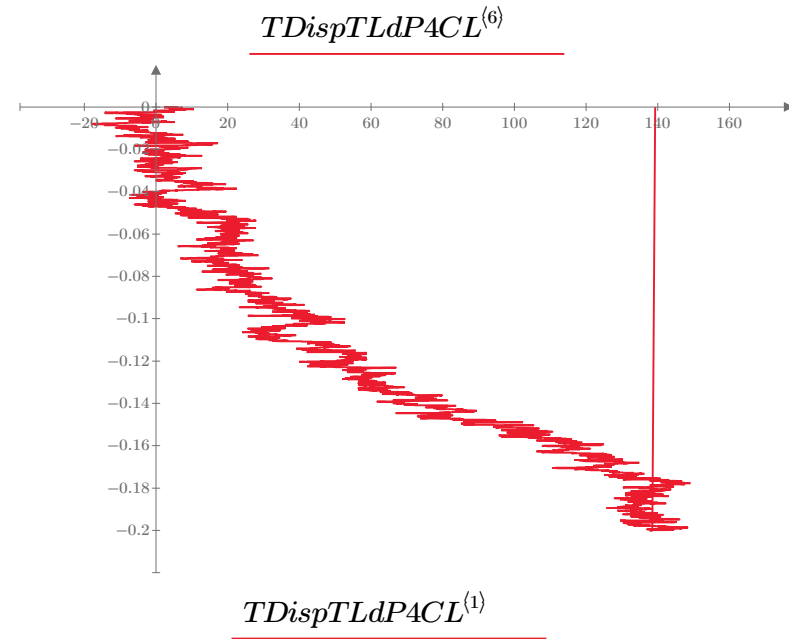


Fig F 32. Load displacement for compression pile P4 CL SG4

Functions for determining the Qult profile from strain gauge location

TOL := 0.00000001

```
SGplotQP(TDispTLdP0CL, PileNum) :=
  QP0 ← if PileNum = 0
    || lookup(-0.15, TDispTLdP0CL(1), TDispTLdP0CL(3), "near")
    || else
    || lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(3), "near")
  QP1 ← if PileNum = 0
    || lookup(-0.15, TDispTLdP0CL(1), TDispTLdP0CL(4), "near")
    || else
    || lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(4), "near")
  QP2 ← lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(5), "near")
  QP3 ← lookup(-0.05, TDispTLdP0CL(1), TDispTLdP0CL(6), "near")
  combined ← if PileNum = 0
    || stack(QP0, QP1, QP1, QP1, QP1, QP1)
    || else if PileNum = 1
    || stack(QP0, QP1, QP1, QP2, QP2, QP2)
    || else
    || stack(QP0, QP1, QP1, QP2, QP2, QP3)
  combined
```


Appendix F Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

$$SGPlotQP4CL := SGplotQP(TDispTLdP4CL, 4) \text{ } \mathbf{kN} = \begin{bmatrix} -610.99 \\ 5.436 \\ 5.436 \\ 49.812 \\ 49.812 \\ 6.022 \end{bmatrix} \text{ } \mathbf{kN}$$

$$SGEmbDP := - \begin{bmatrix} 0.6 + 3.5 & 0.6 + 3.5 & 0.6 + 3.5 & 0.6 + 3.5 & 0.6 + 3.5 \\ 0.6 & 0.6 + 3 & 0.6 + 3 & 0.6 + 2 & 0.6 + 3 \\ 0 & 0.6 + 3 & 0.6 + 3 & 0.6 + 2 & 0.6 + 3 \\ 0 & 0.6 & 0.6 + 2 & 0.6 + 1 & 0.6 + 1 \\ 0 & 0 & 0.6 + 2 & 0.6 + 1 & 0.6 + 1 \\ 0 & 0 & 0.6 & 0.6 & 0.6 \end{bmatrix} \cdot D \cdot Nscale_{0,0}^{selfac}$$

SG embedment depth in prototype scale. Here, colm 0-4 represents P0 to P4. Row 0 to 5 represents depth to strain SG 1 to 4

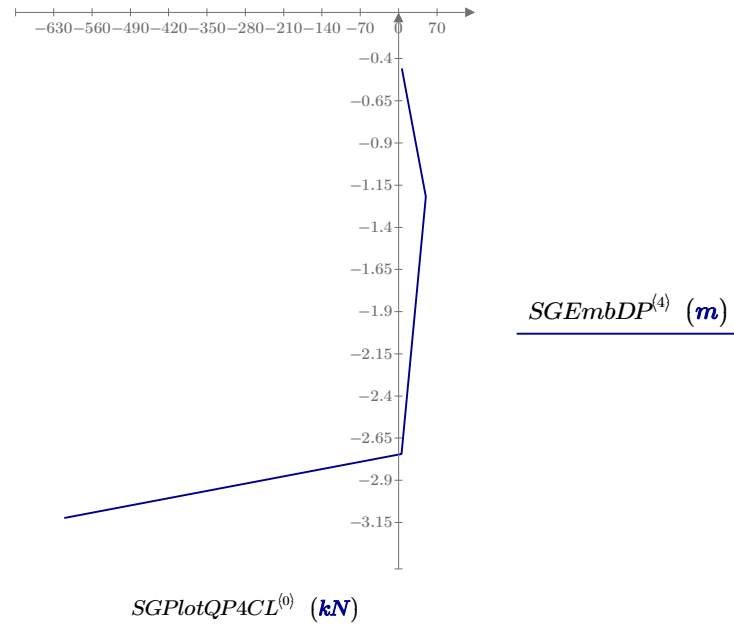


Fig F 33. SG Depth vs Axial Load for P4 pile

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

Functions for calculating EDR from the load displacement curve for each cycles and each pseudostatic loads

TOL := 0.00000001

```
EDR(TDispTLdP0PL1, Pseu1perS, IniTime, IniDisp, LoopNo, SGNo) :=
  m ← TDispTLdP0PL1
  o ← TimeCycLoop(Pseu1perS, IniTime, IniDisp) - IniTime
  w ← -m(1)
  wmax ← max(-m(1))
  if SGNo = 1
    q ← m(3)
    qmax ← max(m(3))
  else if SGNo = 2
    q ← m(4)
    qmax ← max(m(4))
  else if SGNo = 3
    q ← m(5)
    qmax ← max(m(5))
  else if SGNo = 4
    q ← m(6)
    qmax ← max(m(6))
  if LoopNo = 1
    t1 ← m1,0 - IniTime
    t2 ← o1
  else if LoopNo = 2
    t1 ← o1
    t2 ← o2
  else if LoopNo = 3
    t1 ← o2
    t2 ← o3
  else if LoopNo = 4
    t1 ← o3
    t2 ← o4
  tstart ← lookup(t1, (m(0) - IniTime), (m(0) - IniTime), "near")
  tend ← lookup(t2, (m(0) - IniTime), (m(0) - IniTime), "near")
  rowstart ← match(t1, (m(0) - IniTime), "near")
  rowend ← match(t2, (m(0) - IniTime), "near")
  for i ∈ rowstart0,0 .. rowend0,0
    ri ← ((wi - wi-1) * ((qi + qi-1)/2))
```

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

```

area ← ∑ r
EDR ← if qmax = 0
      if wmax = 0
        0
      else
        area
        qmax · wmax
s ← augment((tstart + IniTime), (tend + IniTime), rowstart, rowend, qmax, wmax, area, EDR)
EDR

```

Functions for combining EDR from the load displacement curve for each cycles and each pseudostatic loads

```

EDRPOPLSG(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, PileNo) :=
q1 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1)
q2 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1)
q3 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1)
q4 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1)
r1 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2)
r2 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2)
r3 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2)
r4 ← EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2)
w1 ← if PileNo = 0
      0
    else
      EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 3)
w2 ← if PileNo = 0
      0
    else
      EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 3)
w3 ← if PileNo = 0
      0
    else
      EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 3)
w4 ← if PileNo = 0
      0
    else
      EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3)
s1 ← if PileNo = 0
      0
    else if PileNo = 1
      0
    else
      EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 4)

```

$$NoLoop := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

```

s2 ← if PileNo = 0
    0
else if PileNo = 1
    0
else
    EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 4)
s3 ← if PileNo = 0
    0
else if PileNo = 1
    0
else
    EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 4)
s4 ← if PileNo = 0
    0
else if PileNo = 1
    0
else
    EDR(TDispTLdP0PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 4)
augment(stack(q1, q2, q3, q4), stack(r1, r2, r3, r4), stack(w1, w2, w3, w4), stack(s1, s2, s3, s4))

```

$$EDRP4PL1 := EDRPOPLSG(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, 4) = \begin{bmatrix} -2.766 & -0.141 & -0.173 & -0.157 \\ 4.829 & 0.142 & 0.134 & 0.1 \\ 0.32 & -0.013 & 0.015 & -0.057 \\ -1.418 & -0.051 & -0.057 & -0.065 \end{bmatrix}$$

$$EDRP4PL2 := EDRPOPLSG(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, 4) = \begin{bmatrix} -0.091 & 0.52 & 2.019 & 0.017 \\ -0.063 & 0.43 & 0.972 & 0.174 \\ -0.126 & 0.268 & 0.416 & 0.264 \\ -0.205 & 0.822 & 0.181 & 0.233 \end{bmatrix}$$

$$EDRP4PL3 := EDRPOPLSG(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, 4) = \begin{bmatrix} -0.112 & 0.397 & 0.588 & 0.404 \\ -0.126 & 0.261 & 0.355 & 0.087 \\ 0.426 & -0.057 & 0.228 & 0.103 \\ -0.059 & 0.249 & 0.126 & 0.153 \end{bmatrix}$$

$$EDRP4PL4 := EDRPOPLSG(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, 4) = \begin{bmatrix} -0.129 & 0.958 & 0.575 & 0.875 \\ 0.146 & -0.061 & -0.007 & 0.066 \\ -0.13 & 0.667 & 0.471 & 0.616 \\ -0.16 & 0.746 & 0.432 & 0.653 \end{bmatrix}$$

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

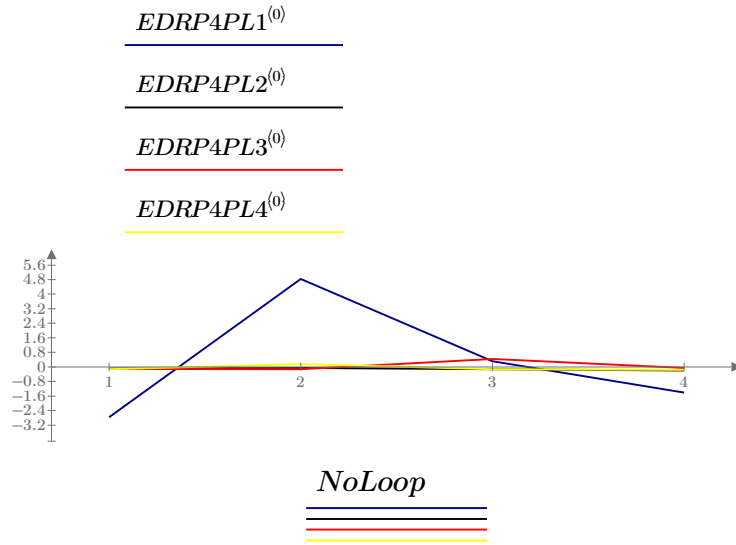


Fig F 34. EDR vs No of loops SG1

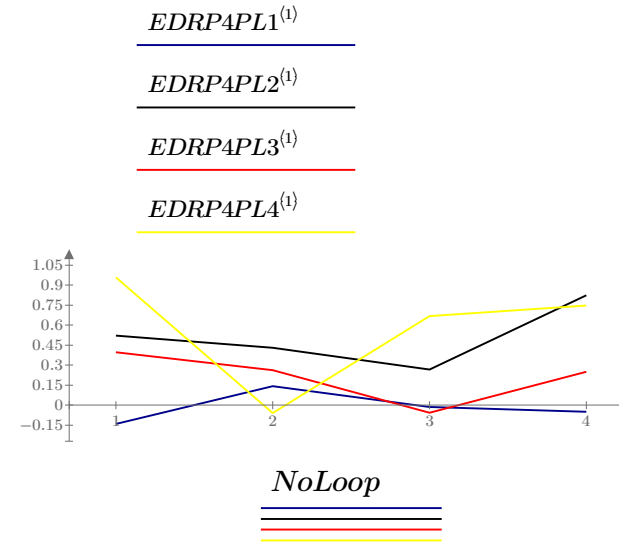


Fig F 35. EDR vs No of loops SG2

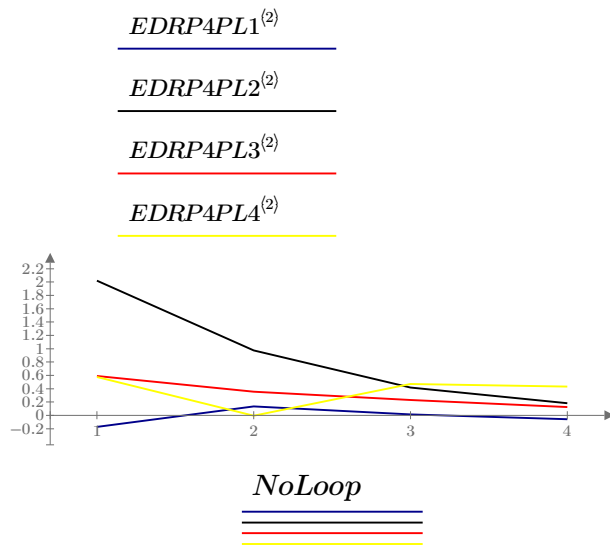


Fig F 36. EDR vs No of loops SG3

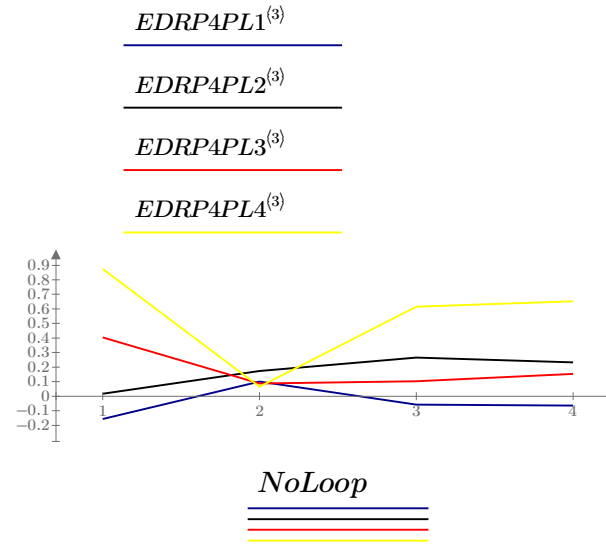


Fig F 37. EDR vs No of loops SG4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

Functions for disintegrating the load-displacement curves into separate cycles

```

DispLd (TDispTLdP0PL1, Pseu1perS, IniTime, IniDisp, LoopNo, SGNo) :=
    m ← TDispTLdP0PL1
    o ← TimeCycLoop (Pseu1perS, IniTime, IniDisp) – IniTime
    w ← –m(1)
    if SGNo = 1
        q ← m(3)
    else if SGNo = 2
        q ← m(4)
    else if SGNo = 3
        q ← m(5)
    else if SGNo = 4
        q ← m(6)
    if LoopNo = 1
        t1 ← o0
        t2 ← o1
    else if LoopNo = 2
        t1 ← o1
        t2 ← o2
    else if LoopNo = 3
        t1 ← o2
        t2 ← o3
    else if LoopNo = 4
        t1 ← o3
        t2 ← o4
    tstart ← lookup (t1, (m(0) – IniTime), (m(0) – IniTime), “near”)
    tend ← lookup (t2, (m(0) – IniTime), (m(0) – IniTime), “near”)
    rowstart ← match (t1, (m(0) – IniTime), “near”)
    rowend ← match (t2, (m(0) – IniTime), “near”)
    for i ∈ rowstart0,0 .. rowend0,0
        di ← w
        ldi ← q
    augment (d, ld)

```

Appendix F
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

$DispLdP4PL1L1SG1 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 1, 1)$

$DispLdP4PL1L2SG1 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 2, 1)$

$DispLdP4PL1L3SG1 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 3, 1)$

$DispLdP4PL1L4SG1 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 4, 1)$

$DispLdP4PL2L1SG1 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 1, 1)$

$DispLdP4PL2L2SG1 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 2, 1)$

$DispLdP4PL2L3SG1 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 3, 1)$

$DispLdP4PL2L4SG1 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 4, 1)$

$DispLdP4PL3L1SG1 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 1, 1)$

$DispLdP4PL3L2SG1 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 2, 1)$

$DispLdP4PL3L3SG1 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 3, 1)$

$DispLdP4PL3L4SG1 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 4, 1)$

$DispLdP4PL4L1SG1 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 1, 1)$

$DispLdP4PL4L2SG1 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 2, 1)$

$DispLdP4PL4L3SG1 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 3, 1)$

$DispLdP4PL4L4SG1 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 4, 1)$

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

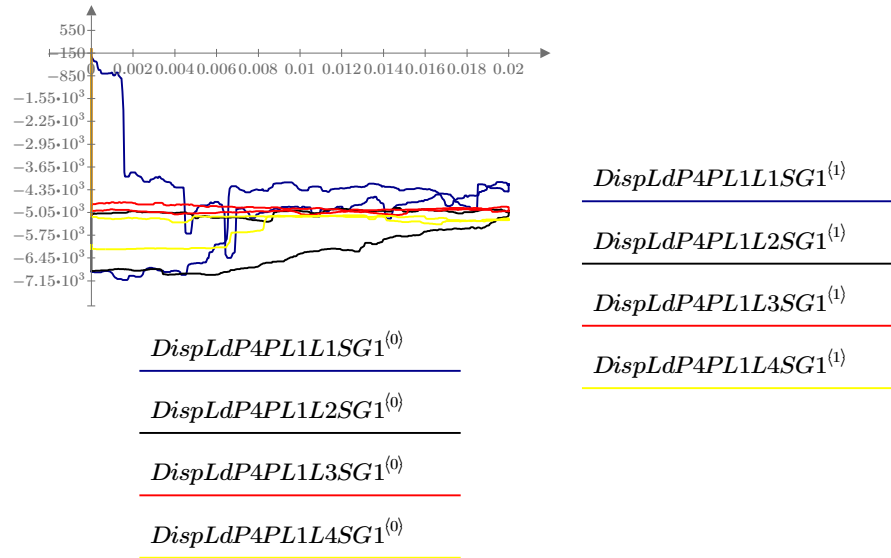


Fig F 38. Load-Displacement for P4 PL1 SG1

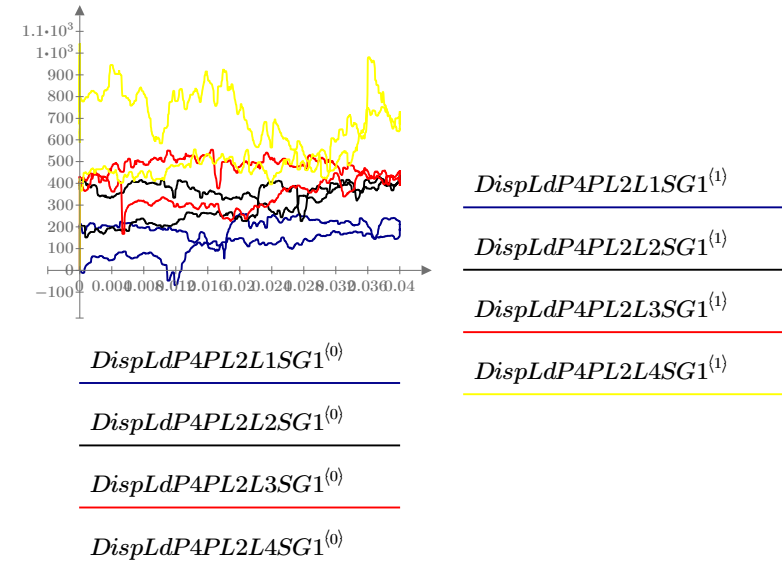


Fig F 39. Load-Displacement for P4 PL2 SG1

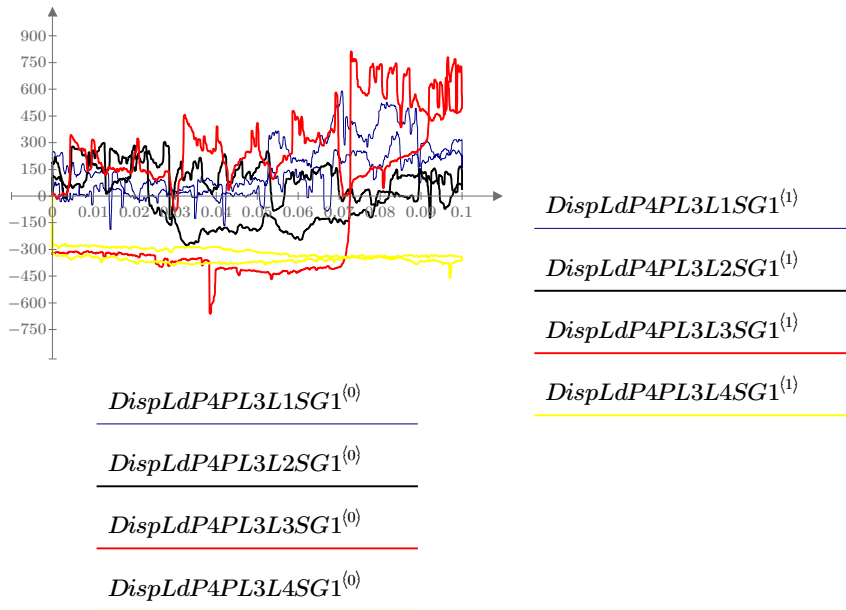


Fig F 40. Load-Displacement for P4 PL3 SG1

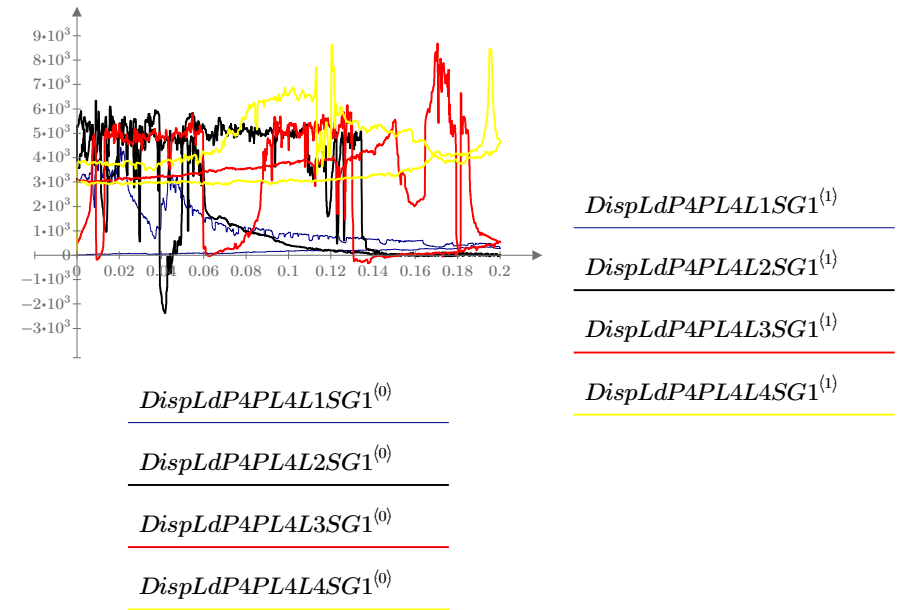


Fig F 41. Load-Displacement for P4 PL4 SG1

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

$$DispLdP4PL1L1SG2 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 1, 2)$$

$$DispLdP4PL1L2SG2 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 2, 2)$$

$$DispLdP4PL1L3SG2 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 3, 2)$$

$$DispLdP4PL1L4SG2 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 4, 2)$$

$$DispLdP4PL2L1SG2 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 1, 2)$$

$$DispLdP4PL2L2SG2 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 2, 2)$$

$$DispLdP4PL2L3SG2 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 3, 2)$$

$$DispLdP4PL2L4SG2 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 4, 2)$$

$$DispLdP4PL3L1SG2 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 1, 2)$$

$$DispLdP4PL3L2SG2 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 2, 2)$$

$$DispLdP4PL3L3SG2 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 3, 2)$$

$$DispLdP4PL3L4SG2 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 4, 2)$$

$$DispLdP4PL4L1SG2 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 1, 2)$$

$$DispLdP4PL4L2SG2 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 2, 2)$$

$$DispLdP4PL4L3SG2 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 3, 2)$$

$$DispLdP4PL4L4SG2 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 4, 2)$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

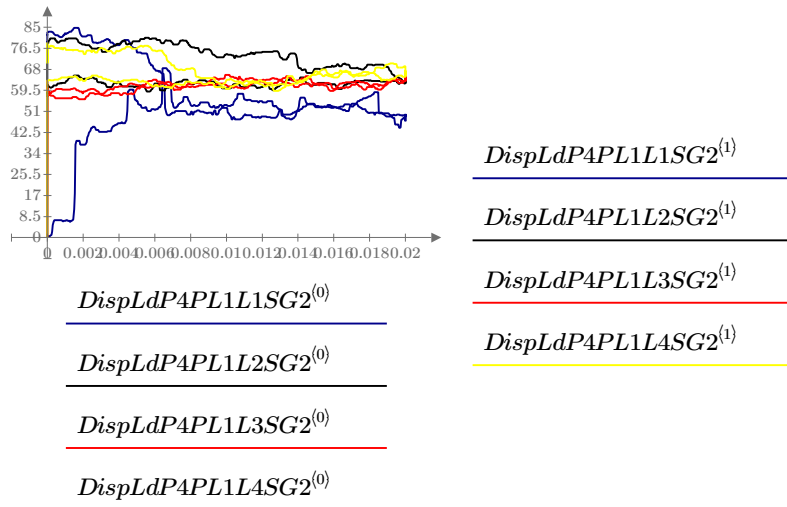


Fig F 42. Load-Displacement for P4 PL1 SG2

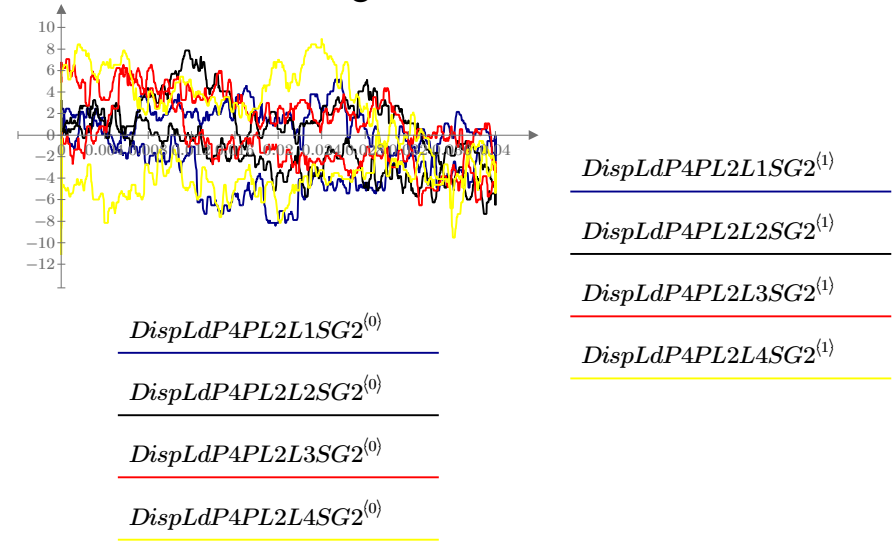


Fig F 43. Load-Displacement for P4 PL2 SG2

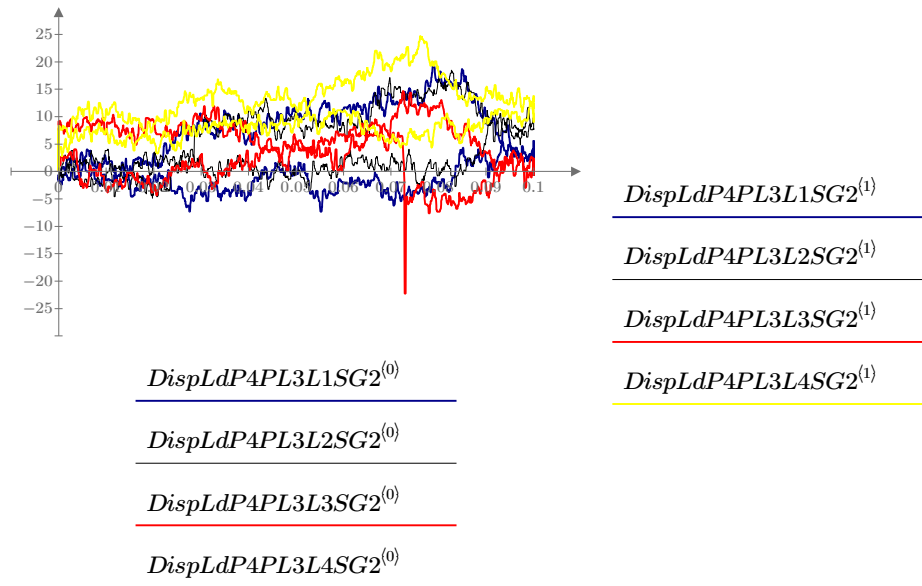


Fig F 44. Load-Displacement for P4 PL3 SG4

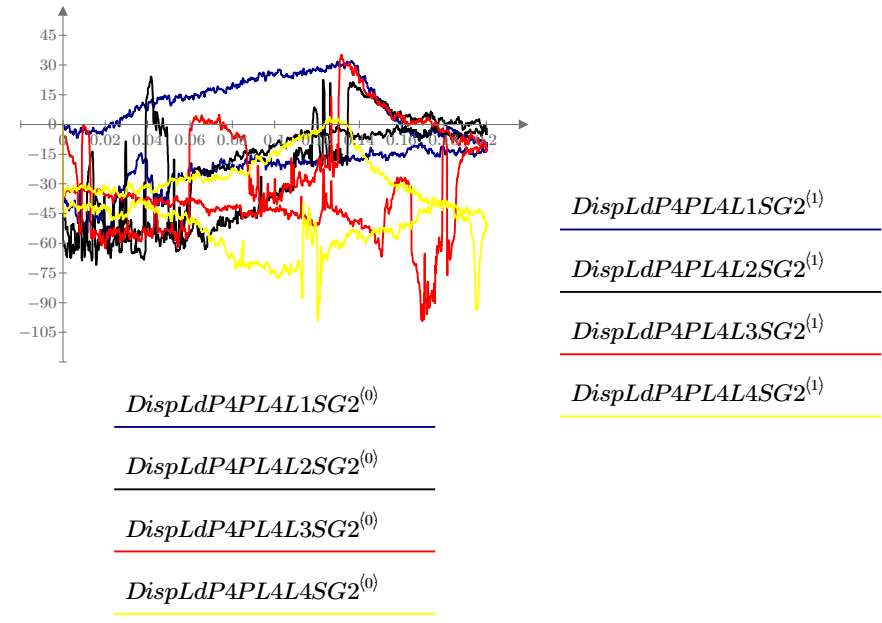


Fig F 45. Load-Displacement for P4 PL4 SG4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

$$DispLdP4PL1L1SG3 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 1, 3)$$

$$DispLdP4PL1L2SG3 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 2, 3)$$

$$DispLdP4PL1L3SG3 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 3, 3)$$

$$DispLdP4PL1L4SG3 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 4, 3)$$

$$DispLdP4PL2L1SG3 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 1, 3)$$

$$DispLdP4PL2L2SG3 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 2, 3)$$

$$DispLdP4PL2L3SG3 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 3, 3)$$

$$DispLdP4PL2L4SG3 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 4, 3)$$

$$DispLdP4PL3L1SG3 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 1, 3)$$

$$DispLdP4PL3L2SG3 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 2, 3)$$

$$DispLdP4PL3L3SG3 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 3, 3)$$

$$DispLdP4PL3L4SG3 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 4, 3)$$

$$DispLdP4PL4L1SG3 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 1, 3)$$

$$DispLdP4PL4L2SG3 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 2, 3)$$

$$DispLdP4PL4L3SG3 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 3, 3)$$

$$DispLdP4PL4L4SG3 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 4, 3)$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

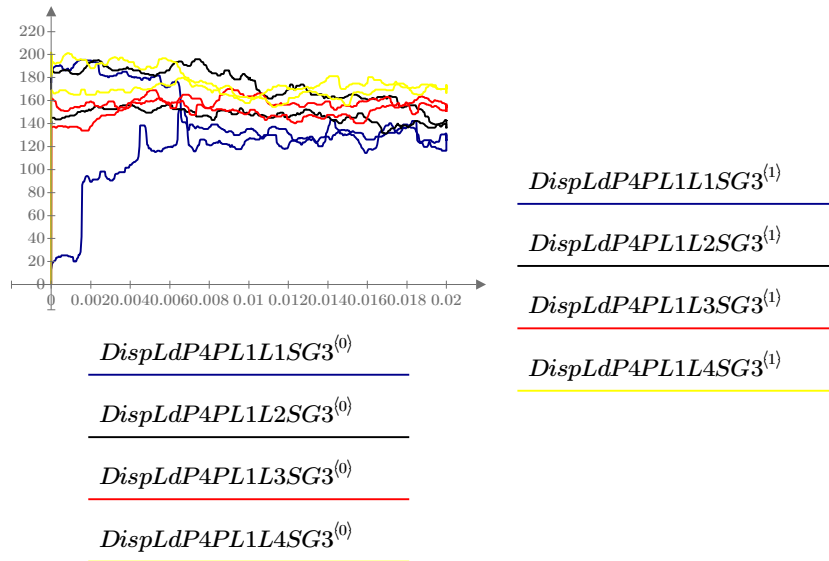


Fig F 46. Load-Displacement for P4 PL1 SG3

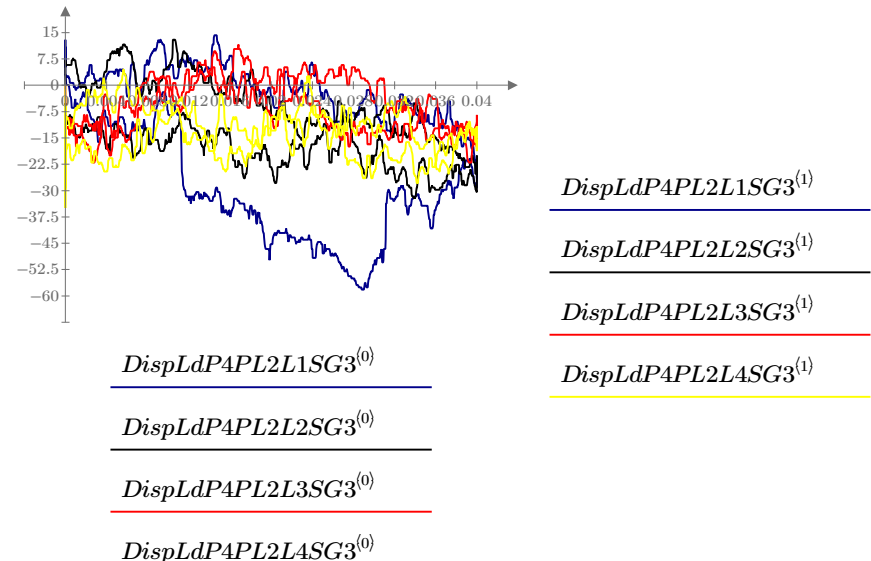


Fig F 47. Load-Displacement for P4 PL2 SG3

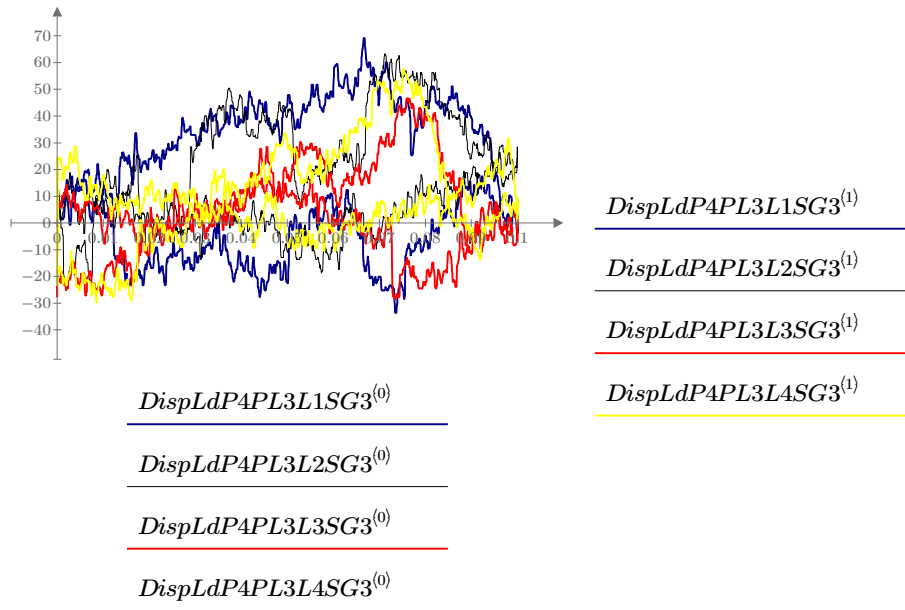


Fig F 48. Load-Displacement for P4 PL3 SG3

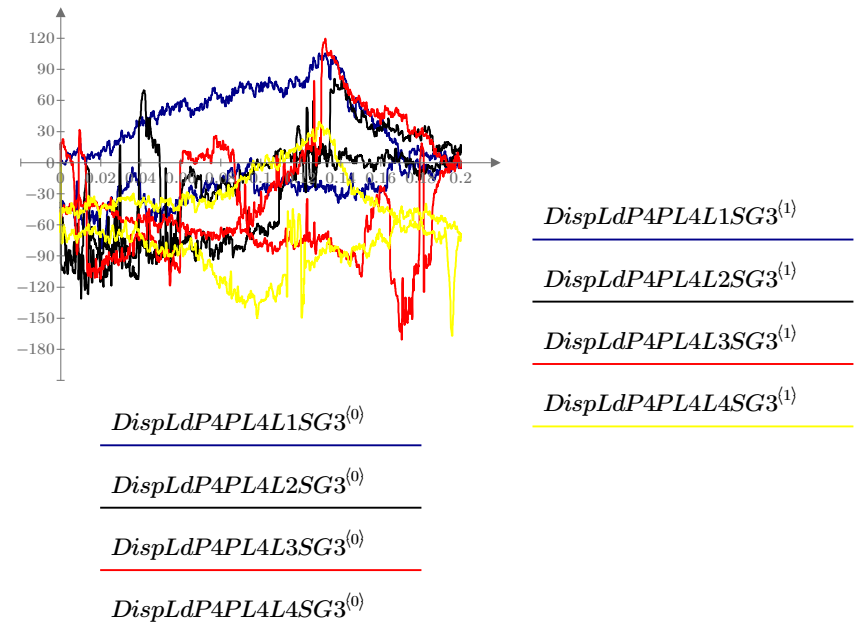


Fig F 49. Load-Displacement for P4 PL4 SG3

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

$$DispLdP4PL1L1SG4 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 1, 4)$$

$$DispLdP4PL1L2SG4 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 2, 4)$$

$$DispLdP4PL1L3SG4 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 3, 4)$$

$$DispLdP4PL1L4SG4 := DispLd(TDispTLdP4PL1, PseuPL1H, IniTimePL1H, IniDisp, 4, 4)$$

$$DispLdP4PL2L1SG4 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 1, 4)$$

$$DispLdP4PL2L2SG4 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 2, 4)$$

$$DispLdP4PL2L3SG4 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 3, 4)$$

$$DispLdP4PL2L4SG4 := DispLd(TDispTLdP4PL2, PseuPL2H, IniTimePL2H, IniDisp, 4, 4)$$

$$DispLdP4PL3L1SG4 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 1, 4)$$

$$DispLdP4PL3L2SG4 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 2, 4)$$

$$DispLdP4PL3L3SG4 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 3, 4)$$

$$DispLdP4PL3L4SG4 := DispLd(TDispTLdP4PL3, PseuPL3H, IniTimePL3H, IniDisp, 4, 4)$$

$$DispLdP4PL4L1SG4 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 1, 4)$$

$$DispLdP4PL4L2SG4 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 2, 4)$$

$$DispLdP4PL4L3SG4 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 3, 4)$$

$$DispLdP4PL4L4SG4 := DispLd(TDispTLdP4PL4, PseuPL4H, IniTimePL4H, IniDisp, 4, 4)$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

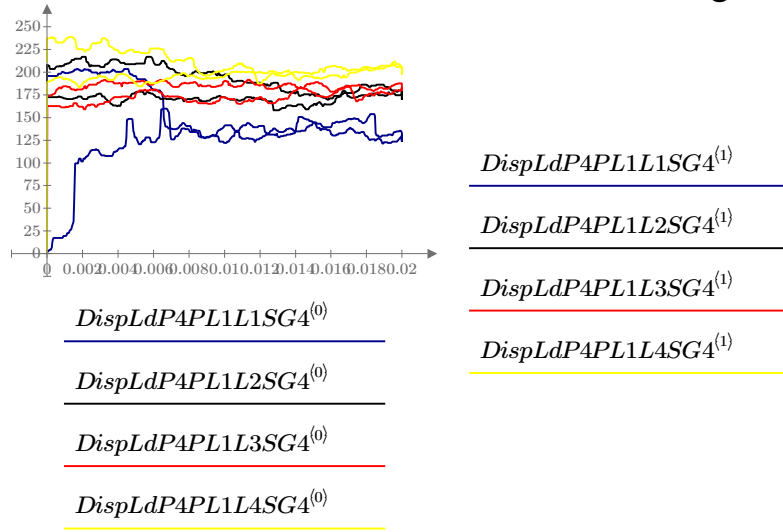


Fig F 50. Load-Displacement for P4 PL1 SG4

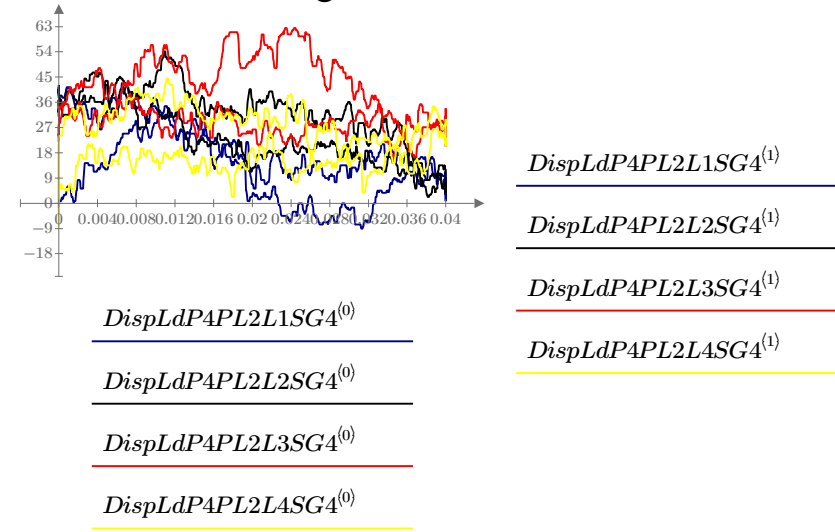


Fig F 51. Load-Displacement for P4 PL2 SG4

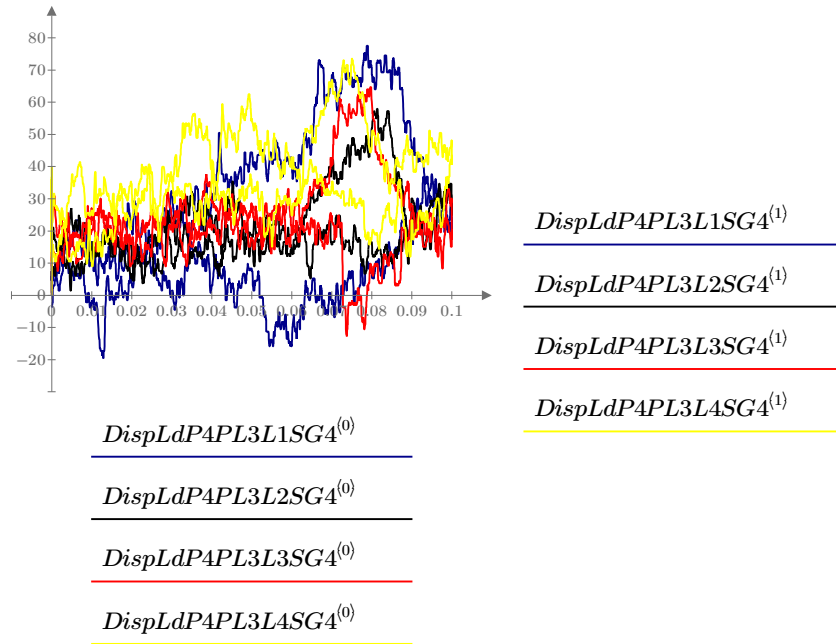


Fig F 52. Load-Displacement for P4 PL3 SG4

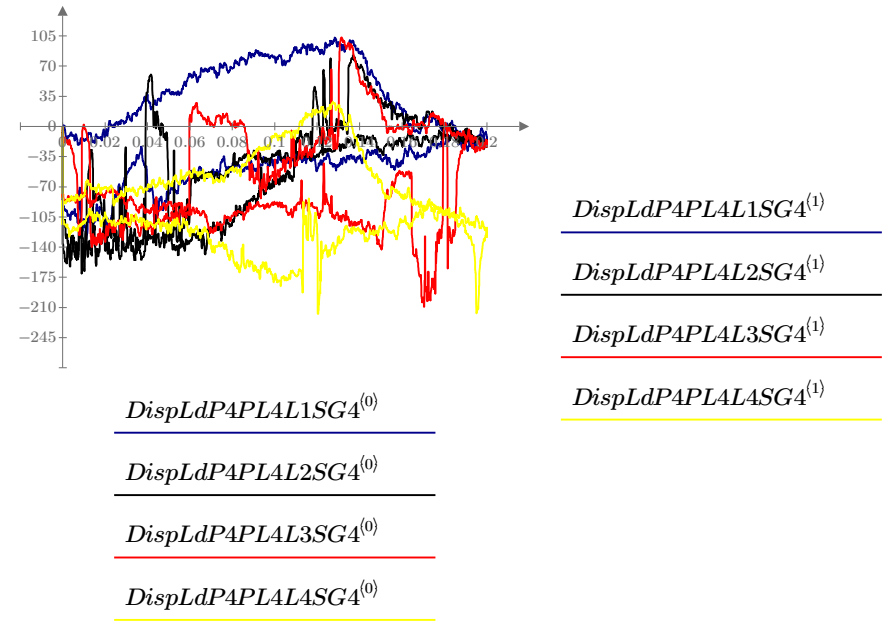


Fig F 53. Load-Displacement for P4 PL4 SG4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

Functions for determining the Q_{max} profile from each loads

TOL := 0.00000001

$$Q_{maxSG}(TDispTLdP2PL1, PileNum) := \begin{cases} QP0 \leftarrow \max(TDispTLdP2PL1^{(3)}) \\ QP1 \leftarrow \max(TDispTLdP2PL1^{(4)}) \\ QP2 \leftarrow \max(TDispTLdP2PL1^{(5)}) \\ QP3 \leftarrow \max(TDispTLdP2PL1^{(6)}) \\ combined \leftarrow \text{if } PileNum = 0 \\ \quad \text{stack}(QP0, QP1, QP1, QP1, QP1, QP1) \\ \text{else if } PileNum = 1 \\ \quad \text{stack}(QP0, QP1, QP1, QP2, QP2, QP2) \\ \text{else} \\ \quad \text{stack}(QP0, QP1, QP1, QP2, QP2, QP3) \\ combined \end{cases}$$

$Q_{maxP4PL1} := Q_{maxSG}(TDispTLdP4PL1, 4) \cdot \text{kN}$

$Q_{maxP4PL2} := Q_{maxSG}(TDispTLdP4PL2, 4) \text{ kN}$

$Q_{maxP4PL3} := Q_{maxSG}(TDispTLdP4PL3, 4) \text{ kN}$

$Q_{maxP4PL4} := Q_{maxSG}(TDispTLdP4PL4, 4) \text{ kN}$

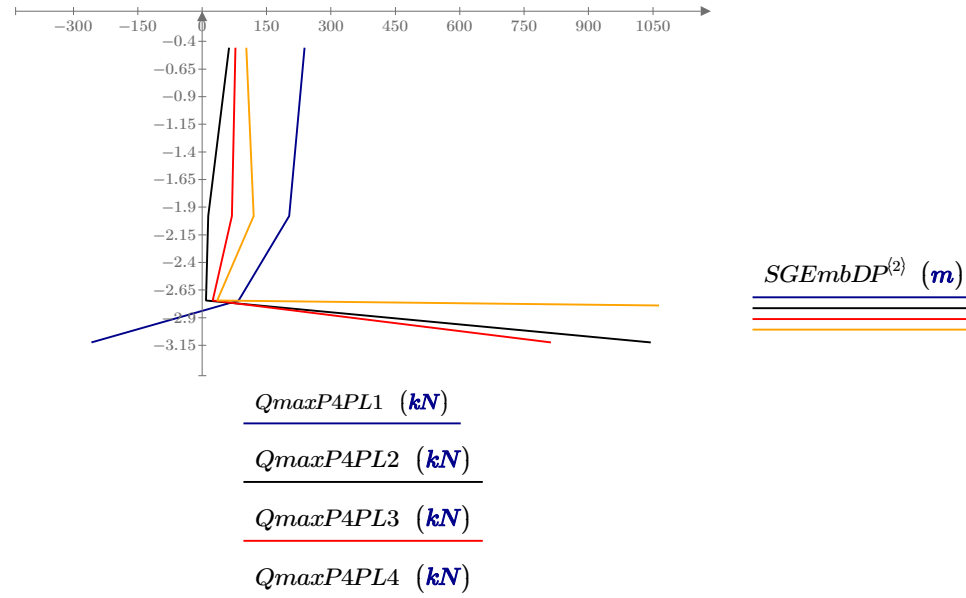
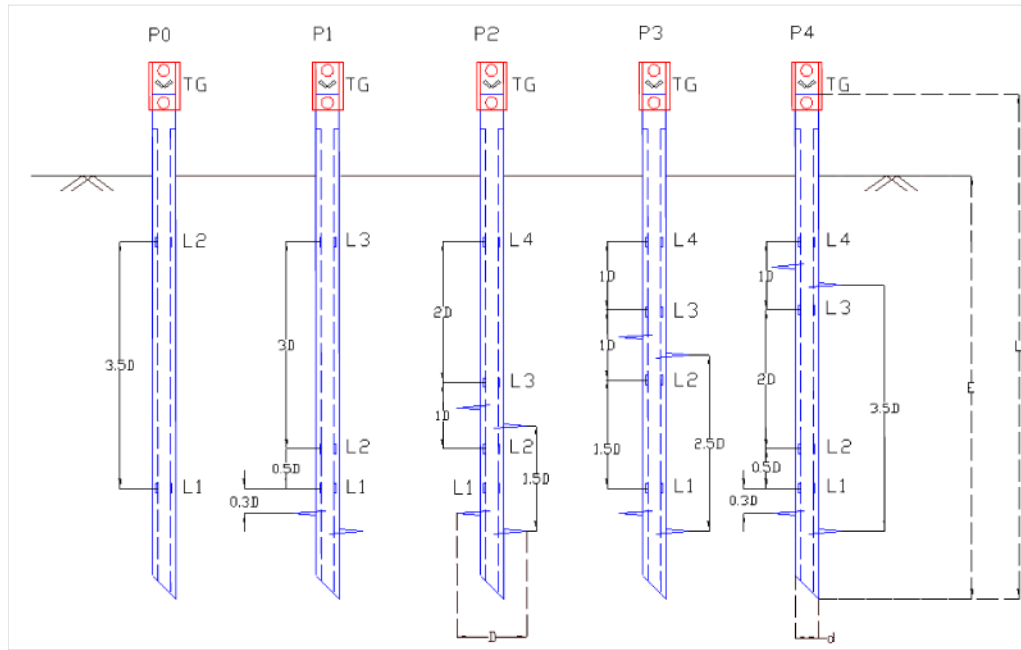


Fig F 54. SG Depth vs Q max from each load amplitude for P4 pile

2.3.3 Skin Friction vs Depth



Strain gauge locations in model piles.

$$HgtShaft := \begin{bmatrix} 3.5 & 0.5 & 0.5 & 1.5 & 0.5 \\ 0 & 3 & 1 & 1 & 2 \\ 0 & 0 & 2 & 1 & 1 \end{bmatrix} \cdot D \cdot Nscale^{sclfac_{0,0}} = \begin{bmatrix} 2.667 & 0.381 & 0.381 & 1.143 & 0.381 \\ 0 & 2.286 & 0.762 & 0.762 & 1.524 \\ 0 & 0 & 1.524 & 0.762 & 0.762 \end{bmatrix} m$$

Height in the shaft segment between two stations in prototype scale. Here, colm 0-4 represents P0 to P4. Row 0 to 2 represents height between SG 1-2, 2-3 & 3-4

$$SurfArea := HgtShaft \cdot \pi \cdot d \cdot Nscale^{sclfac_{0,0}} = \begin{bmatrix} 2.128 & 0.304 & 0.304 & 0.912 & 0.304 \\ 0 & 1.824 & 0.608 & 0.608 & 1.216 \\ 0 & 0 & 1.216 & 0.608 & 0.608 \end{bmatrix} m^2$$

Surface Area of the shaft segment between two stations in prototype scale. Here, colm 0-4 represents P0 to P4. Row 0 to 2 represents surface area between SG 1-2, 2-3 & 3-4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

Function for determining the Unit Shaft Resistance within the shaft segment

```

UntShtRes(LdP, PileNum) :=
  for i ∈ 0, 1 .. rows(LdP) - 1
    for j ∈ 0, 1 .. cols(LdP) - 1
      shaft12i,0 ←  $\frac{(LdP_{i,4} - LdP_{i,3}) \text{ kN}}{\text{submatrix}(\text{SurfArea}, 0, 2, \text{PileNum}, \text{PileNum})_{0,0}}$ 
      shaft23i,1 ← if submatrix(SurfArea, 0, 2, PileNum, PileNum)1 = 0
                     0
                     else
                      $\frac{(LdP_{i,5} - LdP_{i,4}) \text{ kN}}{\text{submatrix}(\text{SurfArea}, 0, 2, \text{PileNum}, \text{PileNum})_1}$ 
      shaft34i,2 ← if submatrix(SurfArea, 0, 2, PileNum, PileNum)2 = 0
                     0
                     else
                      $\frac{(LdP_{i,6} - LdP_{i,5}) \text{ kN}}{\text{submatrix}(\text{SurfArea}, 0, 2, \text{PileNum}, \text{PileNum})_2}$ 
    augment(shaft12(0), shaft23(1), shaft34(2))
  
```

$ShftResP4PL1 := UntShtRes(TDispTLdP4PL1, 2)$

$ShftResP4PL2 := UntShtRes(TDispTLdP4PL2, 2)$

$ShftResP4PL3 := UntShtRes(TDispTLdP4PL3, 2)$

$ShftResP4PL4 := UntShtRes(TDispTLdP4PL4, 2)$

$ShftResP4CL := UntShtRes(TDispTLdP4CL, 2)$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

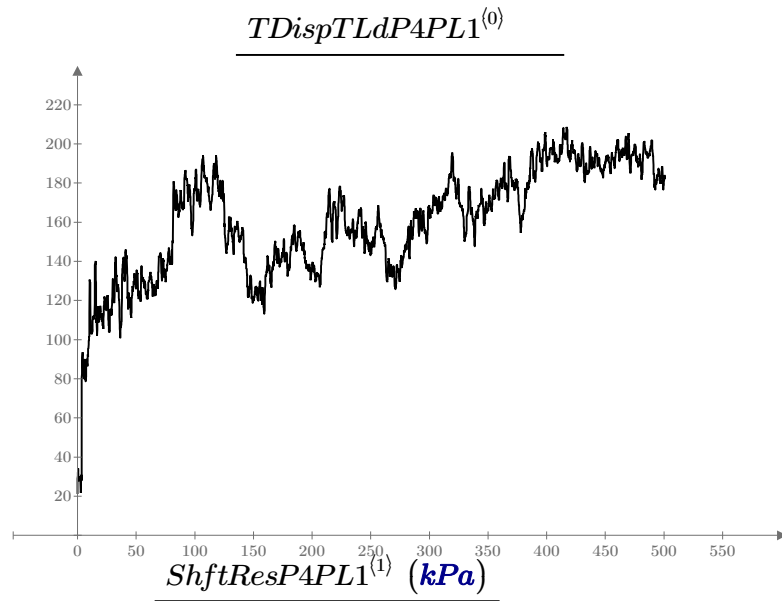


Fig F 55. Shaft Resistances vs Time, P4 PL1

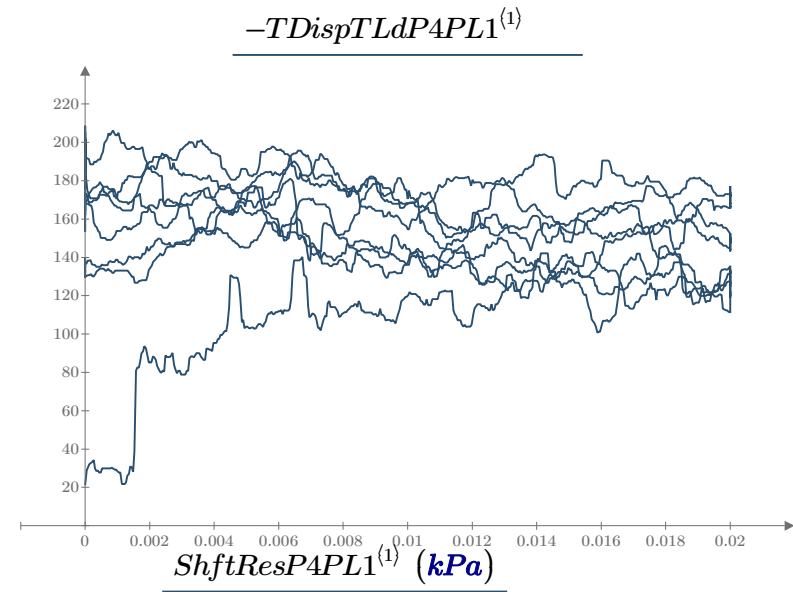


Fig F 56. Shaft Resistances vs Displacement, P4 PL1

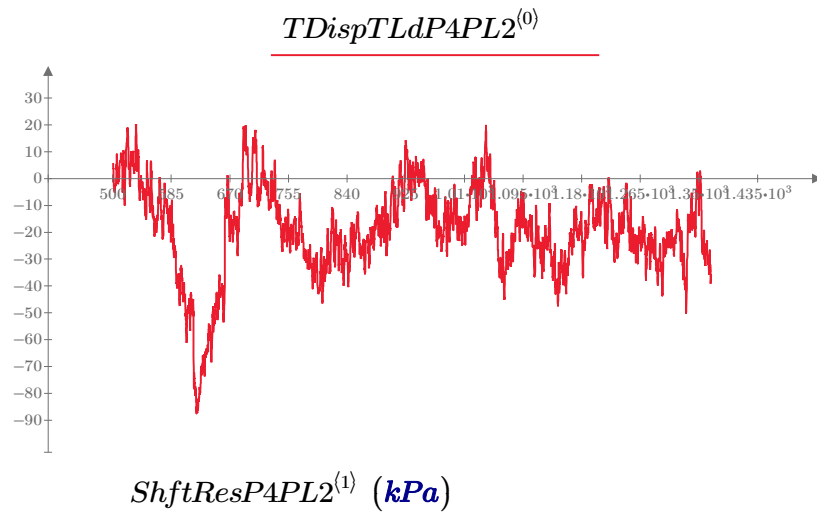


Fig F 57. Shaft Resistances vs Time, P4 PL2

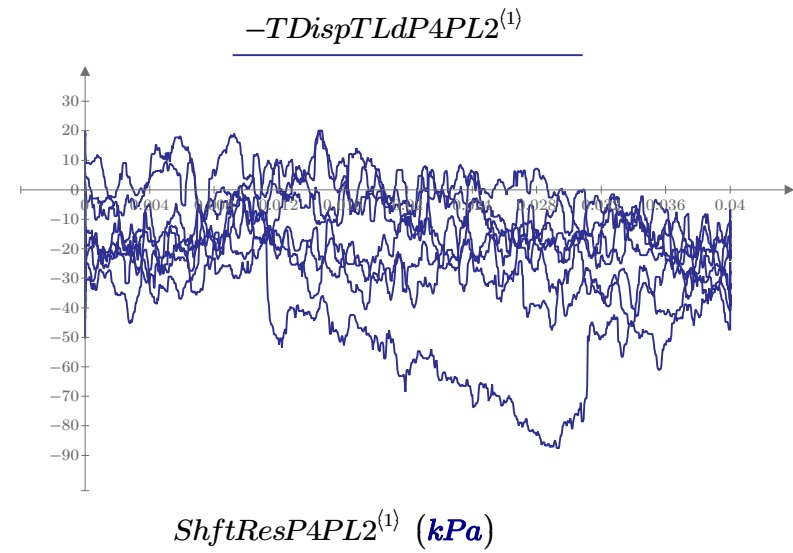
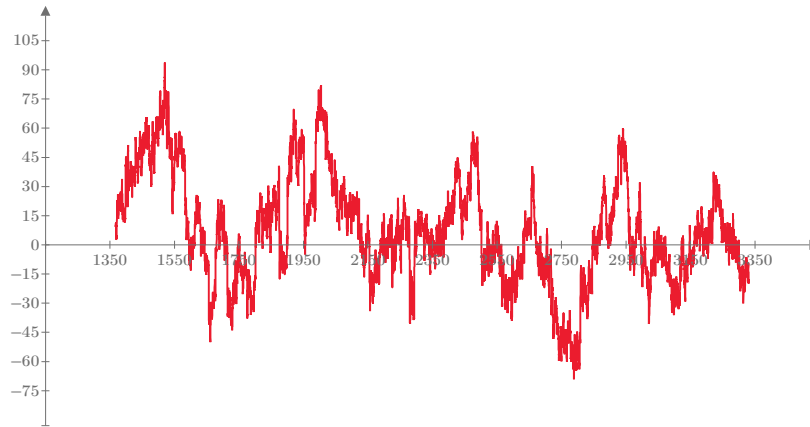


Fig F 58. Shaft Resistances vs Displacement, P4 PL2

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

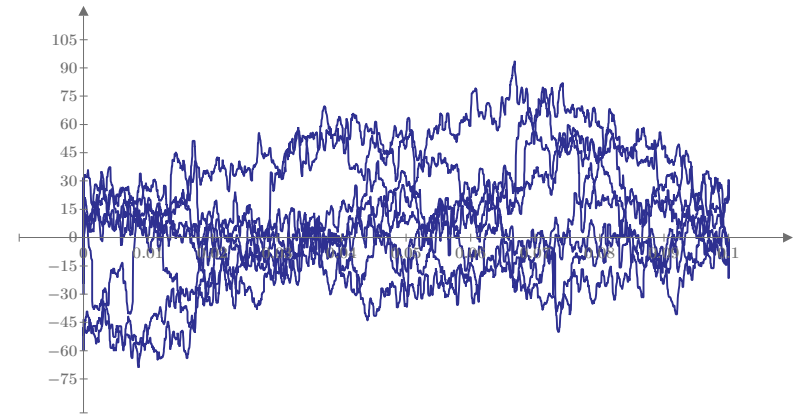
$TDispTLdP4PL3^{(0)}$



$ShftResP4PL3^{(1)}$ (kPa)

Fig F 59. Shaft Resistances vs Time, P4 PL3

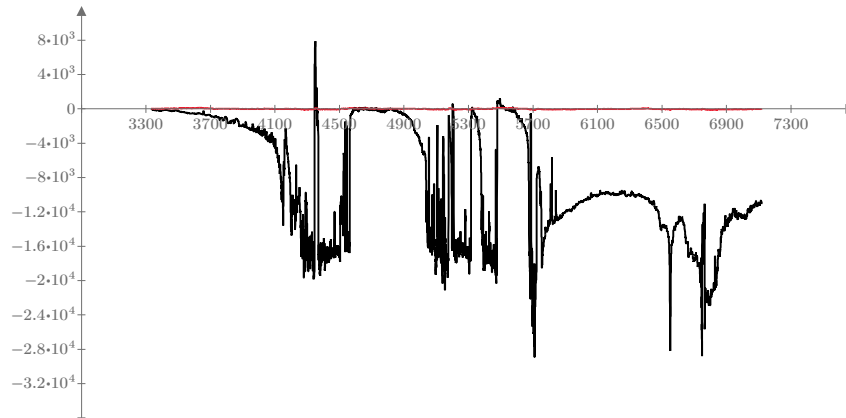
$-TDispTLdP4PL3^{(1)}$



$ShftResP4PL3^{(1)}$ (kPa)

Fig F 60. Shaft Resistances vs Displacement, P4 PL3

$TDispTLdP4PL4^{(0)}$

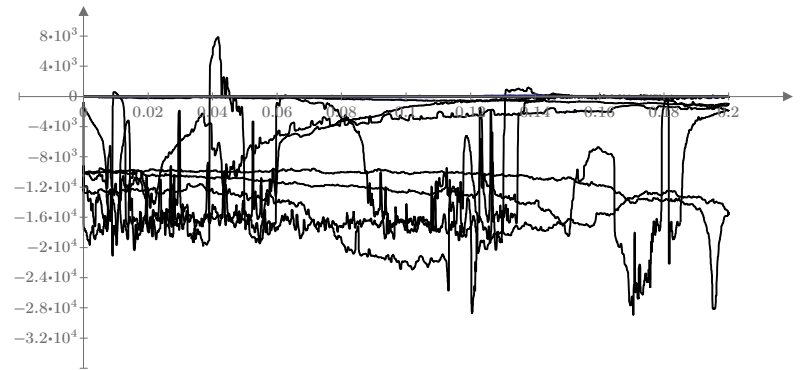


$ShftResP4PL4^{(0)}$ (kPa)

$ShftResP4PL4^{(1)}$ (kPa)

Fig F 61. Shaft Resistances vs Time, P4 PL4

$-TDispTLdP4PL4^{(1)}$



$ShftResP4PL4^{(0)}$ (kPa)

$ShftResP4PL4^{(1)}$ (kPa)

Fig F 62. Shaft Resistances vs Displacement, P4 PL4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

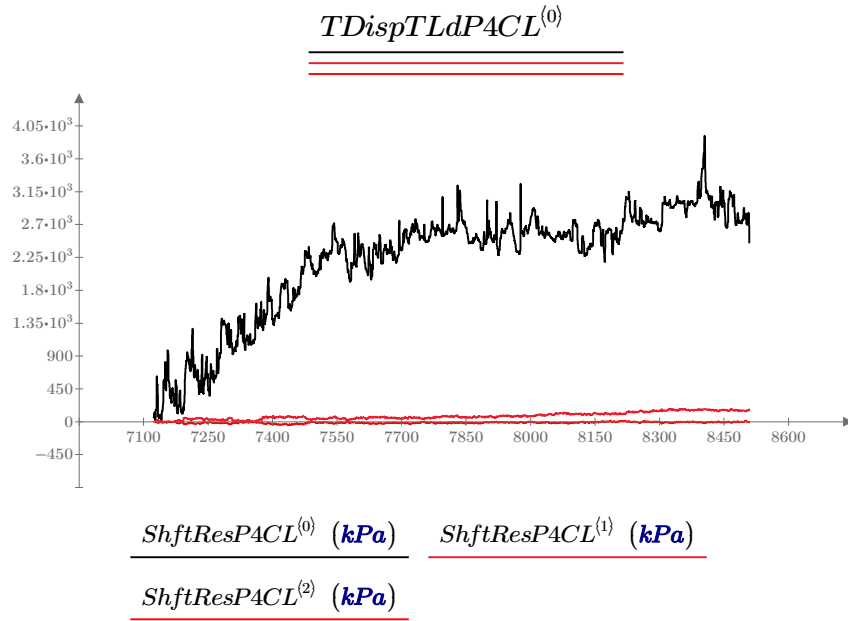


Fig F 63. Shaft Resistances vs Time, P3 CL

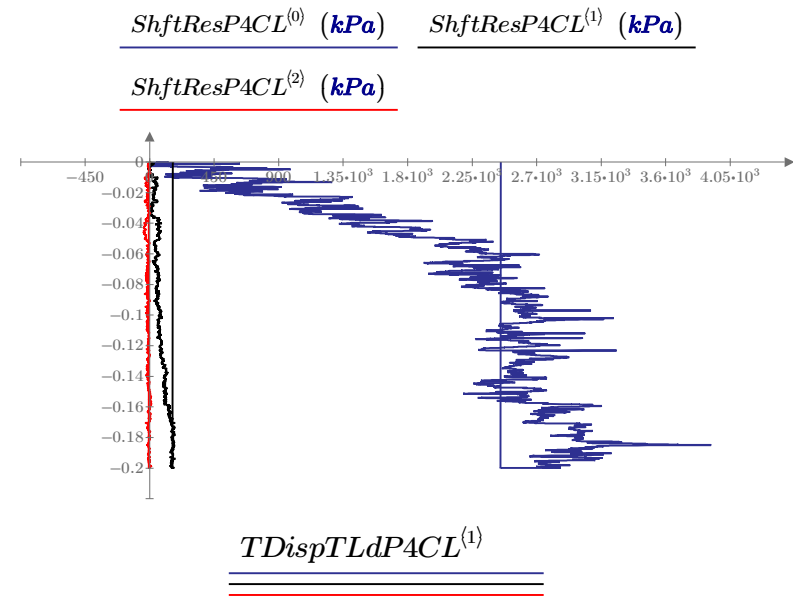


Fig F 64. Shaft Resistances vs Displacement, P3 CL

$$ShftP4CL := \text{augment} \left(TDispTLdP4CL^{(1)}, \frac{ShftResP4CL^{(0)}}{kPa}, \frac{ShftResP4CL^{(1)}}{kPa}, \frac{ShftResP4CL^{(2)}}{kPa} \right)$$

$$UltShReP4_2 := \text{lookup} \left(-0.05, ShftP4CL^{(0)}, ShftP4CL^{(3)}, \text{"near"} \right) = [-36.008]$$

$$UltShReP4_1 := \text{lookup} \left(-0.05, ShftP4CL^{(0)}, ShftP4CL^{(2)}, \text{"near"} \right) = [72.98]$$

$$UltShReP4_0 := \text{lookup} \left(-0.05, ShftP4CL^{(0)}, ShftP4CL^{(1)}, \text{"near"} \right) = [2.028 \cdot 10^3]$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

Functions for calculating the ultimate unit shaft resistance along the depth

```

ShftResplot(ShftP0CL, PileNum) := for i ∈ 0, 1 .. cols(ShftP0CL) - 1
    ||
    || UltShReP0 ← if PileNum = 0
    ||     || lookup(-0.15, ShftP0CL(0), ShftP0CL(1), "near")
    ||     || else
    ||     || lookup(-0.05, ShftP0CL(0), ShftP0CL(1), "near")
    ||
    || UltShReP1 ← if PileNum = 0
    ||     || 0
    ||     || else
    ||     || lookup(-0.05, ShftP0CL(0), ShftP0CL(2), "near")
    ||
    || UltShReP2 ← if PileNum = 0
    ||     || 0
    ||     || else if PileNum = 1
    ||     || 0
    ||     || else
    ||     || lookup(-0.05, ShftP0CL(0), ShftP0CL(3), "near")
    ||
    || combined ← if PileNum = 0
    ||     || stack(UltShReP0, UltShReP0, UltShReP0, UltShReP0, UltShReP0, UltShReP0)
    ||     || else if PileNum = 1
    ||     || stack(UltShReP0, UltShReP0, UltShReP1, UltShReP1, UltShReP1, UltShReP1)
    ||     || else
    ||     || stack(UltShReP0, UltShReP0, UltShReP1, UltShReP1, UltShReP2, UltShReP2)

```

$$ShftResPlotP4CL := ShftResplot(ShftP4CL, 4) \text{ } \mathbf{kPa} = \begin{bmatrix} 2.028 \cdot 10^3 \\ 2.028 \cdot 10^3 \\ 72.98 \\ 72.98 \\ -36.008 \\ -36.008 \end{bmatrix} \text{ } \mathbf{kPa}$$

Appendix F
Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

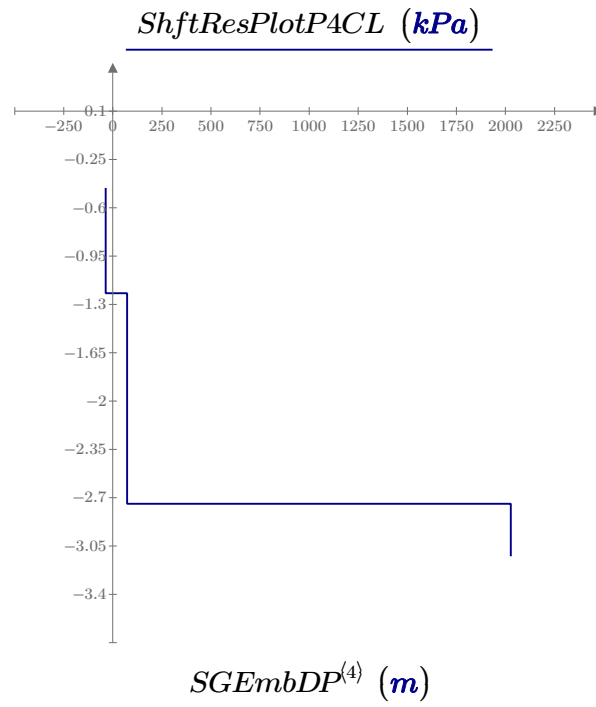


Fig F 65. Strain Gauge Depth vs Unit Shaft Resistance for post cyclic pile P4.

$ShftResplotP_C := \text{augment}(ShftResPlotP4CL, ShftResPlotP4CL, ShftResPlotP4CL, ShftResPlotP4CL, ShftResPlotP4CL)$
Ultimate Shaft resistance on the five compression piles between SGS

Function for estimating Mid depth of SGs on each piles

```
MidDSGsgmt(PileNum) := |||
||| shaft12 ← mean(submatrix(SGEmbDP, 0, 1, PileNum, PileNum))
||| shaft23 ← if mean(submatrix(SGEmbDP, 2, 3, PileNum, PileNum)) = 0
||| 0
||| else
||| mean(submatrix(SGEmbDP, 2, 3, PileNum, PileNum))
||| shaft34 ← if mean(submatrix(SGEmbDP, 4, 5, PileNum, PileNum)) = 0
||| 0
||| else
||| mean(submatrix(SGEmbDP, 4, 5, PileNum, PileNum))
||| stack(shaft12, shaft23, shaft34)
|||
```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

Function for estimating Ks of each piles

```

Ks(ShftResplotP, PileNum) :=
  shaft12 ←  $\frac{\text{mean}(\text{submatrix}(ShftResplotP, 0, 1, PileNum, PileNum))}{\text{mean}(\text{submatrix}(SGEmbDP, 0, 1, PileNum, PileNum)) \cdot \gamma \cdot \tan(\delta)}$ 
  shaft23 ← if PileNum = 2
    0
  else if PileNum = 3
    0
  else
    if mean(submatrix(SGEmbDP, 2, 3, PileNum, PileNum)) = 0
      0
    else
       $\frac{\text{mean}(\text{submatrix}(ShftResplotP, 2, 3, PileNum, PileNum))}{\text{mean}(\text{submatrix}(SGEmbDP, 2, 3, PileNum, PileNum)) \cdot \gamma \cdot \tan(\delta)}$ 
  shaft34 ← if PileNum = 4
    0
  else
    if mean(submatrix(SGEmbDP, 4, 5, PileNum, PileNum)) = 0
      0
    else
       $\frac{\text{mean}(\text{submatrix}(ShftResplotP, 4, 5, PileNum, PileNum))}{\text{mean}(\text{submatrix}(SGEmbDP, 4, 5, PileNum, PileNum)) \cdot \gamma \cdot \tan(\delta)}$ 
  stack(-shaft12, -shaft23, -shaft34)

KsP_C := Ks(ShftResplotP_C, 4)

```

MidDSGsgmtP := augment(MidDSGsgmt(0), MidDSGsgmt(1), MidDSGsgmt(2), MidDSGsgmt(3), MidDSGsgmt(4))

$$Ko := \begin{bmatrix} 1 - \sin(\varphi) & 1 - \sin(\varphi) \end{bmatrix} \quad Kp := \begin{bmatrix} \frac{1 + \sin(\varphi)}{1 - \sin(\varphi)} & \frac{1 + \sin(\varphi)}{1 - \sin(\varphi)} \end{bmatrix} \quad Ka := \begin{bmatrix} \frac{1 - \sin(\varphi)}{1 + \sin(\varphi)} & \frac{1 - \sin(\varphi)}{1 + \sin(\varphi)} \end{bmatrix} = \begin{bmatrix} 0.317 & 0.317 \end{bmatrix}$$

$$K := \begin{bmatrix} 0.09 \cdot e^{0.08 \cdot \left(\varphi \cdot \frac{180}{\pi}\right)} & 0.09 \cdot e^{0.08 \cdot \left(\varphi \cdot \frac{180}{\pi}\right)} \end{bmatrix} \quad \text{Mitsch and Clemence 1985}$$

$$ProtEmbed := \begin{bmatrix} 0 & -E \cdot Nscale^{sclfac_{0,0}} \end{bmatrix} = \begin{bmatrix} 0 & -3.382 \end{bmatrix} \text{m} \quad \text{Pile Embedment in prototype scale unit}$$

$$KsP_C = \begin{bmatrix} 99.199 \\ 5.287 \\ 0 \end{bmatrix}$$

$$MidDSGsgmtP = \begin{bmatrix} -1.791 & -2.934 & -2.934 & -2.553 & -2.934 \\ 0 & -1.6 & -2.362 & -1.6 & -1.981 \\ 0 & 0 & -1.219 & -0.838 & -0.838 \end{bmatrix} \text{m}$$

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

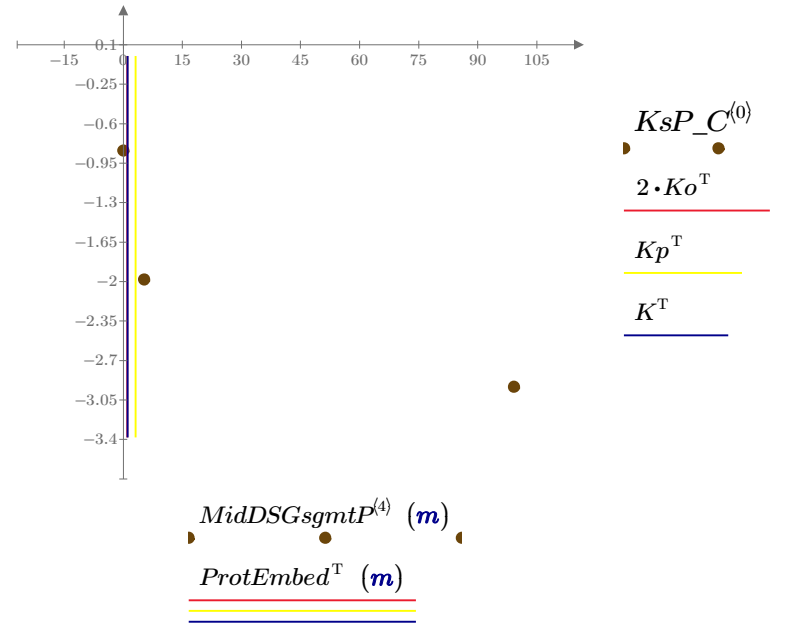


Fig F 66. Ks vs depth for P4

Function for estimating the shaft resistance EDR

```

ShftEDR (TDispTLdP0PL1, ShftResP2PL1, Pseu1perS, IniTime, IniDisp, LoopNo, ShftNo) :=
  m ← TDispTLdP0PL1
  n ← ShftResP2PL1
  n ← kPa
  o ← TimeCycLoop (Pseu1perS, IniTime, IniDisp) - IniTime
  w ← -m(1)
  wmax ← max (-m(1))
  if ShftNo = 1
    q ← n(0)
    qmax ← max (n(0))
  else if ShftNo = 2
    q ← n(1)
    qmax ← max (n(1))
  else if ShftNo = 3
    q ← n(2)
    qmax ← max (n(2))
  if LoopNo = 1
    t1 ← m1,0 - IniTime
    t2 ← o1
  else if LoopNo = 2
    t1 ← o1
    t2 ← o2

```


Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

```

else if LoopNo = 3
    t1 ← o2
    t2 ← o3
else if LoopNo = 4
    t1 ← o3
    t2 ← o4

tstart ← lookup (t1, (m(0) - IniTime), (m(0) - IniTime), "near")
tend ← lookup (t2, (m(0) - IniTime), (m(0) - IniTime), "near")
rowstart ← match (t1, (m(0) - IniTime), "near")
rowend ← match (t2, (m(0) - IniTime), "near")
for i ∈ rowstart0,0 .. rowend0,0
    ri ← ((wi - wi-1) * ((qi + qi-1) / 2))

area ← ∑ r

EDR ← if qmax = 0
    0
    else if wmax = 0
    0
    else if area = 0
    0
    else
    area / (qmax * wmax)

s ← augment ((tstart + IniTime), (tend + IniTime), rowstart, rowend, qmax, wmax, area, EDR)
EDR

```

Function for combining the shaft resistance EDR

```

ShftEDRPOPLSG (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, PileNo) :=
q1 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1)
q2 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1)
q3 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1)
q4 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1)
r1 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2)
r2 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2)
r3 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2)
r4 ← ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2)
w1 ← if PileNo = 0
    0
    else
    ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 3)
w2 ← if PileNo = 0
    0
    else
    ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 3)
w3 ← if PileNo = 0
    0
    else
    ShftEDR (TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 3)

```

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

$$NoLoop := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

```

w4 ← if PileNo = 0
    0
else
    ShftEDR(TDispTLdP0PL1, ShftResP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3)
augment(stack(q1, q2, q3, q4), stack(r1, r2, r3, r4), stack(w1, w2, w3, w4))

```

$$ShftEDRP4PL1 := ShftEDRPOPLSG(TDispTLdP4PL1, ShftResP4PL1, PseuPL1H, IniTimePL1H, 4) = \begin{bmatrix} -0.101 & -0.182 & -0.042 \\ 0.175 & 0.119 & -0.059 \\ 0.011 & 0.033 & -0.291 \\ -0.051 & -0.057 & -0.069 \end{bmatrix}$$

$$ShftEDRP4PL2 := ShftEDRPOPLSG(TDispTLdP4PL2, ShftResP4PL2, PseuPL2H, IniTimePL2H, 4) = \begin{bmatrix} 1.436 & 1.952 & -0.43 \\ 1.003 & 0.81 & -0.046 \\ 1.917 & 0.285 & 0.165 \\ 3.185 & -0.39 & 0.186 \end{bmatrix}$$

$$ShftEDRP4PL3 := ShftEDRPOPLSG(TDispTLdP4PL3, ShftResP4PL3, PseuPL3H, IniTimePL3H, 4) = \begin{bmatrix} 0.151 & 0.542 & -0.165 \\ 0.163 & 0.318 & -0.315 \\ -0.519 & 0.302 & -0.138 \\ 0.081 & 0.045 & 0.055 \end{bmatrix}$$

$$ShftEDRP4PL4 := ShftEDRPOPLSG(TDispTLdP4PL4, ShftResP4PL4, PseuPL4H, IniTimePL4H, 4) = \begin{bmatrix} 0.482 & 0.403 & 0.825 \\ -0.532 & 0.016 & 0.292 \\ 0.48 & 0.378 & 0.274 \\ 0.593 & 0.292 & 0.6 \end{bmatrix}$$

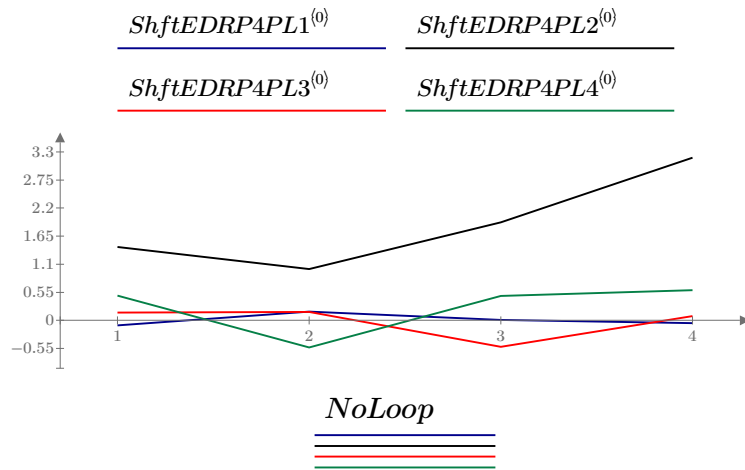


Fig F 67. Shaft EDR vs No of loops Seg1

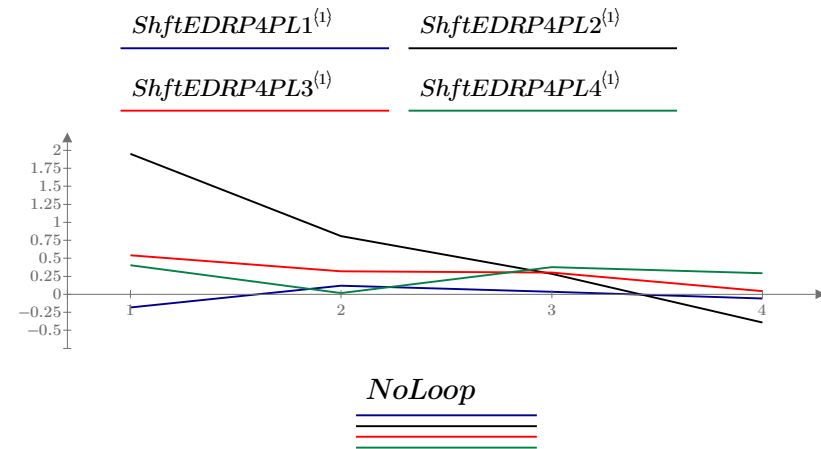


Fig F 68. Shaft EDR vs No of loops Seg 2

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

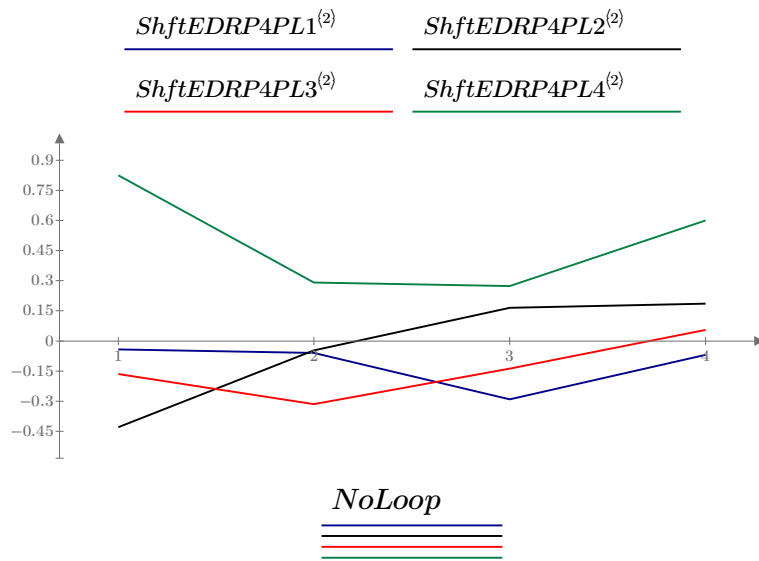
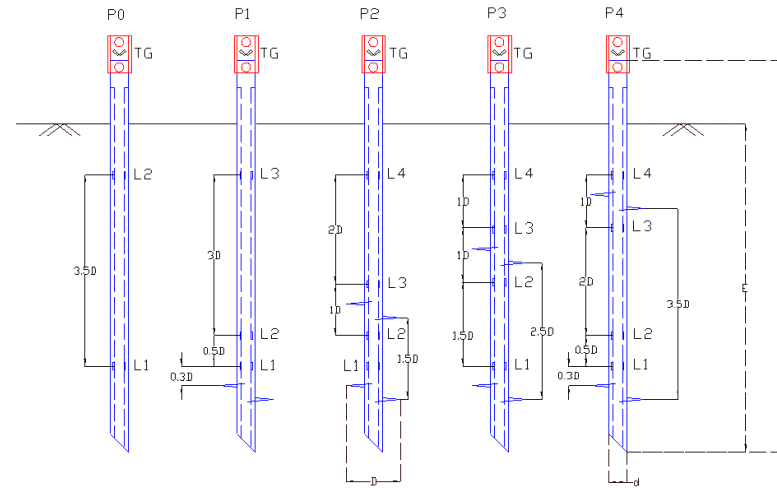


Fig F 69. EDR vs No of loops Seg 3



2.3.4 End Bearing vs Depth

$$A_b := \pi \cdot \frac{\left(D \cdot Nscale^{sclfac_{0,0}}\right)^2}{4} = 0.456 \text{ m}^2$$

Total area at the helix in prototype scale

$$A_d := \pi \cdot \frac{\left(d \cdot Nscale^{sclfac_{0,0}}\right)^2}{4} = 0.051 \text{ m}^2$$

Total area at the shaft in prototype scale

```

EndBrng(TDispTLdP0CL, PileNum) :=
  for i ∈ 0, 1..rows(TDispTLdP0CL) - 1
  for j ∈ 0, 1..cols(TDispTLdP0CL) - 1
    qb1i,0 ← if PileNum = 0
              (TDispTLdP0CLi,3) kN
              Ad
            else
              (TDispTLdP0CLi,3) kN
              Ab - Ad
    qb23i,1 ← if PileNum = 2
              (TDispTLdP0CLi,5 - TDispTLdP0CLi,4) kN
              Ab - Ad
            else if PileNum = 3
              (TDispTLdP0CLi,5 - TDispTLdP0CLi,4) kN
              Ab - Ad
            else
              0
    qb34i,2 ← if PileNum = 4
              (TDispTLdP0CLi,6 - TDispTLdP0CLi,5) kN
              Ab - Ad
            else
              0
  augment(qb1(0), qb23(1), qb34(2))

```

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

$$EndBrng(TDispTLdP4CL, 4) = \begin{matrix} 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ \vdots \\ 13855 \end{matrix} \begin{bmatrix} -28.022 & 0 & -3.743 \\ -36.206 & 0 & -5.077 \\ -39.678 & 0 & -1.363 \\ -43.149 & 0 & -5.077 \\ -44.885 & 0 & -6.136 \\ -46.621 & 0 & -3.481 \\ -49.101 & 0 & -5.077 \\ -69.932 & 0 & -5.077 \\ -70.924 & 0 & -7.196 \\ -70.924 & 0 & 2.09 \\ -70.924 & 0 & 0.494 \\ -70.924 & 0 & -5.077 \\ \vdots \\ \vdots \end{bmatrix} \text{ kPa}$$

$$\frac{-EndBrng(TDispTLdP4CL, 4)^{(0)} \text{ (kPa)}}{-EndBrng(TDispTLdP4CL, 4)^{(2)} \text{ (kPa)}}$$

$$\frac{-EndBrng(TDispTLdP4CL, 4)^{(2)} \text{ (kPa)}}{-EndBrng(TDispTLdP4CL, 4)^{(2)} \text{ (kPa)}}$$

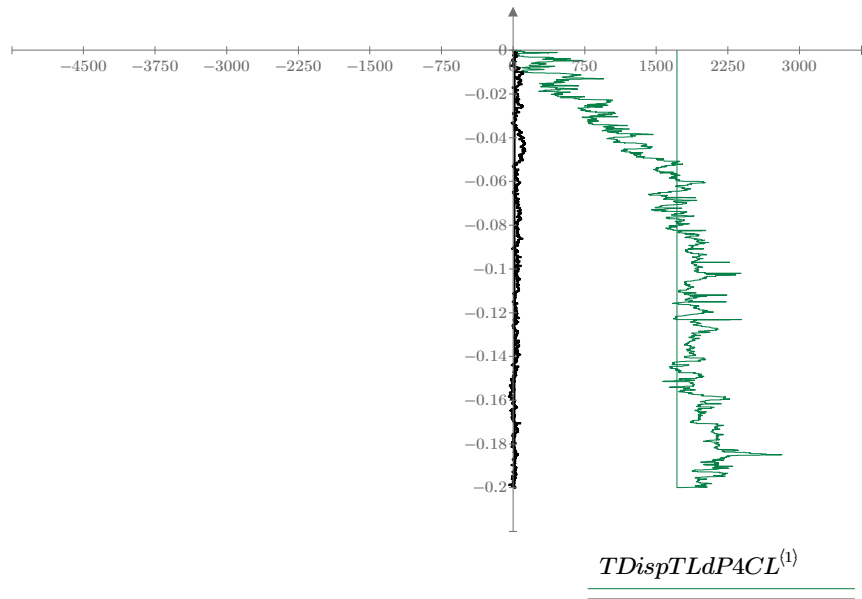


Fig F 70. Depth vs End Bearing for compression pile P4

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

$$UltEndBrngP4_1 := \text{lookup}\left(-0.05, TDispTLdP4CL^{(1)}, EndBrng(TDispTLdP4CL, 4)^{(1)}, \text{"near"}\right) = [0] \text{ } \mathbf{kPa}$$

$$UltEndBrngP4_0 := \text{lookup}\left(-0.05, TDispTLdP4CL^{(1)}, EndBrng(TDispTLdP4CL, 4)^{(0)}, \text{"near"}\right) = [-1507.256] \text{ } \mathbf{kPa}$$

$$HelixLoc := - \begin{bmatrix} 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 & 0.6 + 3.5 + 0.3 + 0.17 \\ 0 & 0 & 0.6 + 2 + 0.3 + 0.17 & 0.6 + 1 + 0.3 + 0.17 & 0.6 + 0.3 + 0.17 \end{bmatrix} \cdot D \cdot Nscale^{scifac_{0,0}}$$

$$\text{stack}\left(\frac{UltEndBrngP4_0}{-HelixLoc_{0,4} \cdot \gamma}, \frac{UltEndBrngP4_1}{-HelixLoc_{1,4} \cdot \gamma}\right) = \begin{bmatrix} -26.884 \\ 0 \end{bmatrix}$$

$$HelixLoc = \begin{bmatrix} -3.482 & -3.482 & -3.482 & -3.482 & -3.482 \\ 0 & 0 & -2.339 & -1.577 & -0.815 \end{bmatrix} \mathbf{m}$$

$$BrngP4PL1 := EndBrng(TDispTLdP4PL1, 4)$$

$$BrngP4PL2 := EndBrng(TDispTLdP4PL2, 4)$$

$$BrngP4PL3 := EndBrng(TDispTLdP4PL3, 4)$$

$$BrngP4PL4 := EndBrng(TDispTLdP4PL4, 4)$$

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

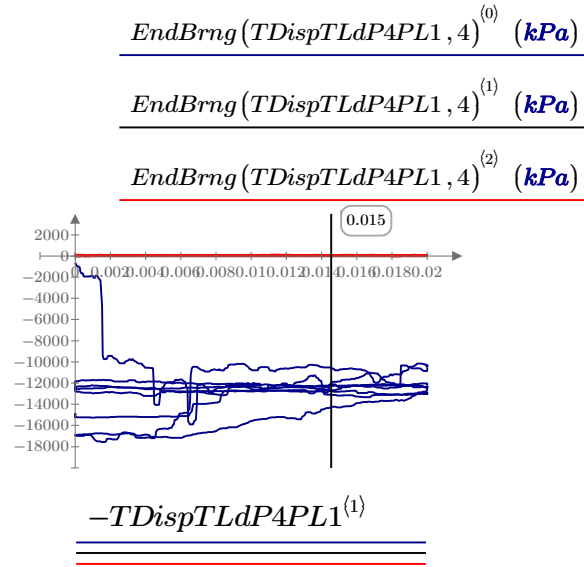


Fig F 71. End Bearing vs Depth for P4 PL1

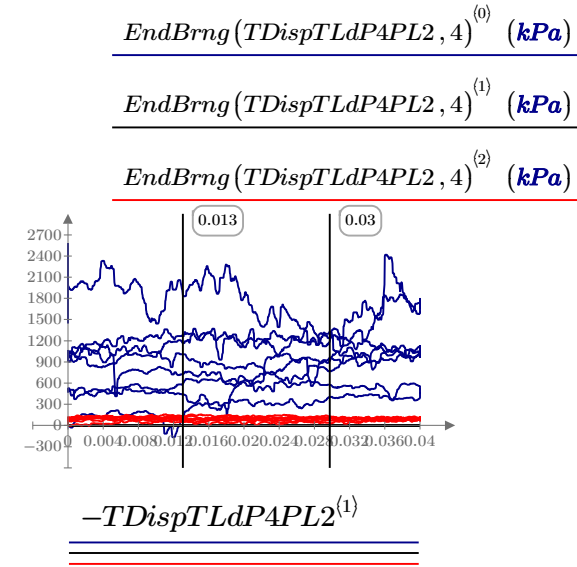


Fig F 72. End Bearing vs Depth for P4 PL2

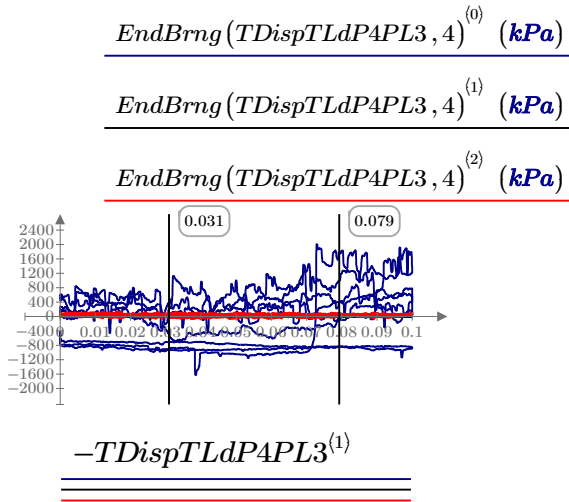


Fig F 73. End Bearing vs Depth for P4 PL3

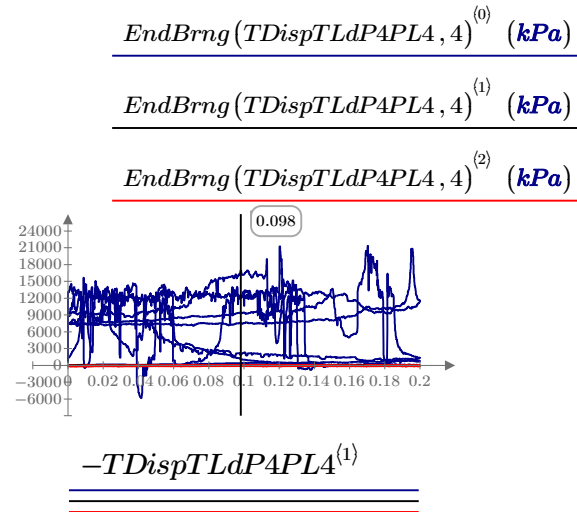


Fig F 74. End Bearing vs Depth for P4 PL4

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

Functions for calculating the EDR from the bearing resistances

```

BrngEDR (TDispTLdP0PL1 , BrngP2PL1 , Pseu1perS , IniTime , IniDisp , LoopNo , ShftNo) :=
  m ← TDispTLdP0PL1
  n ←  $\frac{BrngP2PL1}{kPa}$ 
  o ← TimeCycLoop (Pseu1perS , IniTime , IniDisp) - IniTime
  w ← -m(1)
  umax ← max (-m(1))
  if ShftNo = 1
    q ← n(0)
    qmax ← max (n(0))
  else if ShftNo = 2
    q ← n(1)
    qmax ← max (n(1))
  else if ShftNo = 3
    q ← n(2)
    qmax ← max (n(2))

  if LoopNo = 1
    t1 ← m1,0 - IniTime
    t2 ← o1
  else if LoopNo = 2
    t1 ← o1
    t2 ← o2
  else if LoopNo = 3
    t1 ← o2
    t2 ← o3
  else if LoopNo = 4
    t1 ← o3
    t2 ← o4

  tstart ← lookup (t1 , (m(0) - IniTime) , (m(0) - IniTime) , "near")
  tend ← lookup (t2 , (m(0) - IniTime) , (m(0) - IniTime) , "near")
  rowstart ← match (t1 , (m(0) - IniTime) , "near")
  rowend ← match (t2 , (m(0) - IniTime) , "near")
  for i ∈ rowstart0,0 .. rowend0,0
    ri ←  $\left( (w_i - w_{i-1}) \cdot \left( \frac{q_i + q_{i-1}}{2} \right) \right)$ 

  area ← ∑ r

  EDR ← if qmax = 0
    0
    else if umax = 0
    0
    else if area = 0
    0
    else
     $\frac{area}{qmax \cdot umax}$ 

  s ← augment ((tstart + IniTime) , (tend + IniTime) , rowstart , rowend , qmax , umax , area , EDR)
  EDR

```


Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

Function for compiling EDR for the end bearing in loading cycles

$$BrngEDRPOPLSG(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, PileNo) := \begin{array}{l} q1 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 1) \\ q2 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 1) \\ q3 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 1) \\ q4 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 1) \\ r1 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 2) \\ r2 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 2) \\ r3 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 2) \\ r4 \leftarrow BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 2) \\ w1 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 1, 3) \\ w2 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 2, 3) \\ w3 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 3, 3) \\ w4 \leftarrow \text{if } PileNo = 0 \\ \quad \parallel 0 \\ \quad \text{else} \\ \quad \parallel BrngEDR(TDispTLdP0PL1, BrngP2PL1, PseuPL1S, IniTimePL1S, IniDisp, 4, 3) \\ \text{augment}(\text{stack}(q1, q2, q3, q4), \text{stack}(r1, r2, r3, r4), \text{stack}(w1, w2, w3, w4)) \end{array}$$

$$NoLoop := \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

$$BrngEDRP4PL1 := BrngEDRPOPLSG(TDispTLdP4PL1, BrngP4PL1, PseuPL1H, IniTimePL1H, 4) = \begin{bmatrix} -2.766 & 0 & -0.042 \\ 4.829 & 0 & -0.059 \\ 0.32 & 0 & -0.291 \\ -1.418 & 0 & -0.069 \end{bmatrix}$$

$$BrngEDRP4PL2 := BrngEDRPOPLSG(TDispTLdP4PL2, BrngP4PL2, PseuPL2H, IniTimePL2H, 4) = \begin{bmatrix} -0.091 & 0 & -0.43 \\ -0.063 & 0 & -0.046 \\ -0.126 & 0 & 0.165 \\ -0.205 & 0 & 0.186 \end{bmatrix}$$

$$BrngEDRP4PL3 := BrngEDRPOPLSG(TDispTLdP4PL3, BrngP4PL3, PseuPL3H, IniTimePL3H, 4) = \begin{bmatrix} -0.112 & 0 & -0.165 \\ -0.126 & 0 & -0.315 \\ 0.426 & 0 & -0.138 \\ -0.059 & 0 & 0.055 \end{bmatrix}$$

$$BrngEDRP4PL4 := BrngEDRPOPLSG(TDispTLdP4PL4, BrngP4PL4, PseuPL4H, IniTimePL4H, 4) = \begin{bmatrix} -0.129 & 0 & 0.825 \\ 0.146 & 0 & 0.292 \\ -0.13 & 0 & 0.274 \\ -0.16 & 0 & 0.6 \end{bmatrix}$$

Appendix F

Data Conversion and Processing Sheet for NI02 series of Centrifuge Tests on P4 Helix Pile

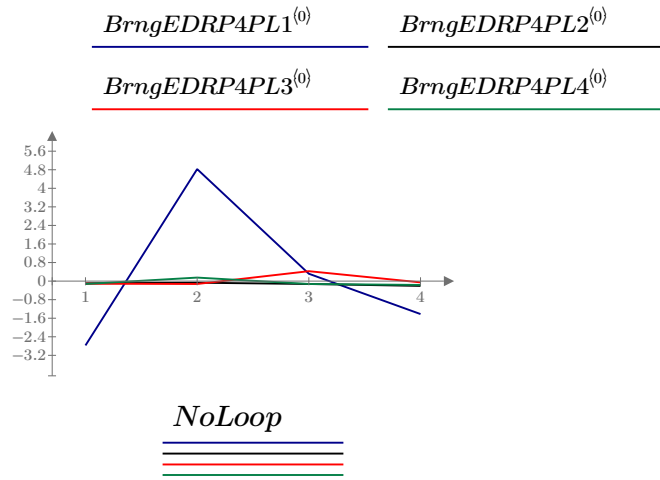


Fig E 75. Shaft EDR vs No of loops Helix Location 1 SG 1

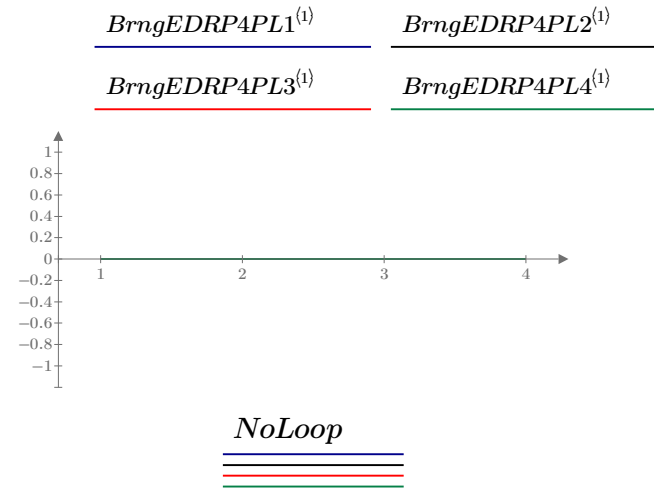


Fig F 76. Shaft EDR vs No of loops Helix Location 2 SG 2-3

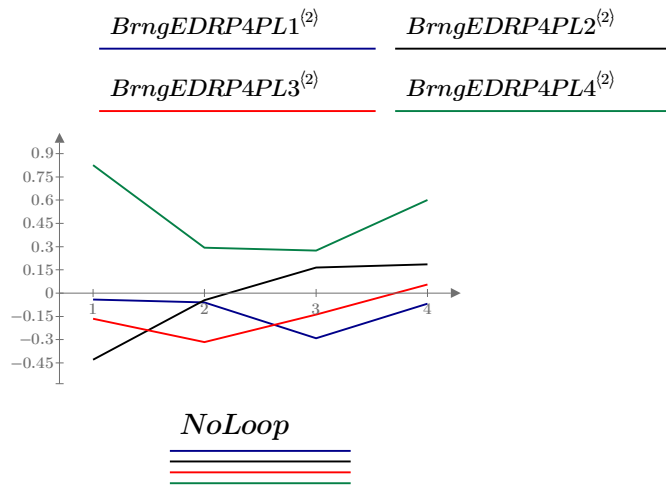
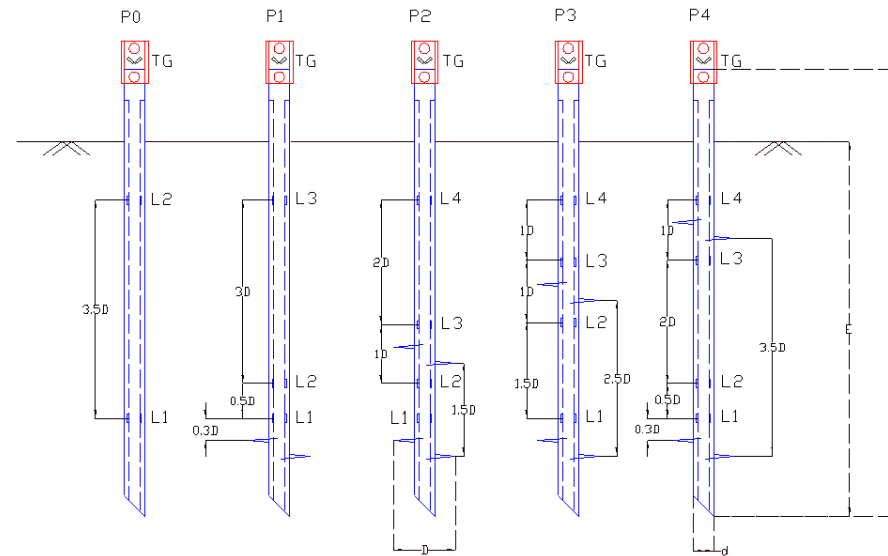


Fig F 77. EDR vs No of loops Helix Location 3 SG 3-4



Appendix G

Calibration of Strain Gauges

1. Calibration of Axial Strain Gauges

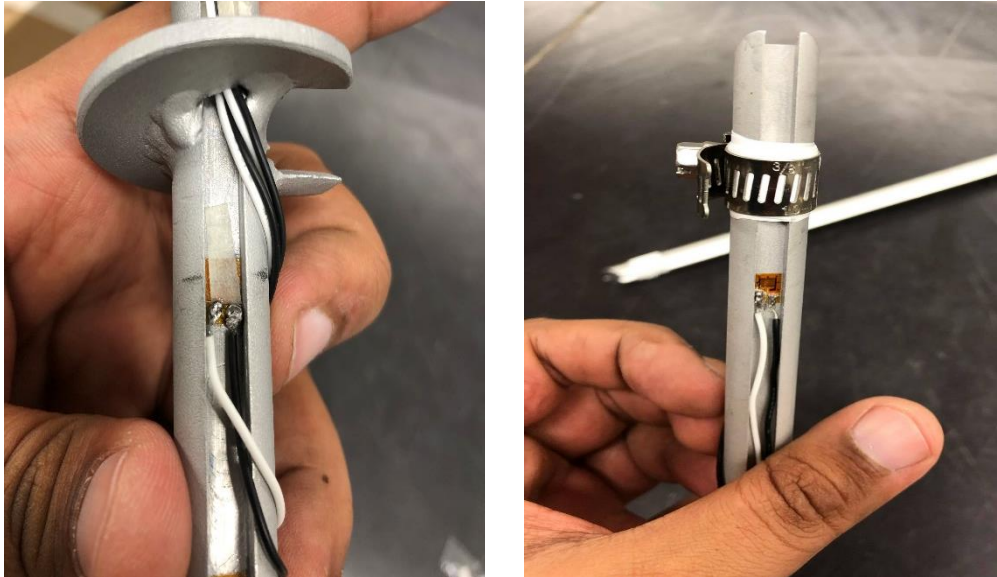
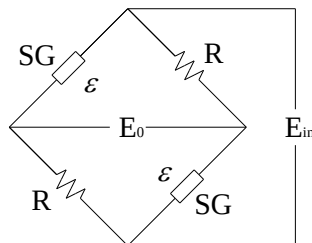


Figure A 1. Installed axial strain gages

The axial strain gauge Half bridge circuit is shown in Figure A2:



a) Axial

Figure A 2. Half bridge circuit for axial strain measurement, where SG = axial strain gauge on pile shaft and R = complementary resistor embedded in the data logger

Analytical Calculations,

Young's Modulus of the Aluminum,

Appendix G Calibration of Strain Gauges

$$E_{al} := 70 \cdot \text{GPa}$$

Diameter of the pile head,

$$d_{X_pile} := 12.7 \text{ mm}$$

Cross sectional area of the pile head,

$$A_{X_pile} := \pi \cdot \frac{(d_{X_pile})^2}{4} = 126.677 \text{ mm}^2$$

Groove width,

$$b := 5 \text{ mm}$$

Groove depth,

$$h := 3.27 \text{ mm}$$

Arc angle,

$$\theta := 2 \cdot \arccos \left(\frac{\frac{b}{2}}{\frac{d_{X_pile}}{2}} \right) \cdot \frac{180}{\pi} = 133.63$$

Cross sectional area at the strain gage location,

$$\begin{aligned} A_{SG_pile} := & 2 \cdot \frac{1}{2} \cdot \left(\frac{d_{X_pile}}{2} \right)^2 \cdot \left(\left(\frac{\pi}{180} \cdot \theta \right) - \sin \left(\theta \cdot \frac{\pi}{180} \right) \right) + 90.529 \text{ mm}^2 \\ & + \left(2 \cdot \sqrt{\left(\left(\frac{d_{X_pile}}{2} \right)^2 - \left(\frac{b}{2} \right)^2} \right) - (2 \cdot h)} \right) \cdot b \end{aligned}$$

Poisson's ratio,

$$\nu := 0.3$$

Shear Modulus of the Aluminum,

$$G_{al} := \frac{E_{al}}{2(1+\nu)} = 26.923 \text{ GPa}$$

Outer diameter of the adaptor,

$$d_{adap_out} := d_{X_pile} + 1.5875 \text{ mm} = 14.288 \text{ mm}$$

Appendix G

Calibration of Strain Gauges

Inner diameter of the adaptor,

$$d_{adap_in} := d_{X_pile} = 12.7 \text{ mm}$$

Polar moment of inertia of the adaptor,

$$J_{adaptor} := \pi \cdot \frac{\left(\left(\frac{d_{adap_out}}{2} \right)^4 - \left(\frac{d_{adap_in}}{2} \right)^4 \right)}{2} = (1.537 \cdot 10^3) \text{ mm}^4$$

Output signal factor,

$$a := 200$$

Output voltage,

$$E_0 := 1 \cdot \text{mV}$$

Input voltage,

$$E_{in} := 1 \cdot \text{V}$$

Axial Gage Factor,

$$GF_{axial} := 2.14 \leq \text{Manufacturer}$$

Axial Strain,

$$\varepsilon_a := 2 \cdot a \cdot \frac{E_0}{E_{in} \cdot GF_{axial}} = 0.187$$

Axial Force,

$$F := E_{al} \cdot A_{SG_pile} \cdot \varepsilon_a = 1184.5 \text{ kN}$$

The theoretical axial force per 1mV/V of HBM output are estimated.

Adopted Load Combinations

$$F_1 := 43.43 \text{ N} \quad \varepsilon_1 := \frac{F_1}{E_{al} \cdot A_{SG_pile}} = 6.853 \frac{1}{\text{m}} \cdot \mu\text{m}$$

$$F_2 := 78.18 \text{ N} \quad \varepsilon_2 := \frac{F_2}{E_{al} \cdot A_{SG_pile}} = 12.337 \frac{1}{\text{m}} \cdot \mu\text{m}$$

$$F_3 := 133.51 \text{ N} \quad \varepsilon_3 := \frac{F_3}{E_{al} \cdot A_{SG_pile}} = 21.068 \frac{1}{\text{m}} \cdot \mu\text{m}^{[3]}$$

Appendix G

Calibration of Strain Gauges

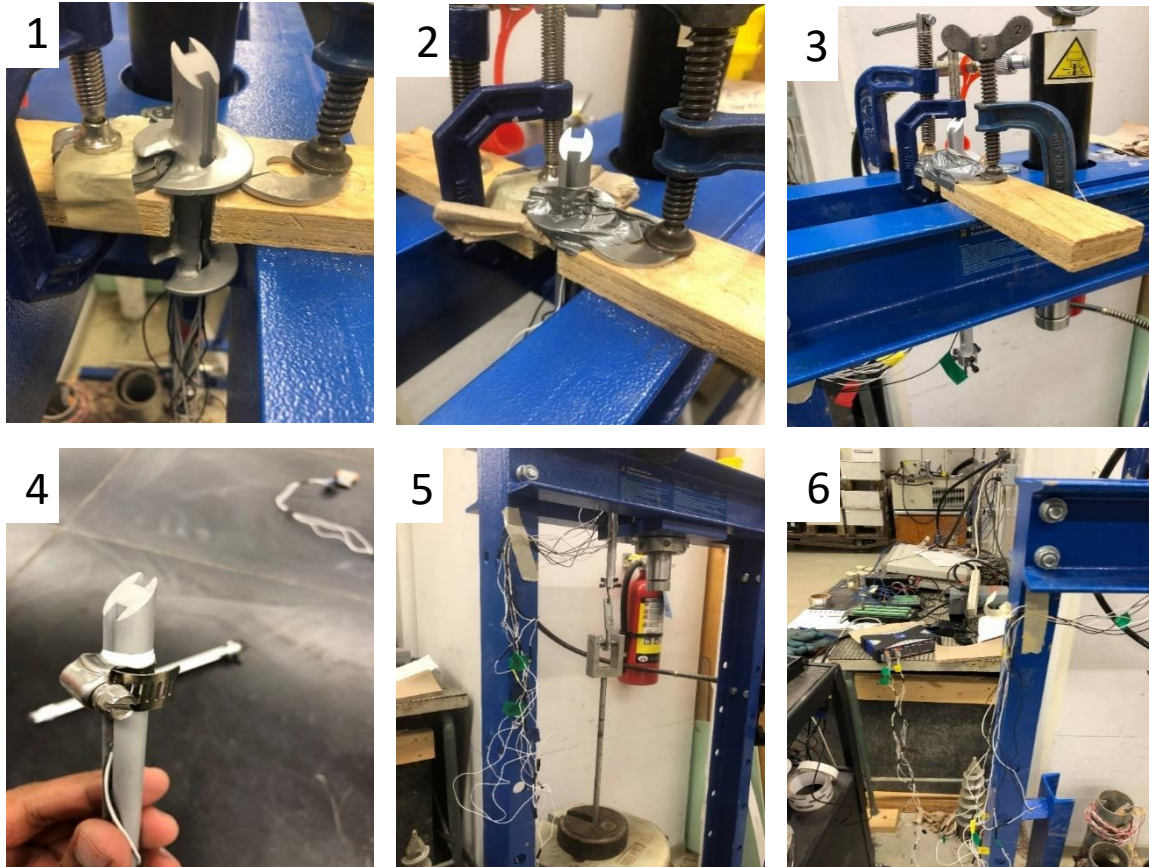


Figure A 3. Axial strain gauge calibration setup

Appendix G

Calibration of Strain Gauges

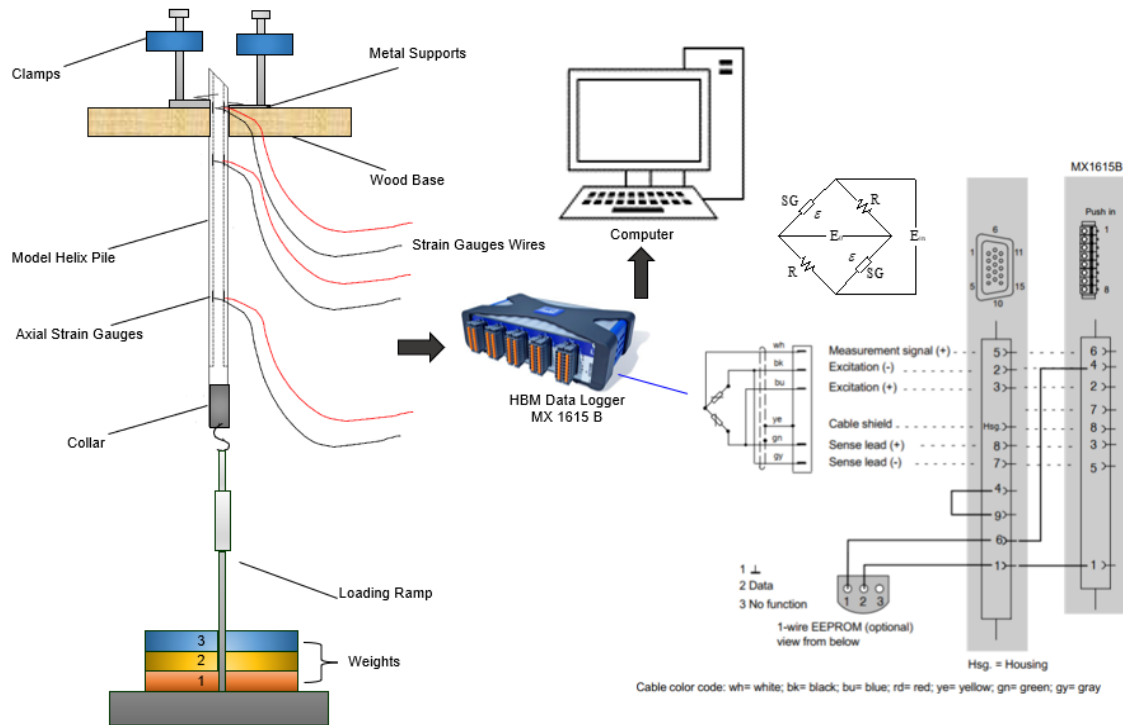


Figure A 4. Schematic calibration of axial strain gauges.

Table A 1. Calibration measurements for Axial Strain Gauges from the HBM Data Logger

Pile	Applied Load (N)	HBM Strain ($\mu\text{m/m}$)	HBM readings 10-3 (mV/V)	K_a (kN/mV/V)
P1	43.43	7.30	0.037	1190
	78.18	12.53	0.063	1248
	133.51	23.23	0.116	1149
P2	43.43	6.83	0.034	1273
	78.18	12.30	0.062	1271
	133.51	22.05	0.110	1211
P3	43.43	7.28	0.036	1194
	78.18	12.23	0.061	1278
	133.51	23.16	0.116	1153
P4	43.43	7.33	0.037	1186
	78.18	12.64	0.063	1237

Appendix G

Calibration of Strain Gauges

Pile	Applied Load (N)	HBM Strain ($\mu\text{m/m}$)	HBM readings 10-3 (mV/V)	K_a (kN/mV/V)
	133.51	21.14	0.106	1263
P0	43.43	6.97	0.035	1246
	78.18	12.60	0.063	1241
	133.51	23.36	0.117	1143
Average K_a (kN/mV/V)				1219

Table A 2. Summary of the axial strain gauge calibration results

SG type	Gauge Factor	Bridge type	Rosette	Excitation (V)	Calibration factor
Axial	2.14	Half	Axial	10	1219 kN/(mV/V)

2. Calibration of Torque Strain Gauges

Appendix G

Calibration of Strain Gauges

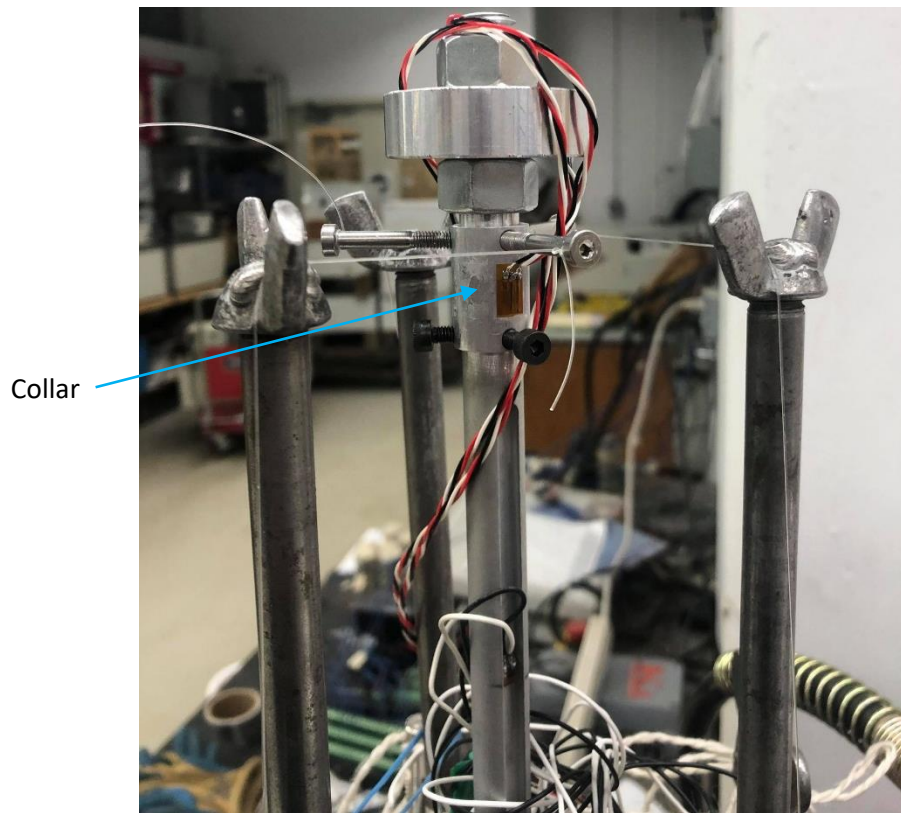


Figure A 5. Installed Torque Strain gages on the collar

Analytical Calculations

Appendix G

Calibration of Strain Gauges

Young's Modulus of the Aluminum, $E_{al} := 70 \cdot \text{GPa}$

Diameter of the pile head, $d_{X_pile} := 12.7 \text{ mm}$

Cross sectional area of the pile head, $A_{X_pile} := \pi \cdot \frac{(d_{X_pile})^2}{4} = 126.677 \text{ mm}^2$

Groove width, $b := 5 \text{ mm}$ Groove depth, $h := 3.27 \text{ mm}$

Arc angle, $\theta := 2 \cdot \arccos\left(\frac{\frac{b}{2}}{\frac{d_{X_pile}}{2}}\right) \cdot \frac{180}{\pi} = 133.63$

Cross sectional area at the strain gage location,

$$A_{SG_pile} := 2 \cdot \frac{1}{2} \cdot \left(\frac{d_{X_pile}}{2}\right)^2 \cdot \left(\left(\frac{\pi}{180} \cdot \theta\right) - \sin\left(\theta \cdot \frac{\pi}{180}\right)\right) + \left(2 \cdot \sqrt{\left(\left(\frac{d_{X_pile}}{2}\right)^2 - \left(\frac{b}{2}\right)^2\right) - (2 \cdot h)}\right) \cdot b = 90.529 \text{ mm}^2$$

Poisson's ratio, $\nu := 0.3$

Shear Modulus of the Aluminum, $G_{al} := \frac{E_{al}}{2(1+\nu)} = 26.923 \text{ GPa}$

Outer diameter of the adaptor, $d_{adap_out} := d_{X_pile} + 1.5875 \text{ mm} = 14.288 \text{ mm}$

Inner diameter of the adaptor, $d_{adap_in} := d_{X_pile} = 12.7 \text{ mm}$

Polar moment of inertia of the adaptor, $J_{adaptor} := \pi \cdot \frac{\left(\left(\frac{d_{adap_out}}{2}\right)^4 - \left(\frac{d_{adap_in}}{2}\right)^4\right)}{2} = (4.091 \cdot 10^{-3}) \text{ mm}^4$

Output signal factor, $a := 200$ Output voltage, $E_0 := 1 \cdot \text{mV}$

Input voltage, $E_{in} := 1 \cdot \text{V}$

Axial Gage Factor, $GF_{axial} := 2.14$ <= Manufacturer

Axial Strain, $\varepsilon_a := 2 \cdot a \cdot \frac{E_0}{E_{in} \cdot GF_{axial}} = 0.187$

Axial Force, $F := E_{al} \cdot A_{SG_pile} \cdot \varepsilon_a = 1184.5 \text{ kN}$

Torque Gage Factor, $GF_{torque} := 2.11$ <= Manufacturer

Maximum shear strain, $\gamma_{max} := 2 \cdot a \cdot \frac{E_0}{E_{in} \cdot GF_{torque}} = 0.19$

Torque, $T := G_{al} \cdot \gamma_{max} \cdot \frac{J_{adaptor}}{\frac{d_{adap_out}}{2}} = 2.923 \text{ kN} \cdot \text{m}$

Appendix G

Calibration of Strain Gauges

Adopted Torque Loads

$$T_1 = 0.14 \text{ N}\cdot\text{m} \quad \gamma_{max1} := \frac{T_1 \cdot \frac{d_{adap_out}}{2}}{G_{al} \cdot J_{adaptor}} = 9.08 \frac{1}{\text{m}} \cdot \mu\text{m}$$

$$T_2 = 0.21 \text{ N}\cdot\text{m} \quad \gamma_{max2} := \frac{T_2 \cdot \frac{d_{adap_out}}{2}}{G_{al} \cdot J_{adaptor}} = 13.621 \frac{1}{\text{m}} \cdot \mu\text{m}$$

$$T_3 = 0.35 \text{ N}\cdot\text{m} \quad \gamma_{max3} := \frac{T_3 \cdot \frac{d_{adap_out}}{2}}{G_{al} \cdot J_{adaptor}} = 22.701 \frac{1}{\text{m}} \cdot \mu\text{m}$$

The torque strain gauge Full bridge circuit is shown in Figure A 6.

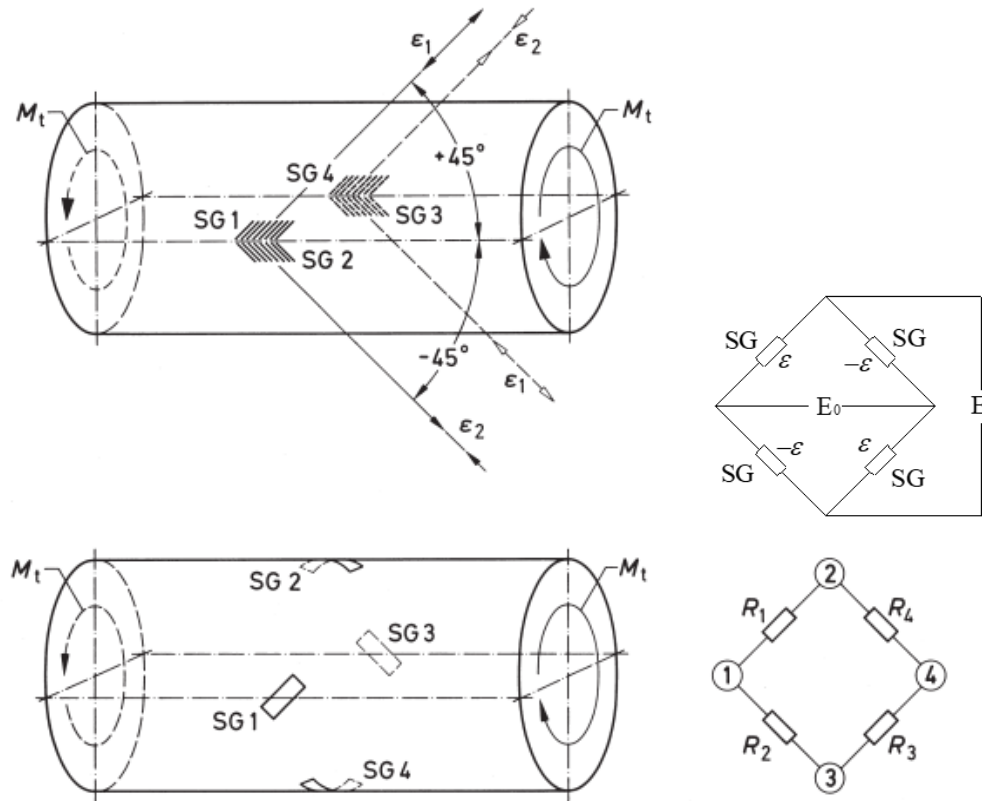


Figure A 6. Full bridge circuit for torque strain measurement, where SG = torque strain gauge on the collar over the pile shaft

For the twisted shaft,

Appendix G

Calibration of Strain Gauges

$$|\varepsilon_1| = |\varepsilon_2| = \varepsilon_{45^\circ}$$

$$\Rightarrow \varepsilon_1 = \varepsilon_{45^\circ} \text{ then } \varepsilon_2 = -\varepsilon_{45^\circ}$$

ε_{45° = Normal strain measured by individual gauge on the torque gauge pad (at 45 deg wrt. to the longitudinal axis of the shaft)

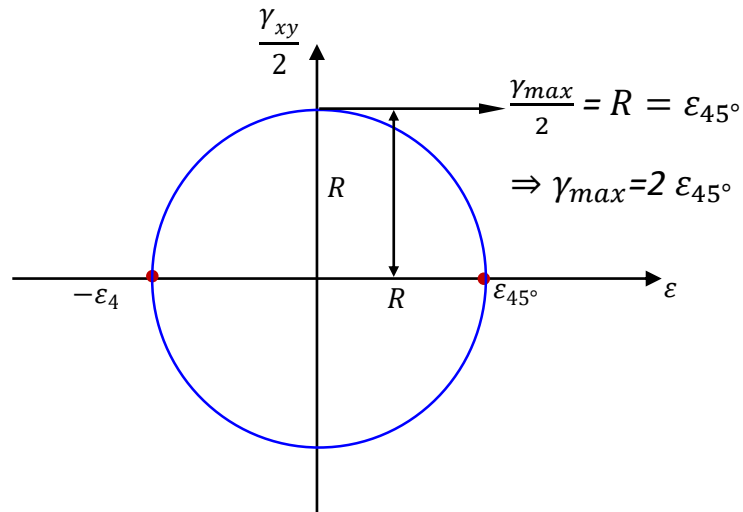


Figure A 7. Strain Mohr circle for torque strain gauge

For torque gauges, maximum shear strain induced by external torque, $\gamma_{max} = 2 \varepsilon_{45^\circ}$

Appendix G

Calibration of Strain Gauges

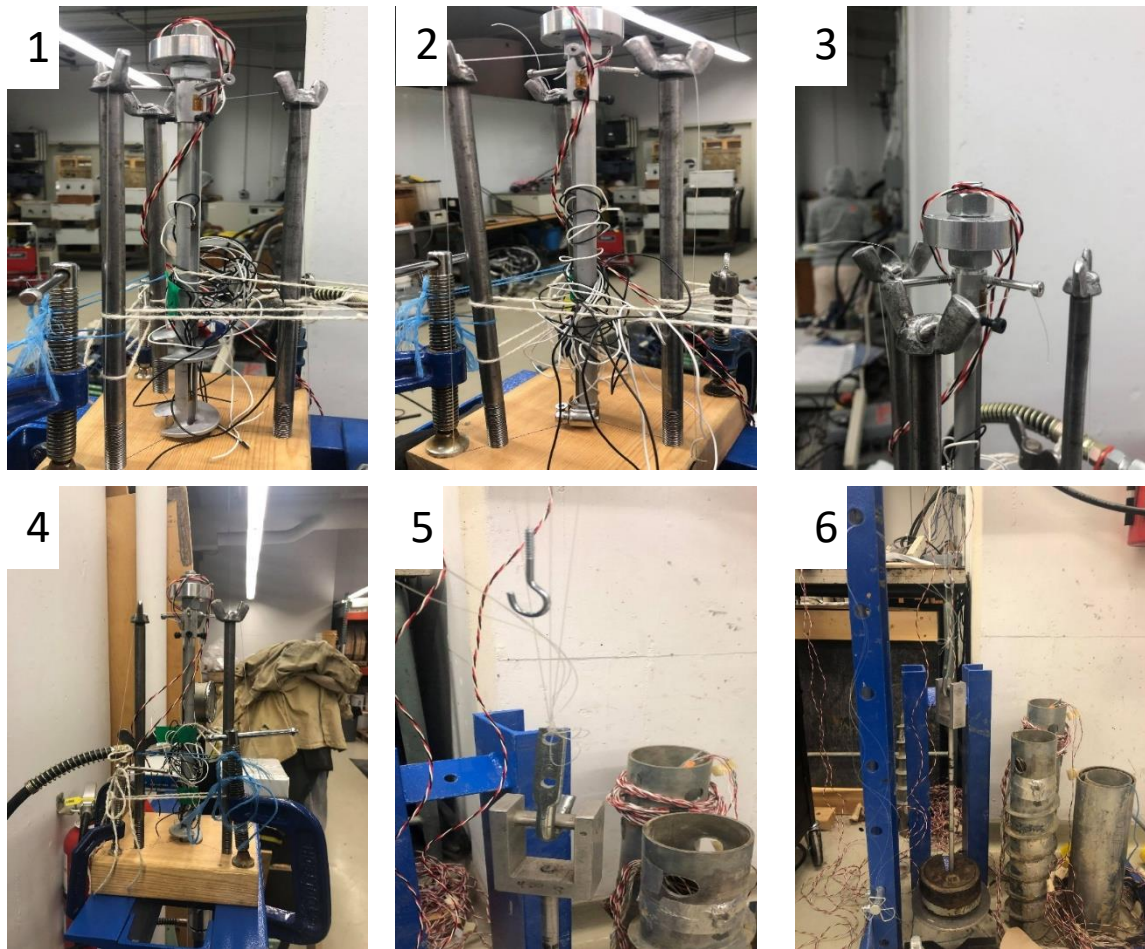


Figure A 8. Torque strain gauge calibration setup

Appendix G

Calibration of Strain Gauges

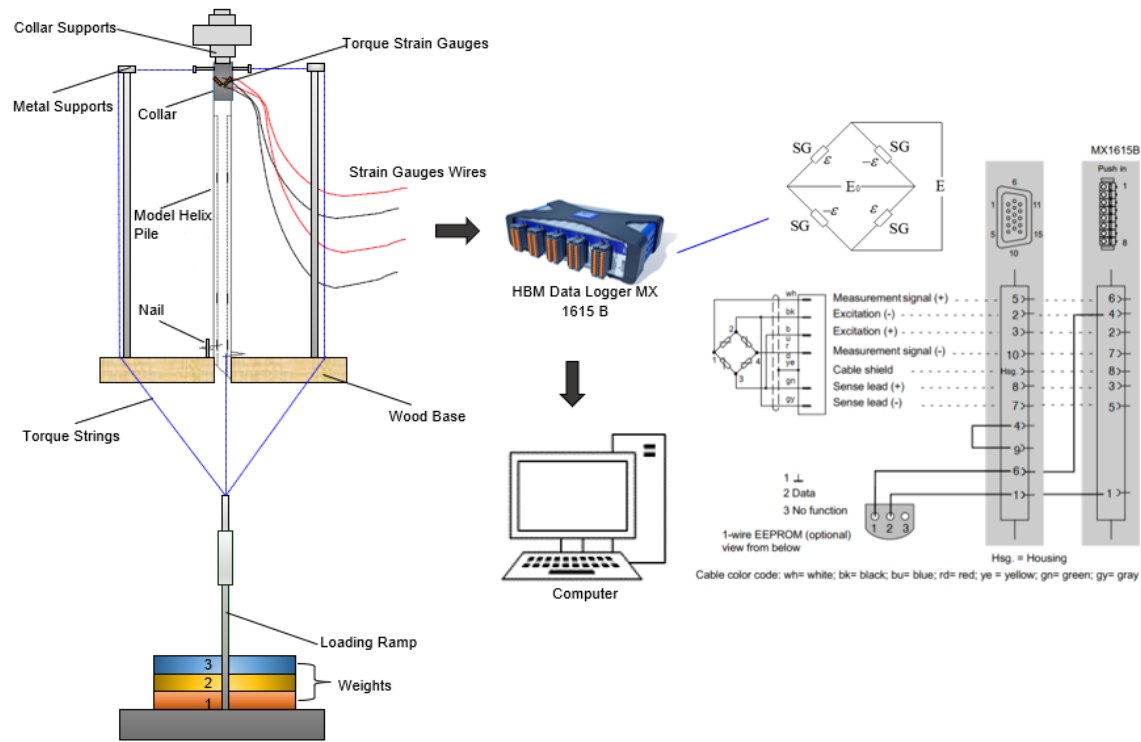


Figure A 9. Schematic of calibration setup for torque strain gauge.

Table A 3. Calibration measurements for Torque strain gauges from the HBM Data Logger

Pile	Applied Torque (N-m)	HBM Strain ($\mu\text{m/m}$)	HBM readings 10^{-3} (mV/V)	K_t (kN-m/mV/V)
P1	0.14	9.286	0.046	3.105
	0.21	13.792	0.069	2.989
	0.35	22.4	0.112	3.128
P2	0.14	9.01	0.045	3.200
	0.21	13.166	0.066	3.132
	0.35	22.991	0.115	3.047
P3	0.14	9.26	0.046	3.113
	0.21	13.218	0.066	3.119
	0.35	22.241	0.111	3.150
P4	0.14	9.178	0.046	3.141

Appendix G

Calibration of Strain Gauges

Pile	Applied Torque (N-m)	HBM Strain ($\mu\text{m}/\text{m}$)	HBM readings 10^{-3} (mV/V)	K_t (kN-m/mV/V)
P0	0.21	13.455	0.067	3.064
	0.35	22.8	0.114	3.073
	0.14	9.128	0.046	3.159
	0.21	13.8	0.069	2.988
	0.35	22.89	0.114	3.061

Average K_t (kN-m/mV/V) **3.098**

Table A 4. Summary of the axial strain gauge calibration results

SG type	Gauge Factor	Bridge type	Rosette	Excitation (V)	Calibration factor
Torque	2.115	Full	45°	5	3.098 kN-m/(mV/V)