SUREFOOT

CONCRETE FREE FOOTING SYSTEM

EDISON AWARDS
WINNER
2017

SUREFOOT

CONCRETE FREE FOOTING SYSTEM

WHAT IS SUREFOOT

BASIS OF DESIGN

- Surefoot is a newly developed footing system. With its unique pile configuration, the system is able to distribute load to a larger volume of soil and thereby achieving higher load resistance compare to the traditional concrete systems. Furthermore, Surefoot is easy to handle on-site, the installation of which requires only man-held-lightweight tools and can be done in 15 to 30 minutes. As the installation does not require excavation and concrete grouting, disturbance to the local ecosystem, topography, landscape, drainage pattern is minimal. Also, steel footings have embodied energy approximately 20% lower than concrete systems of similar size and application.

BASIS OF DESIGN

- The Surefoot system does not fall into the conventional footing categories of shallow foundation; semi-deep or deep foundation. The unique shape of each Surefoot which contains four to ten inclined micropiles, makes the interaction of the system with surrounding soil complicated.
- Due to the layout of micropiles in the Surefoot system, including spacing, orientation and group effects, they behave like reticulated micropiles, therefore the group effect is disregarded.

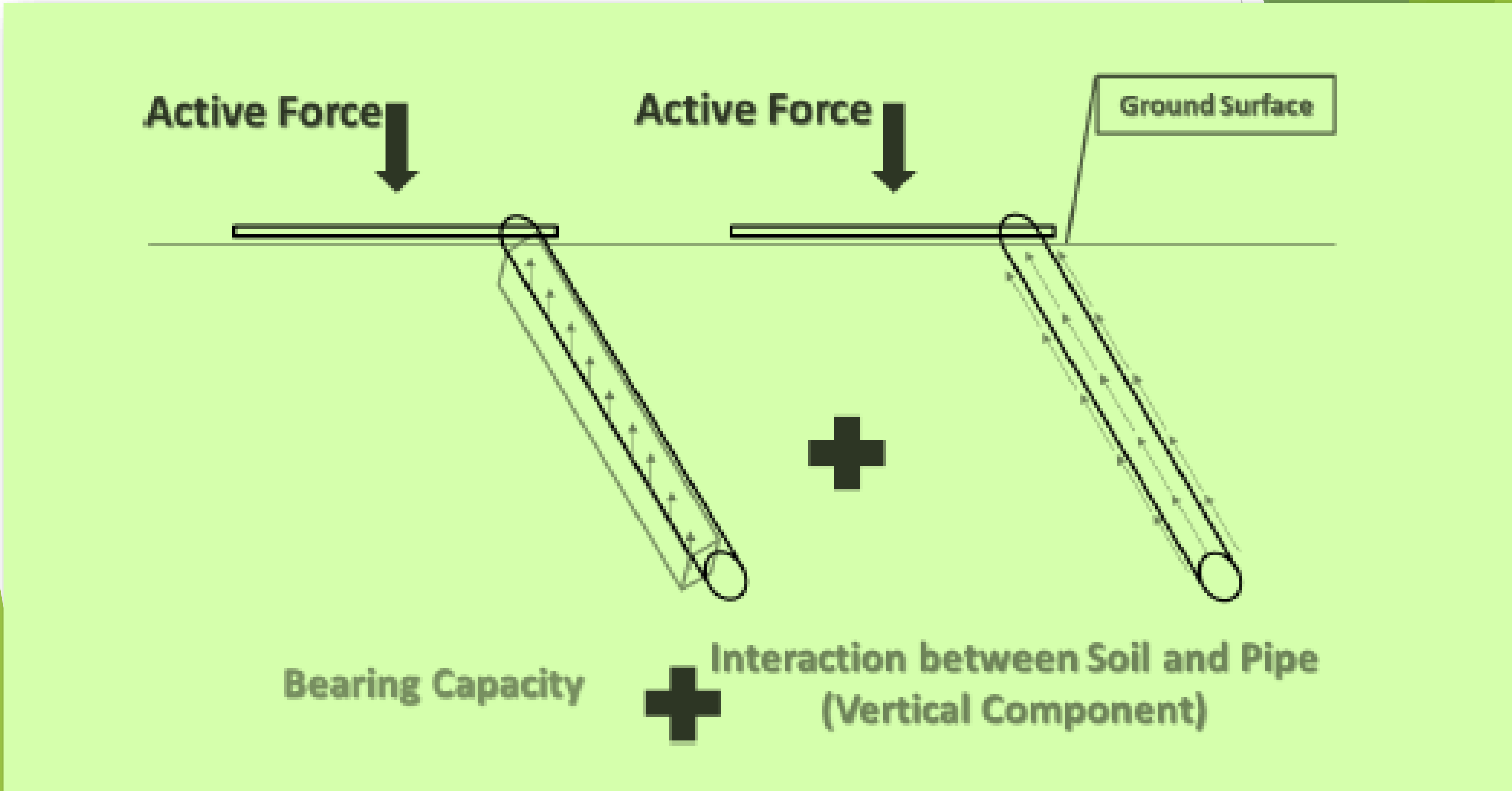
BASIS OF DESIGN - COMPRESSION

- The combination of bearing capacity and skin friction of micropiles resist the gravity forces imposed on Surefoot system (Figure 20). The bearing capacity of each micropile can be estimated based on the bearing capacity of shallow foundations using methods developed by Terzaghi or Meyerhof. Skin friction (only on the outer wall of the pipes) can be estimated using available deep foundation or pull-out theory.

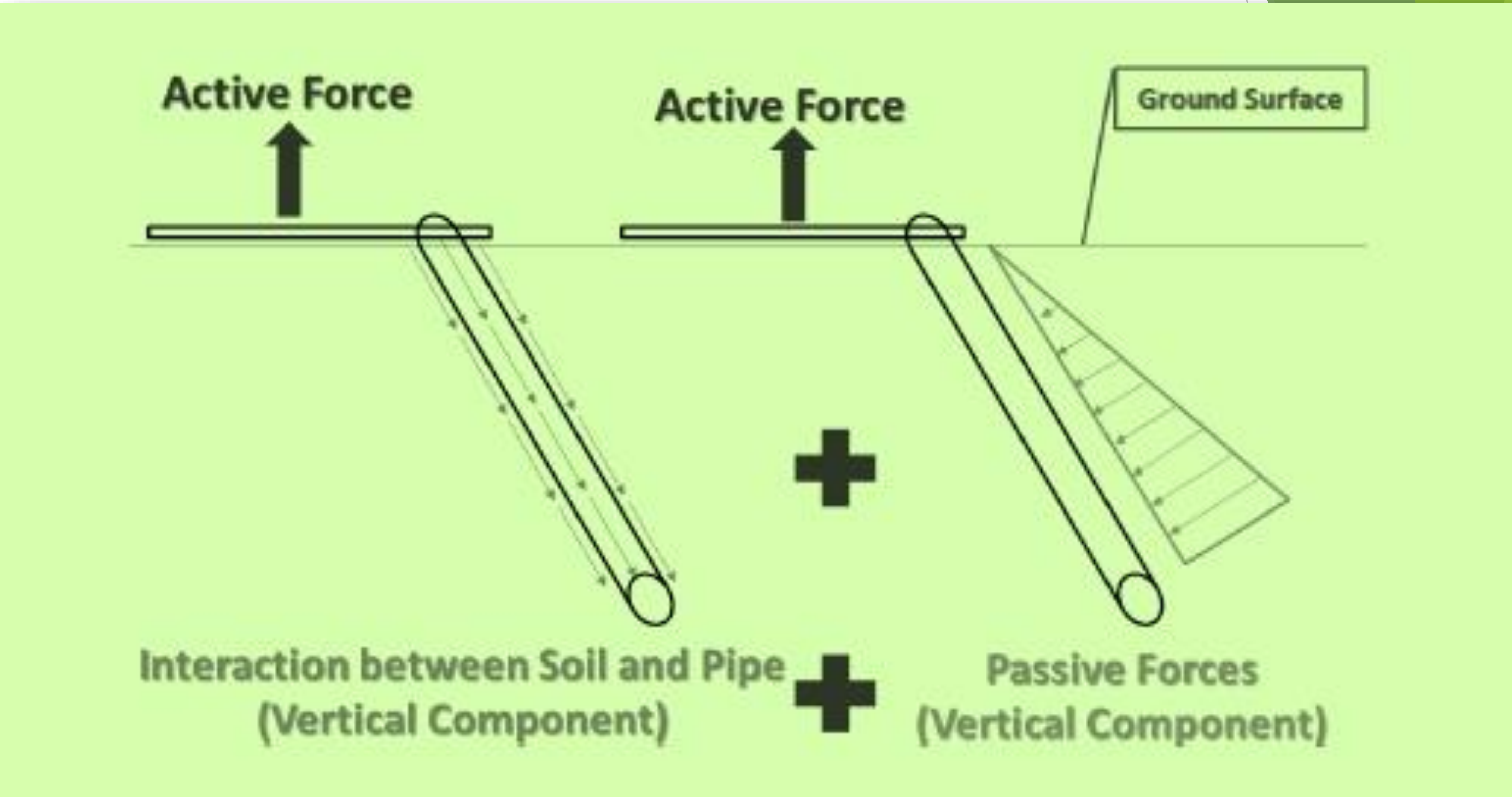
BASIS OF DESIGN - TENSION

- The resisting forces against upward active forces are the skin friction of each micropile plus the passive force

BASIS OF DESIGN - COMPRESSION



BASIS OF DESIGN - TENSION



FACTUAL MECHANISMS OF BEARING THEORY AND SHALLOW FOUNDATION

- Terzaghi (1943) and Meyerhof (1951) bearing theories are the most used theories for evaluating the bearing capacity of shallow foundations. Both theories are based on the arguments that (1) The soil bearing strength is contributed by unit weight (γ), cohesion (c), friction (ϕ), total and effective overburden pressure at foundation level (Po and $P'o$) and geometry of the foundation (width (B)), where γ, D and c are not interactive; (2) loading leads to general failure. The mathematical form is shown as equation (1) whereNc, N q, and $N\gamma$ are capacity factors.

$$q_{u,gross} = cN_c + P_o'(N_q - 1) + \frac{B\gamma_{eff}}{2} N_\gamma + P_o$$

MECHANISMS OF BEARING THEORY AND SHALLOW FOUNDATION

- The difference between Terzaghi and Meyerhof is the soil movement or failure pattern on which they premised. Terzaghi considers 3 zones of soil movement and interaction as shown in Figure 2; whereas Meyerhof assumes a slightly more complicated pattern, by which he argued that the soil above foundation level also has contribution to the capacity. To account for the difference, the numerical values of Meyerhof's capacity factors are different to those of Terzaghi. The depth (D) of the foundation is considered only in determining the Meyerhof's capacity factors.

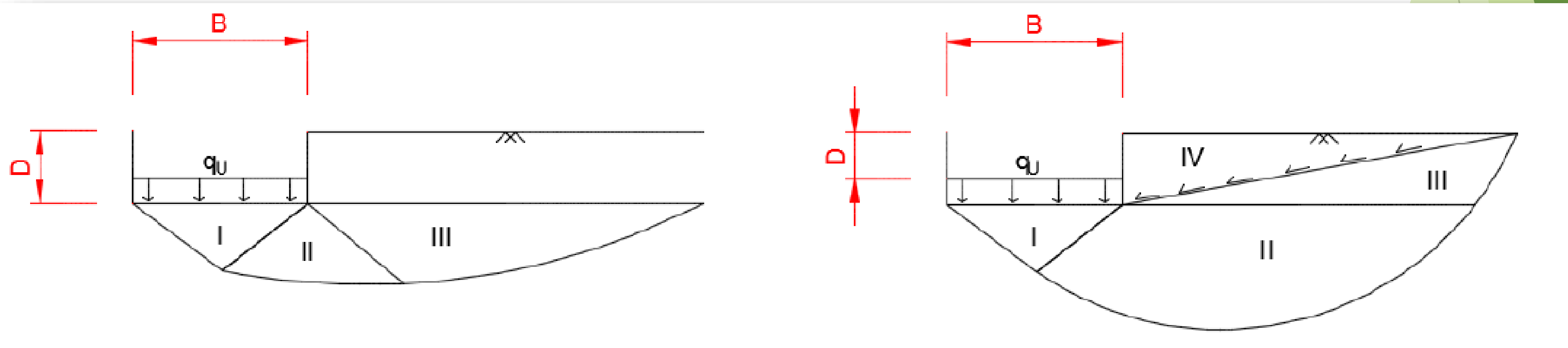


Figure 2: Soil movement and failure pattern; Terzaghi (left); Meyerhof (right)

MECHANISMS OF BEARING THEORY AND SHALLOW FOUNDATION

From Surefoot's Design Principles (V2). The capacity per pile under compression loadings refers to the following formulae

$$Q_{ult} = q_{ult} * A_{Shaft} \qquad \text{(kN)}$$

$$q_{ult} = cN_cS_cd_c + qN_qS_qd_q + 0.5\gamma B'N_\gamma S_\gamma d_\gamma \qquad \text{(kPa)}$$

where:

c	=	soil cohesion
q	=	D_f,
D_f	=	Embedment depth,
B or B'	=	footing width
L	=	footing length.
*A*shaft	=	Pile external surface area in m2

MECHANISMS OF BEARING THEORY AND SHALLOW FOUNDATION

$$N_q = e^{\pi tan\emptyset} tan^2\left(45 + {}^{\emptyset}/_{2}\right)$$

$$N_c = \left(N_q - 1\right) cot\emptyset$$

$$N_\gamma = \left(N_q - 1\right) \tan(1.4\emptyset)$$

$$S_c = 1 + 0.2\,\frac{1+sin\emptyset}{1-sin\emptyset} * \frac{B}{L}$$

$$S_q = S_\gamma = 1 + 0.1K_p\frac{B}{L};\qquad S_q = S_\gamma = 1 \text{ for } \emptyset = 0$$

$$d_c = 1 + 0.2\sqrt{K_p}\frac{D}{B}$$

$$d_q = d_\gamma = 1 + 0.1\sqrt{K_p}\frac{D}{B};\qquad d_q = d_\gamma = 1 \text{ for } \emptyset = 0$$

FACTUAL MECHANISMS OF SKIN FRICTION AND FRICTION PILE

- Skin friction is the resistant force provided by adhesion and friction of the soil along pile’s axial direction. Alpha (α) and lambda (λ) methods are the most common technique used to calculate skin friction for pile founded in clay (Vanapalli et al., 2012).

- The Lambda method is a wholly empirically based solution developed by Vijayvergiya and Focht (1972). It is derived from direct observation of the behaviour of vertically driven-pipe-piles in clay. For its simplicity and that it is fairly accurate from field observation, Lambda method has been used extensively in practice for pipe-pile design (Poulos et al., 1980).

MECHANISMS OF SKIN FRICTION AND FRICTION PILE

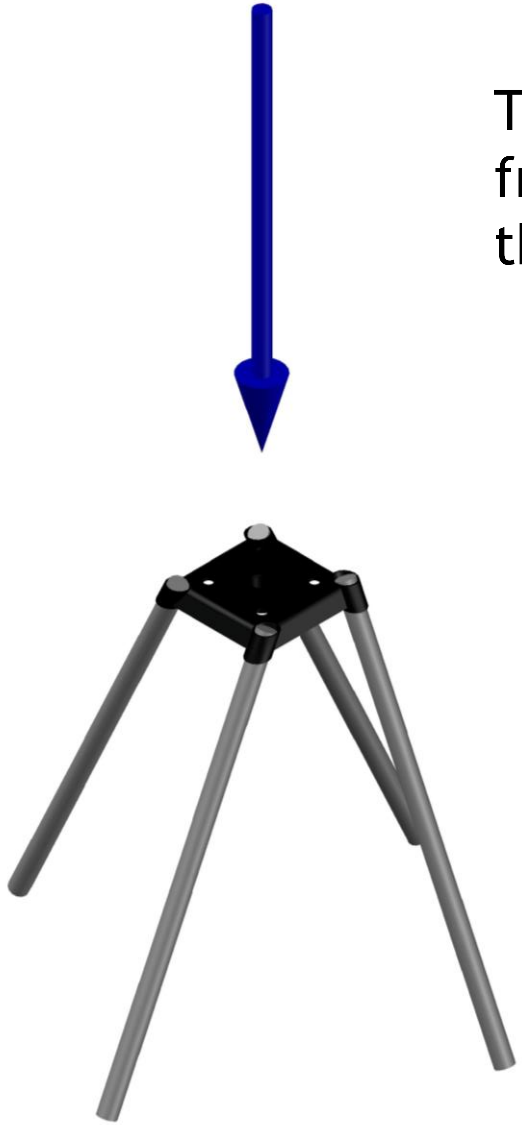
- From Surefoot's design Principles, the friction capacity per pile is as follows:

$$Q_{Shaft} = \sum f \times A_{Shaft}$$

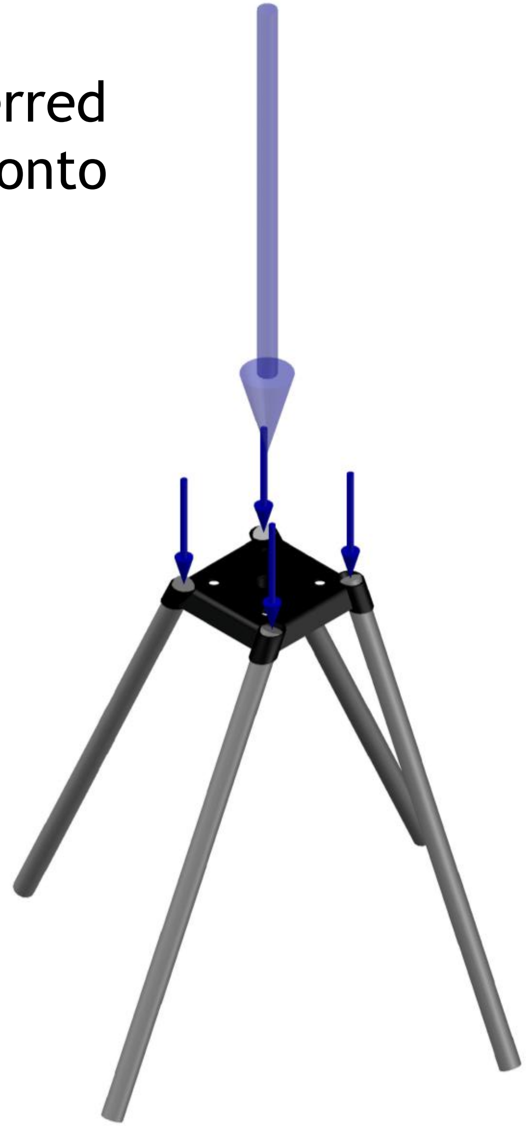
$$f = \lambda(\overline{\sigma'_v} + 2c_u)$$

where:	$\overline{\sigma'_v}$	= Mean effective vertical stress for the entire embedment length
	λ	= factor that varies with the length of pile.
	A_{shaft}	= Pile external surface area in m^2

BASIS OF DESIGN – AXIAL FORCE

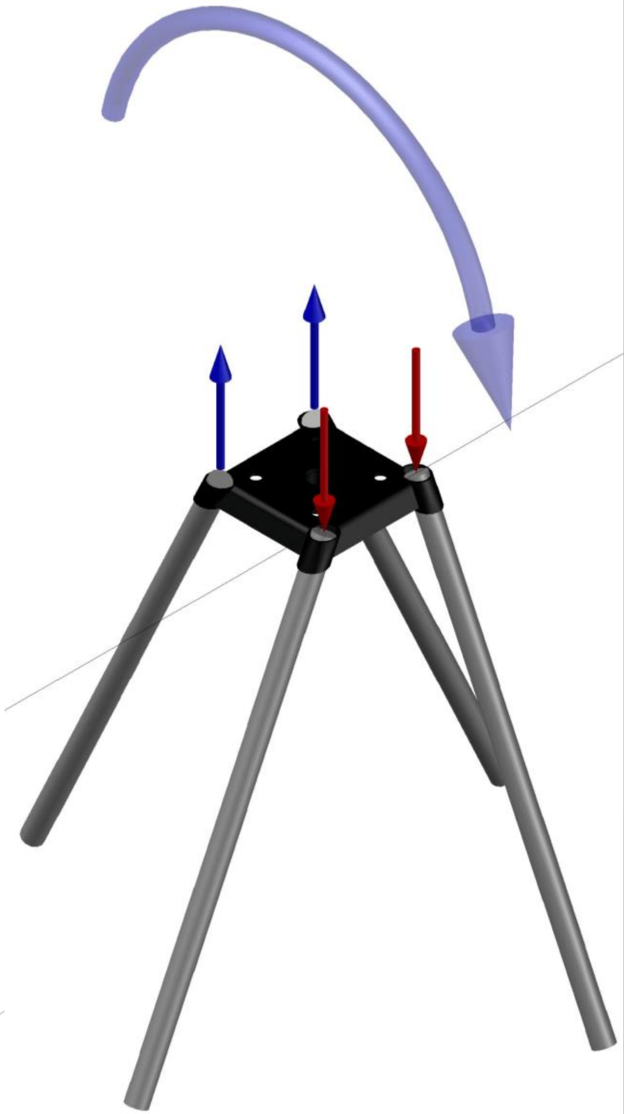


The force is transferred from the pile cap onto the micropiles



BASIS OF DESIGN – BENDING MOMENT

Since the bending moment applied transforms into a pair of forces, and the difference in the capacity between piles under compression load and piles under tension load is wide, it is more conservative to disregard the effect of piles under compression and only design the bending moment being resisted by the piles under tension loading, with a new neutral axis now closer to the compression side.



SUREFOOT'S DESIGN PRINCIPLES

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Surefoot Design Principles

Introduction

Surefoot engineering principles are based on current piling methodology. Total resistance is calculated by using a combination of skin friction and bearing along the length of the pile for compression; lateral pressure and soil weight for tension; and soil's elasticity modulus acting as a non-uniform spring system for shear displacement.

This document has been prepared specifically for consulting engineer's or certifiers who are using the Surefoot design spreadsheet V5.9.6 for *preliminary design assessment* and is intended to provide detailed design information that forms the basis of the capacities calculated using the spreadsheet.

Design capacity calculations are based on the working stress method using soil properties derived from widely accepted geotechnical data for skin friction, bearing pressure and various other parameters.
Galvanised steel piles (steel tube) of 32 Nominal Bore (overall diameter of 42.4mm) with wall thicknesses of 2.6mm to 4.0mm are driven through the Surefoot plate to the design embedment depth.
Soil properties, pile section properties, Surefoot plate properties and various parameters used for design are tabulated in Appendix A and a worked example can be found in Appendix B.

Further information can be found in the "Resources" section on the Surefoot website which can be downloaded from http://www.surefootfootings.com.au/#!resources/cjg1f.

Surefoot Spreadsheet – Explanation of required data and reported values

The spreadsheet requires the following parameters to be entered as the basis of design:

Applied Moment	(M)	–	Applied bending moment in kNm (ultimate load)
Tension or uplift	(N_t)	–	Applied tension/uplift force in kN (ultimate load)
Compression or gravity	(N_c)	–	Applied compression/gravity force in kN (ultimate load)
Shear Force	(V)	–	Applied horizontal shear force in kN (ultimate load)
Soil Density	(γ)	–	Soil's consistency or density in kN/m³.
Cohesion	(C_u)	–	Frictional resistance on cohesive soils. (kPa)
Angle of friction	(°)	–	Soil's angle of friction. (degrees)
Surefoot Type		–	The selected size of Surefoot for design. (SF50 to SF600)
Pile Size		–	The selected size of piles for design. (2.6 to 4.0mm wall thickness)
Pile Embedment		–	The physical length of the piles considered for design.
Total Embedment Required		–	Total length of the piles plus the standard distance (100mm) out of the ground.

Pile forces are reported based on the applied loads resolved by the pile angle of 25 degrees from vertical. The reported force is for *each pile* thus will vary depending on what Surefoot size is used. Forces are separated into three categories based on the applied loads entered by the user:

Axial Load	–	Axial Compression (Gravity) or tension (Uplift) force per pile in kN.
Axial Load from Moment	–	Axial force per pile from vector components of applied moment in kN.
Shear Force	–	Sum of horizontal components of loads plus applied shear force in kN.

Design capacities and stress ratios are reported based on design assessment of the pile cross section and resistance within each relevant soil layer:

Gravity Capacity	–	Total shaft friction capacity plus point bearing capacity in kN.
Uplift Capacity	–	Total shaft friction capacity plus cone pull out capacity in kN.
Bending Moment	–	Section moment capacity based on pile cross section in kNm.
Bending Moment	–	Nominal shear yield capacity based on pile cross section in kN.

Design Procedure

Section 1 – Resolving applied loads for design force per pile

(1.1) Pile axial forces from applied vertical loads:

$$N_{\mathrm{v}} = \frac{N}{p_{\mathrm{n}}}$$ (kN) <Eq. 1-1>

$$N_{\mathrm{p}} = N_{v} * \cos(25)$$ (kN) <Eq. 1-2>

$$N_{\mathrm{h}} = N_{V} * \sin(25)$$ (kN) <Eq. 1-3>

where:
N = applied axial force ($N_{c\ (Comp.)}$ or $N_{t\ (Tens.)}$) in kN
N_{v} = vertical component from axial force ($N_{c,v\ (Comp.)}$ or $N_{t,v\ (Tens.)}$) in kN
N_{h} = horizontal component from axial force ($N_{c,h\ (Comp.)}$ or $N_{t,h\ (Tens.)}$) in kN
N_{p} = axial force per pile ($N_{c,p\ (Comp.)}$ or $N_{t,p\ (Tens.)}$) in kN
p_{n} = number of piles from Surefoot type

(1.2) Pile axial forces from applied moment:

$$M_{\mathrm{v}} = \frac{M \times 10^3 \times \mathrm{Y^*i}}{\sum(p_{\mathrm{nm}}\ \mathrm{Yi}\ \ \mathrm{Y^*i})}$$ (kN) <Eq. 1-4>

$$M_{\mathrm{p}} = M_{v} * \cos(25)$$ (kN) <Eq. 1-5>

$$M_{\mathrm{h}} = M_{\mathrm{v}} * \sin(25)$$ (kN) <Eq. 1-6>

where:
M = applied bending moment in kNm
M_{v} = vertical component from applied moment in kN
M_{h} = horizontal component from applied moment in kN
M_{p} = axial force per pile from applied moment in kN
p_{nm} = number of piles from Surefoot type resisting moment
Yi, Y*i = lever arms based on Surefoot size & effective piles (refer Table A1)

(1.3) Pile forces from applied shear:

$$V_{\mathrm{p}} = \frac{\mathrm{V}}{p_{\mathrm{n}}} + \max(N_{\mathrm{c,h}}\ , N_{\mathrm{t,h}}) + M_{\mathrm{h}}$$ (kN) <Eq. 1-7>

where:
V = applied shear force in kN
V_{p} = total horizontal shear force per pile in kN
N_{h} = max. horizontal component ($N_{\mathrm{c,h}}$ compression or $N_{\mathrm{t,h}}$ tension) in kN

Section 2 – Design capacities

(2.1) Section moment capacity of pile. (AS4100 Clause 5.2)

$$\phi M_s = \phi f_y Z_e \times 10^{-6} \quad \text{(kNm)} \quad \text{<Eq. 1-8>}$$

where:
- ϕ = Capacity factor for bending from AS4100 Table 3.4, = 0.9
- f_y = yield strength of pile in MPa
- Z_e = effective section modulus of pile, (x10^3 mm^3)

(2.2) Shear yield capacity of pile for a circular hollow section. (AS4100 Clause 5.11.4)

$$\phi V_w = \phi\, 0.36\, f_y A_e \times 10^{-3} \quad \text{(kN)} \quad \text{<Eq. 1-9>}$$

where:
- ϕ = Capacity factor for shear from AS4100 Table 3.4, = 0.9
- f_y = yield strength of pile in MPa
- A_e = effective sectional area taken as gross area A_g. (mm^2)

(2.3) Pile capacity under compression. (Gravity loads)

(2.3.1) Pile friction capacity from compressive loading

$$Q_{Shaft} = \sum f \times A_{Shaft} \quad \text{(kN)} \quad \text{<Eq. 1-10>}$$

$$f = \lambda(\overline{\sigma'_v} + 2c_u) \quad \text{(kPa)} \quad \text{<Eq. 1-11>}$$

where:
- $\overline{\sigma'_v}$ = Mean effective vertical stress for the entire embedment length
- λ = factor that varies with the length of pile.
- A_{shaft} = Pile external surface area in m^2

(2.3.2) Pile bearing capacity

$$Q_{ult} = q_{ult} * A_{Shaft} \quad \text{(kN)} \quad \text{<Eq. 1-12>}$$

$$q_{ult} = cN_cS_cd_c + qN_qS_qd_q + 0.5\gamma B' N_\gamma S_\gamma d_\gamma \quad \text{(kPa)} \quad \text{<Eq. 1-13>}$$

where:
- c = soil cohesion
- q = D_f,
- D_f = Embedment depth,
- B or B' = footing width
- L = footing length.
- Ashaft = Pile external surface area in m2

$$N_q = e^{\pi \tan\emptyset} \tan^2\left(45 + \emptyset/2\right) \quad \text{<Eq. 1-14>}$$

$$N_c = (N_q - 1)\cot\emptyset \quad \text{<Eq. 1-15>}$$

$$N_\gamma = (N_q - 1)\tan(1.4\emptyset) \quad \text{<Eq. 1-16>}$$

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$$S_c = 1 + 0.2\frac{1+sin\emptyset}{1-sin\emptyset} * \frac{B}{L}$$ <Eq. 1-17>

$$S_q = S_\gamma = 1 + 0.1K_p\frac{B}{L}; \qquad S_q = S_\gamma = 1 \text{ for } \emptyset = 0$$ <Eq. 1-18>

$$d_c = 1 + 0.2\sqrt{K_p}\frac{D}{B}$$ <Eq. 1-19>

$$d_q = d_\gamma = 1 + 0.1\sqrt{K_p}\frac{D}{B}; \qquad d_q = d_\gamma = 1 \text{ for } \emptyset = 0$$ <Eq. 1-20>

(2.3.3) Total pile capacity under compression. (Gravity loads)

$$Q_c = \frac{Q_{shaft} + Q_{ult}}{SF}$$ (kN) <Eq. 1-21>

where: SF = Safety factor for compression

(2.4) Pile capacity under tension. (Uplift loads)

(2.3.1) Pile friction capacity from tension loading

$$Q_{Shaft} = \sum f \times A_{Shaft}$$ (kN) <Eq. 1-10>

$$f = \lambda(\overline{\sigma'_v} + 2c_u)$$ (kPa) <Eq. 1-11>

where:
$\overline{\sigma'_v}$ = Mean effective vertical stress for the entire embedment length
λ = factor that varies with the length of pile. (0.4)
A_{shaft} = Pile external surface area in m^2

(2.4.1) Passive Earth Pressure applied to pile:

$$Q_p = \sigma_p * A_{Shaft}$$ (kN) <Eq. 1-22>

$$\sigma_p = K_p\sigma_v + 2C_u\sqrt{K_p}$$ (kPa) <Eq. 1-23>

where:
$K_p = \frac{1+sin\emptyset}{1-sin\emptyset}$
σ_v = Soil's shear stress (γ * Z)
Z = Average depth per layer of soil
C_u = Frictional resistance on cohesive soils.
A_{shaft} = Pile external surface area in m^2

(2.4.2) Total pile capacity under tension. (Uplift loads)

$$Q_t = \frac{Q_{shaft} + Q_p}{SF}$$ (kN) <Eq. 1-24>

where: SF = Safety factor for tension

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(2.5) Pile bending moment check for lateral forces. (Horizontal loads)

(2.5.1) Bending moment of pile with applied lateral load using Winkler's Model:

$$M_F = \frac{H}{2\lambda} \quad \text{(kN.m)} \quad \text{<Eq. 1-25>}$$

$$\lambda = \sqrt[4]{\frac{k}{4E_p I_p}} \quad (\text{mm}^{-1}) \quad \text{<Eq. 1-26>}$$

$$k = k_s * D \quad \left({}^{\text{N}}/_{\text{mm}^2}\right) \quad \text{<Eq. 1-27>}$$

$$k_s = \frac{2E_s}{B(1-v_s{}^2)} \quad \left(\frac{{}^{\text{N}}/_{\text{mm}^2}}{\text{mm}}\right) \quad \text{<Eq. 1-28>}$$

where:

E_p	=	Elasticity Modulus for the pile material
I_p	=	Second moment of area of the pile section
D	=	Diameter of pile
v_s	=	Poisson coefficient for the soil. (0.4 average)
E_s	=	Elasticity Modulus for the soil.

(2.5.2) Total pile capacity for bending moment. (Lateral Loads)

$$M_t = \frac{M_F}{SF} \quad \text{(kN.m)} \quad \text{<Eq. 1-29>}$$

where: SF = Safety factor for moment

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Appendix A

Table A1 – Surefoot Plate Properties

Surefoot Model (Gr. 250 MPa)	Nom. Plate Dimensions (mm)	Plate Thickness (mm)	Product Weight (kg/each)	Number of piles (p_n) (each)	No. piles resisting moment (p_{nm}) (each)	Yi & Y*i (mm)	$\Sigma(p_{nm}$ Yi Y*i) See Note (1)
SF50	274	4	2.5	3	1	227	51529
SF150	262 x 262	8	5	4	2	200	80000
SF300	382 x 382	10	15	6	2	328	296410
SF400	482 x 482	10	25	8	3	333	395640
SF500	482 x 482	10	25	12	4	345	702666
SF600	632 x 632	10	40	16	5	488	1607622

Notes: (1) Includes contribution of additional piles (where applicable) multiplied by their lever arm distances.

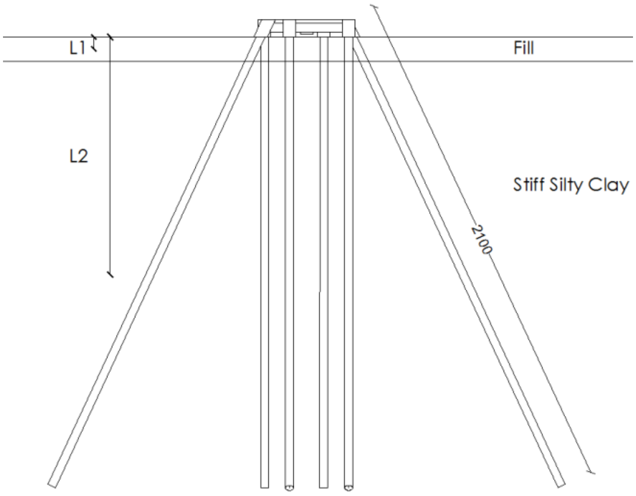
Table A2 – Pile Section Properties

Designation for 32NB (Nominal Bore) O/A Diameter (Do = 42.4) (mm)	Wall Thick. t (mm)	Gross Section Area A_g (mm²)	Internal Section Area A_{gi} (mm²)	Mass per meter kg/m	External Surface Area A_{se} m²/m	Internal Surface Area A_{si} m²/m	Yield Strength f_y (MPa)	Moment of Inertia I_{xx}/I_{yy} x10⁶mm⁴	Radius of gyration r_{xx}/r_{yy} mm	Effective Section Modulus Z_e x10³mm³
32NB 2.6	2.6	325	1087	2.55	0.133	0.117	350	0.0646	14.1	4.12
32NB 3.2	3.2	394	1018	3.09	0.133	0.113	250	0.0762	13.9	4.93
32NB 4.0	4.0	483	929	3.79	0.133	0.108	250	0.0899	13.6	5.92

Appendix B – Worked Example

Estimate the capacity of a SF300 pile cap, with 6/32NBx2.6mm piles (2100mm total length) driven through the following layers:

- 100mm of fill
  - Cu= 0 kPa
  - Φ= 15°
  - γ= 16 kN/m³
  - Es= 10 MPa
- Firm Silty Clay to 2100mm.
  - Cu= 75 kPa
  - Φ= 0°
  - γ= 18.5 kN/m³
  - Es= 40MPa



- Applied working loads from the superstructure are as follows:

Compression (Gravity)*	($N_{c,v}$)	=	40	kN
Tension (Uplift)*	($N_{t,v}$)	=	15	kN
Applied shear force*	(V)	=	3.0	kN
Applied bending moment*	(M)	=	1.5	kNm

- * Ultimate loading from Structural Analysis

<u>Step 1 – Checking applied forces to the piles</u>

(1.1) Pile axial forces from applied vertical loads:

For compression (Gravity load)

$$N_{c,v} = \frac{N_c}{p_n} = \frac{40}{6} = 6.66 \quad (kN)$$ <Eq. 1-1>

$$N_{c,p} = N_{c,v} * \cos(25) = 6.66 * \cos(25) = 7.36 \quad (kN)$$ <Eq. 1-2>

$$N_h = N_{c,v} * \sin(25) = 2.82 \quad (kN)$$ <Eq. 1-3>

For tension (Uplift load)

$$N_{t,v} = \frac{N_t}{p_n} = \frac{15}{6} = 2.50 \quad (kN)$$ <Eq. 1-1>

$$N_{t,p} = N_{t,v} * \cos(25) = 2.50 * \cos(25) = 2.27 \quad (kN)$$ <Eq. 1-2>

$$N_h = N_{t,v} * \sin(25) = 1.06 \quad (kN)$$ <Eq. 1-3>

(1.2) Pile axial forces from applied moment:

$$M_v = \frac{M \times 10^3 \times Y^*i}{\sum(p_{nm} Yi\, Y^*i)} = \frac{1.5 \times 10^3 \times 328}{296410} = 1.66 \quad (kN)$$ <Eq. 1-4>

$$M_p = M_v * \cos(25) = 1.50 \quad (kN)$$ <Eq. 1-5>

$$M_h = M_v * \sin(25) = 0.70 \quad (kN)$$ <Eq. 1-6>

(1.3) Pile forces from applied shear:

$$V_p = \frac{V}{p_n} + \max(N_{c,h}, N_{t,h}) + M_h = \frac{3}{6} + 2.82 + 0.70 \quad = 4.02 \quad \text{(kN)} \quad \text{<Eq. 1-7>}$$

Step 2 – Checking design capacities

(2.1) Section moment capacity of pile. (AS4100 Clause 5.2)

$$\phi M_s = \phi\, f_y\, Z_e \times 10^{-6} = 0.9 \text{ x } 350 \text{ x } 4.12\text{x}10^3 \text{ x}10^{-6} \quad = 1.30 \quad \text{(kNm)} \quad \text{<Eq. 1-8>}$$

(2.2) Shear yield capacity of pile for a circular hollow section. (AS4100 Clause 5.11.4)

$$\phi V w = \phi\, 0.36\, f y A e \times 10^{-3} = 0.9 \text{ x } 0.36 \text{ x } 350 \text{ x } 325\text{x}10^{-3} \quad = 36.86 \quad \text{(kN)} \quad \text{<Eq. 1-9>}$$

(2.3) Pile capacity under compression. (Gravity loads)

(2.3.4) Pile friction capacity from compressive loading

$$f = \lambda(\overline{\sigma'_v} + 2c_u) \quad \text{(kPa)} \quad \text{<Eq. 1-11>}$$

$$f_1 = 0.4(\gamma_1 * L1 + 2 * 0) \quad = 0.32$$

$$f_2 = 0.4(\gamma_2 * L2 + 2 * 75) \quad = 66.3$$

$$Q_{Shaft} = \sum f \times A_{Shaft} \quad \text{(kN)} \quad \text{<Eq. 1-10>}$$

$$Q_{Shaft} = 0.32 * (2 * \pi * r * L1) + 66.3 * (2 * \pi * r * L2) \quad = 16.7\text{kN}$$

(2.3.5) Pile bearing capacity

$$N_q = e^{\pi tan\emptyset} tan^2\left(45 + {}^{\emptyset}/_{2}\right) \quad \text{<Eq. 1-14>}$$

$$N_{q1} = e^{\pi tan15} tan^2\left(45 + {}^{15}/_{2}\right) \quad = 3.94$$
$$N_{q2} = e^{\pi tan0} tan^2\left(45 + {}^{0}/_{2}\right) \quad = 1$$

$$N_c = \left(N_q - 1\right) cot\emptyset \quad \text{<Eq. 1-15>}$$

$$N_{c1} = \left(N_q - 1\right) cot15 \quad = 10.98$$
$$N_{c2} = 5.14$$

$$N_\gamma = \left(N_q - 1\right) \tan(1.4\emptyset) \quad \text{<Eq. 1-16>}$$

$$N_{\gamma 1} = (3.94 - 1)\tan(1.4(15)) \quad = 1.13$$
$$N_{\gamma 2} = (1 - 1)\tan(1.4(0)) \quad = 0$$

$$S_c = 1 + 0.2\frac{1 + sin\emptyset}{1 - sin\emptyset} * \frac{B}{L} \quad \text{<Eq. 1-17>}$$

$$S_c = 1.01$$
$$S_c = 1.01$$

$$S_q = S_\gamma = 1 + 0.1K_p\frac{B}{L}; \qquad S_q = S_\gamma = 1 \text{ for } \emptyset = 0 \quad \text{<Eq. 1-18>}$$

$$S_{q1} = 1.01$$

$S_{q2} = 1.00$

$$d_c = 1 + 0.2\sqrt{K_p}\frac{D}{B}$$ <Eq. 1-19>

$d_{c1} = 1.01$
$d_{c2} = 1.19$

$$d_q = d_\gamma = 1 + 0.1\sqrt{K_p}\frac{D}{B}; \qquad d_q = d_\gamma = 1 \text{ for } \emptyset = 0$$ <Eq. 1-20>

$d_{q1} = 1.01$
$d_{q2} = 1.00$

$$q_{ult} = cN_cS_cd_c + qN_qS_qd_q + 0.5\gamma B'N_\gamma S_\gamma d_\gamma$$ (kPa) <Eq. 1-13>

$q_{ult1} = 12$
$q_{ult2} = 481$

$$Q_{ult} = 38.6kN$$ (kN) <Eq. 1-12>

(2.3.6) Total pile capacity under compression. (Gravity loads)

$$Q_c = \frac{Q_{shaft} + Q_{ult}}{SF} = \frac{38.6kN}{SF}$$ (kN) <Eq. 1-21>

(2.6) Pile capacity under tension. (Uplift loads)

(2.3.2) Pile friction capacity from tension loading

$$Q_{Shaft} = \sum f \times A_{Shaft} = 16.7kN$$

(2.4.3) Passive Earth Pressure applied to pile:

$$\sigma_p = K_p\sigma_v + 2C_u\sqrt{K_p}$$ (kPa) <Eq. 1-23>

$$\sigma_{p1} = K_p\sigma_v + 2C_u\sqrt{K_p} = 1.70 * \gamma_1 * L1 + 2 * 0 * \sqrt{1.70} = 2.72$$
$$\sigma_{p2} = K_p\sigma_v + 2C_u\sqrt{K_p} = 1.00 * \gamma_2 * (L_1 + L_2) + 2 * 75 * \sqrt{1.00} = 183.53$$

(2.4.4) Total pile capacity under tension. (Uplift loads)

$$Q_p = (\sigma_{p1} + \sigma_{p2}) * A_{Shaft} = 6.7kN$$

$$Q_t = \frac{Q_{shaft} + Q_p}{SF}$$ (kN) <Eq. 1-24>

$$Q_t = \frac{Q_{shaft} + Q_p}{SF} = \frac{16.7kN}{SF}$$

(2.7) Pile bending moment check for lateral forces. (Horizontal loads)

(2.5.3) Bending moment of pile with applied lateral load using Winkler's Model:

Since the highest deflection and the highest bending moment occurs in the top of the pile, then the check is done only on the first soil layer.

$$k_s = \frac{2E_s}{B(1-v_s{}^2)} \quad \text{(kN)} \quad \text{<Eq. 1-28>}$$

$$k_{s1} = \frac{2*10}{42.4*(1-0.4^2)} = 0.2$$

$$k = k_s * D \quad \text{(kN)} \quad \text{<Eq. 1-27>}$$

$$k = k_s * 42.4 = 7.1$$

$$\lambda = \sqrt[4]{\frac{k}{4E_p I_p}} \quad \text{(kN)} \quad \text{<Eq. 1-26>}$$

$$\lambda = \sqrt[4]{\frac{7.1}{4*200000*64600}} = 0.0034$$

$$M_F = \frac{4200N}{2*.0034} = 0.59kN.m$$

(2.5.4) Total pile capacity for bending moment. (Lateral Loads)

$$M_\mathrm{t} = \frac{0.59kN.m}{SF}$$

PILE DESIGN CAPACITY SUMMARY

Load Description	Pile Force	Design Capacity	Stress Ratio	Status
Gravity Capacity	$N_{c,p}$ = 7.55 kN	Q_c = 55.28 kN	13.65 %	OK
Uplift Capacity	$N_{t,p}$ = 3.77 kN	Q_t = 23.37 kN	16.13 %	OK
Moment Capacity	M'_p = 0.59 kNm	ϕM_p = 1.30 kNm	45.16 %	OK
Shear Capacity	V_p = 4.02 kN	ϕV_w = 36.86 kN	10.90 %	OK

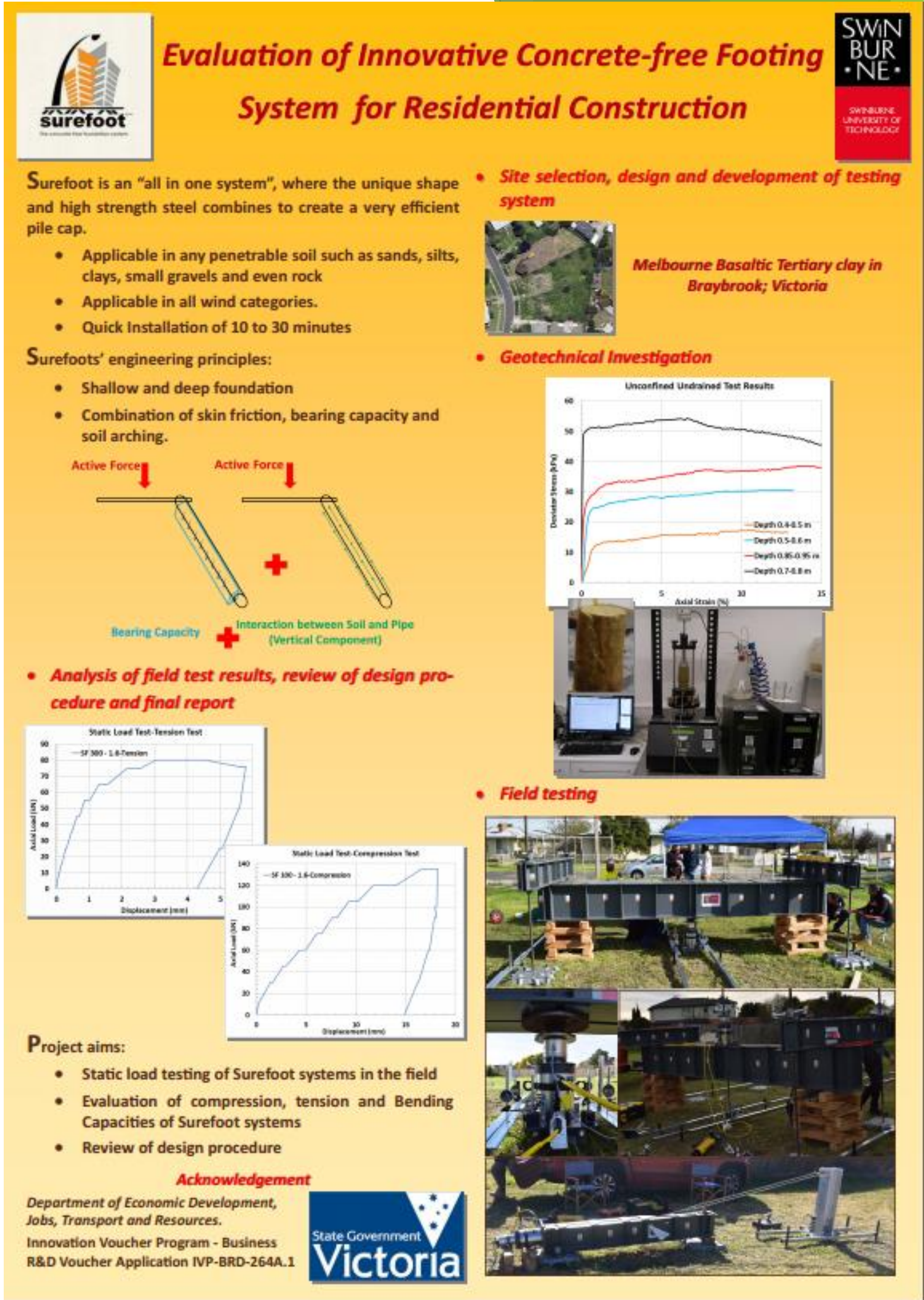
HENCE, ADOPT SUREFOOT SF300 WITH 6/32NBx2.6mm GALVANISED PILES AT 2100mm TOTAL LENGTH FULLY DRIVEN INTO FIRM SILTY CLAY

CORROBORATION OF FORMULAE

- From Surefoot's database, we have gather information from all the installations and projects done up to date. Nonetheless, the two major testings that we have done to international Standards have been the following:
  - Braybrook testing (done to ASTM D1143), for static compression and tension loading
  - Fingal testing (currently in progress), for static compression, tension, cyclic, long term and lateral loading.

BRAYBROOK TESTING

- This test was performed by Swinburne University under the Victorian Government's Innovation Voucher Program for Research
- The test was done in Braybrook, Victoria, usually a site of clays with a high plasticity level.
- The site consisted on two layers of soil, which were:
  - A layer classified as fill with a standard depth of 400mm
  - A layer of silty clay with a depth of up to 10m.

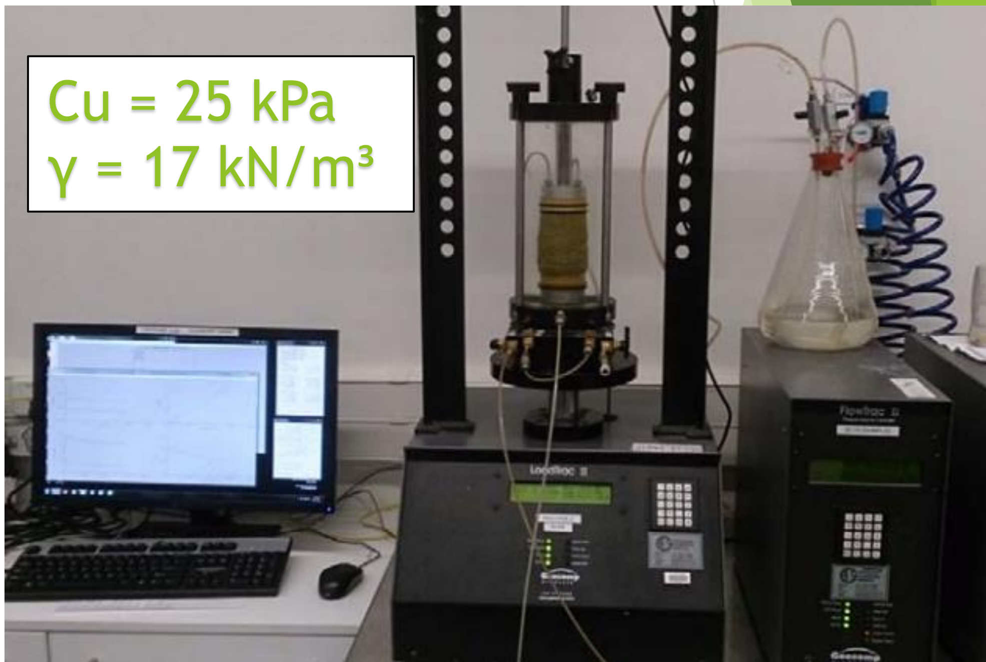


SUT - STATIC TESTING

BRAYBROOK SOIL

Table 2. Triaxial UU tests results

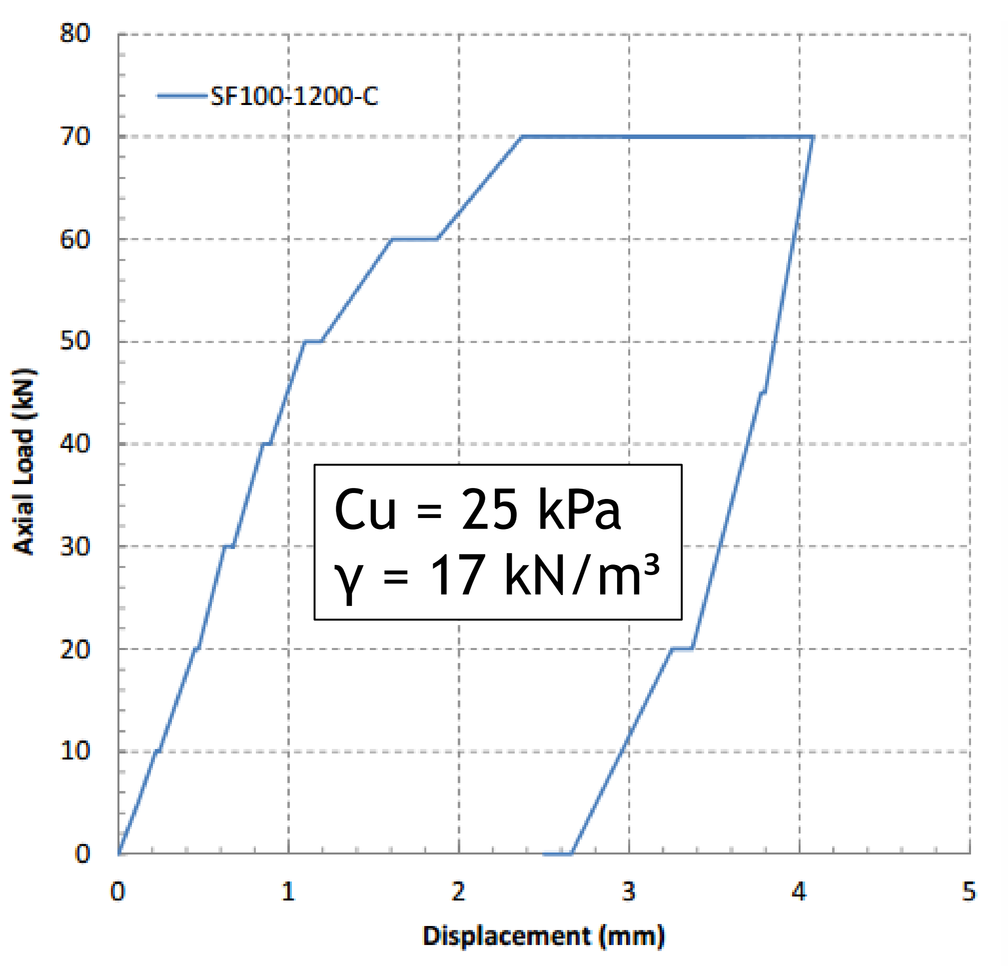
BH No.	Depth (mm)	Undrained Shear Strength (kPa)	Soil Type
1	500-600	16	Fill
2	400-500	8.5	Fill
3	700-800	27	Clay
3	850-950	19.5	Clay
5	1100-1200	26	Clay
5	1200-1300	18.5	Clay

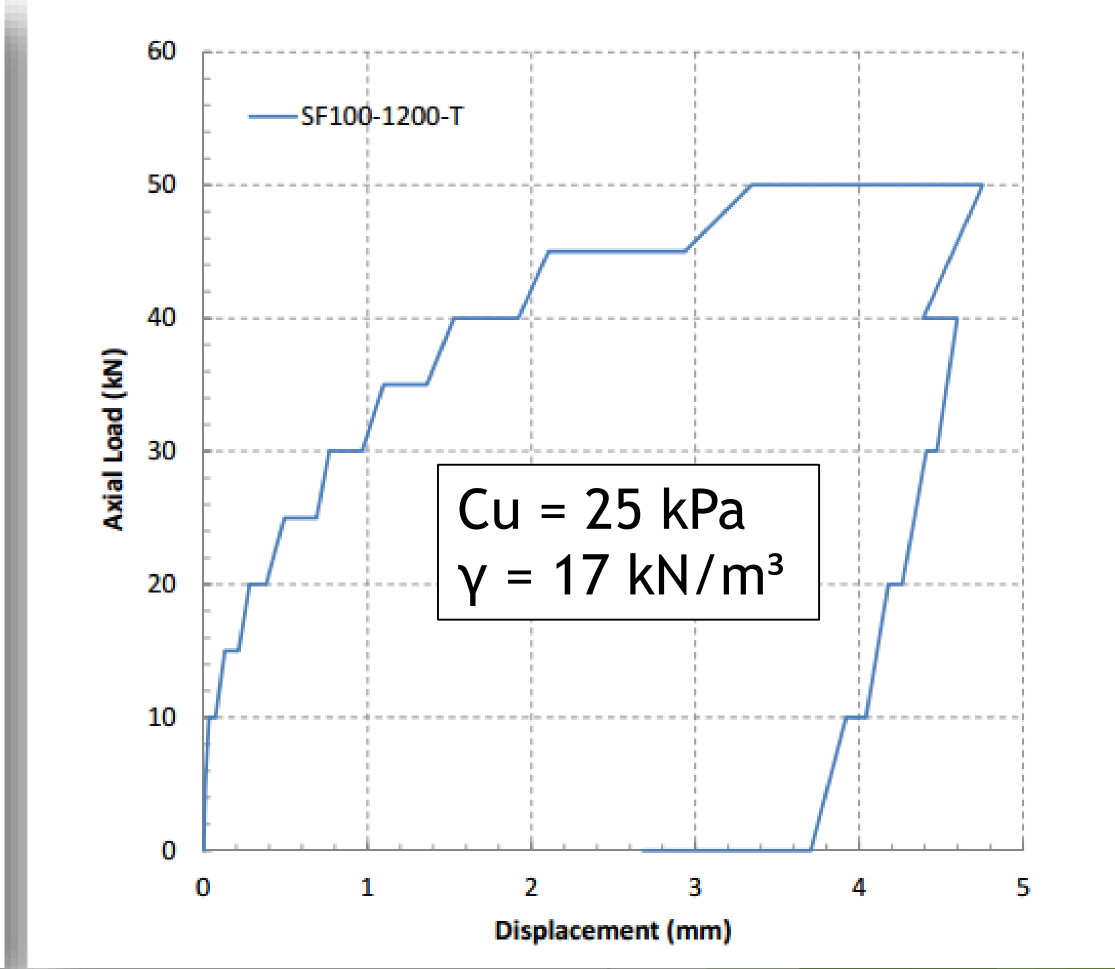


Cu = 25 kPa

γ = 17 kN/m³

STATIC TESTING S250 AT 1200mm





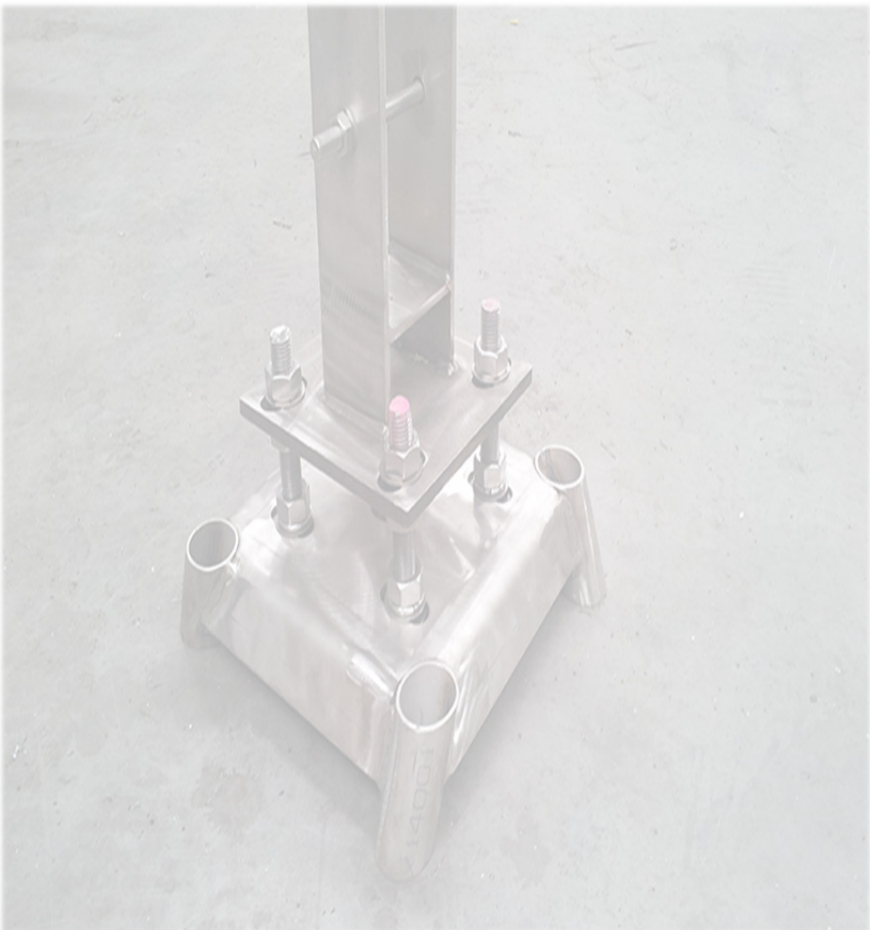
S250 Qu = 70kN

S250 Tension = 50kN

Evaluation of Innovative Concrete-Free Footing System for Residential Construction

Innovation Voucher Program – Business R&D Voucher
Application IVP-BRD-264A.1

March, 2016



Swinburne University of Technology

Faculty of Science, Engineering and Technology

Department of Civil and Construction Engineering

Centre for Sustainable Infrastructure

Acknowledgement

This project would not have been possible without the financial support of the State Department of Economic Development, Jobs, Transport and Resources, Victorian Government, R&D Voucher Program IVP-BRD-264A.1

Project Information

Title: Evaluation of Innovative Concrete-free System for Residential Construction

Project Partner: Surefoot Pandoe Pty Ltd

Project Team

Swinburne University of Technology:

Dr. Mahdi Disfani: Chief Investigator

Dr. Robert Evans: Chief Investigator

Professor Emad Gad: Chief Investigator

Mr. Amir Mehdizadeh: Project Manager, Report Author

Mr. Aruna Karunarathne: Site Engineer

Surefoot Pandoe Pty Ltd:

Mr. Neil Despotellis: Partner Investigator

Mr. William Jennings: Civil/Structural Engineer

Mr. Alberto Escobar: Civil/Structural Engineer

Date: Tuesday, 22 March 2016

Report Version: Final Version

Table of Contents

Executive Summary

Swinburne University of Technology was engaged by the State Government of Victoria (Department of Economic Development, Jobs, Transport and Resources) and Surefoot Pandoe Pty Ltd to undertake the research project titled “Evaluation of innovative concrete-free footing system for residential construction”. The project was funded under the “Innovation Voucher Program – Business R&D Voucher Application IVP-BRD-264A.1”.

The aim of this project was to test a range of new Surefoot footing systems under field conditions to determine their maximum axial compressive and tensile load capacity. Securing quality field test data will not only provide greater confidence for this newly developed footing system, but will also be used to review and update the current design procedure. This project was conducted in several phases, as set out below:

1. Site selection,
2. Design and development of testing system
3. Field testing
4. Analysis of field test results, and
5. Review of design procedure

The primary focus of this project was to develop and build the field testing device, perform the field tests, and conduct a back-analysis of the results to gain a better understanding of the behaviour of this new footing system. In the future, these results should lead to an improved cost-effective design method and provide greater confidence for clients and customers.

Introduction

A new innovative concrete-free footing system known as Surefoot is gaining popularity due to its cost-effectiveness and quick and easy installation method. It requires only light-weight (hand-held) power tools to install, minimum site access and causes minimum soil disturbance during installation. Furthermore, the overall carbon-footprint is much lower when compared to traditional reinforced concrete footing systems.

Surefoot is essentially a steel plate (acting as a micropile group cap) with a number of steel micropiles attached. The micropiles are steel tubular sections (40 mm in diameter) driven at an angle (typically 25° from the vertical) through guiding sleeves, which are attached to the top plate as shown in Figure 1. These steel micropiles are driven into the ground by a light (hand-held) jackhammer. As a result, Surefoot does not require excavation, drilling or any concrete. Together, all of these benefits make Surefoot a viable sustainable alternative to traditional footing techniques in a wide range of applications.

The concept of the new Surefoot system was inspired by the supporting action of a tree root. When roots spread through soil, a much larger area is engaged that provides greater resistance.

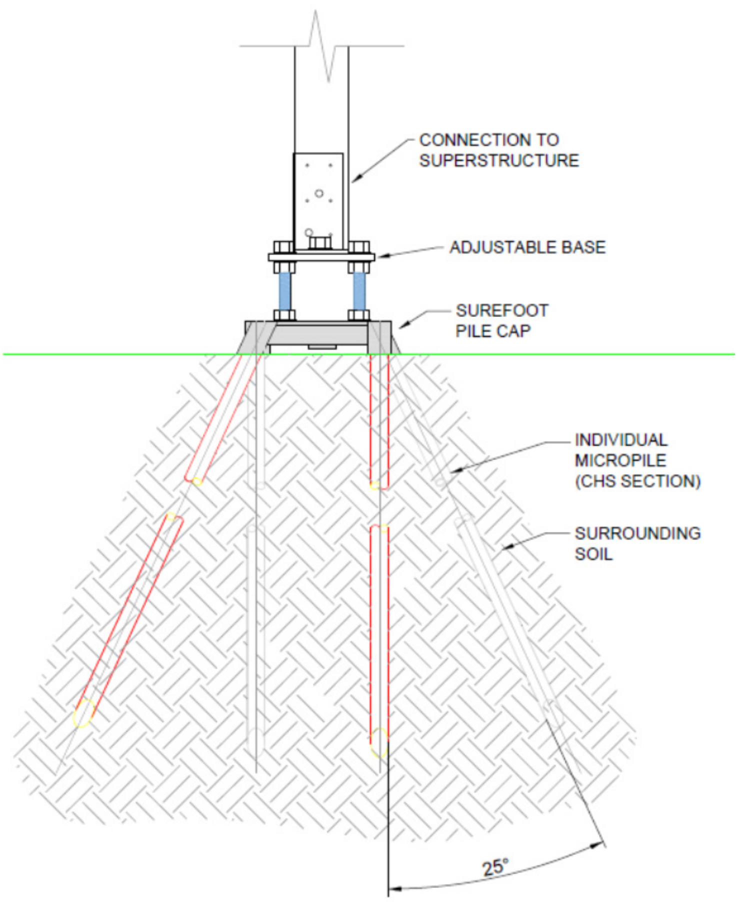


Figure 1: A typical Surefoot system with surrounding soil and connections

The Surefoot footing system comes in a range of different capping system configurations and micropile numbers based on design load, load type and site conditions. The embedment depth can also change based on design load and soil conditions. SF50, SF100, SF200, SF300, SF400, SF500 and SF600 are available Surefoot footing products.

Some of Surefoot's advantages are summarized below:

- Ability to support various types of loading such as compression, tension, lateral loads as well as bending moments and shear forces
- Installation time ranges from 10 to 30 minutes per footing
- Applicable in all wind categories
- Applicable in any penetrable soil such as sands, silts, clays, fine gravels and even rock
- Flexibility in design may satisfy specific project requirements
- Applicable in on-shore and off-shore projects
- Minimal soil and site disturbance (i.e. no costly spoil removal)
- Restricted site access is often not an issue.
- Possibility of reusing the major structural parts several times and recycling the hollow micropiles
- Low carbon footprint when compared to traditional reinforced concrete footings
- Cost and time effective

Surefoot's engineering principles are based on a combination of shallow and deep foundation design principles. It uses the theory of bearing capacity of a shallow foundation plus the skin friction and toe resistance of a deep foundation, which is believed to contribute to the overall capacity of the Surefoot system. Due to Surefoot's different mechanism of operation compared to conventional micropiles or shallow footings; field-testing was considered the most reliable approach to ascertain a true bearing capacity of this innovative footing system.

To evaluate the ultimate capacity of the Surefoot system under compression and pull-out resistance, and to assess the overall performance of the system; a series of static pile load tests were performed. This series of load tests covered various geometric configurations and foundation depths. Compression and pull-out tests (with the addition of creep tests) were performed. These tests were all conducted in a quaternary basaltic clay geological formation in Melbourne's western suburb of Braybrook.

This report presents results of site classification, in-situ and laboratory strength testing of the soil, along with the field static load tests on the Surefoot system. The field test results were analysed using a range of methods to determine the most reliable method and anticipated failure load. This not only satisfied the required confidence for this newly developed footing system, but the results of the study were used to review the current design procedure. The design review will help to make the current design more rational and consequently more competitive in the market.

Project Methodology

This project can be divided into five main parts: (i) site selection and geotechnical investigation, (ii) development of testing system, (iii) field testing, (iv) analysis of field test results and (v) review of design procedure.

A residential site in Braybrook (Victoria) was selected for this project. The geological maps of this area revealed the upper soil layer to be basaltic clay deposits derived from quaternary volcanic basalt. The geotechnical investigation of the site involved drilling several holes across the site, logging the ground encountered, and collecting disturbed and undisturbed samples for testing. Laboratory testing of the soil's strength parameters comprised of a series of unconsolidated undrained triaxial tests and consolidated undrained triaxial tests. A series of dynamic cone penetrometer (DCP) tests were also performed during the field investigation to assess the strength of the soil in-situ.

The field testing system was designed and manufactured based on the Standard Test Methods for Deep Foundations under Static Axial Compressive Load (ASTM 1143-1994) as a benchmark. This involved construction of the load beams, assembly of the hydraulic loading system and associated instrumentation for monitoring and calibration.

Two current Surefoot systems (SF100 and SF300) at two different embedment depths (1200 and 1500 mm) were tested under compression and pull-out conditions. Creep testing was also performed on these footings. Details and dimensions of SF100 and SF 300 systems are shown in Figure 2 and Figure 3.

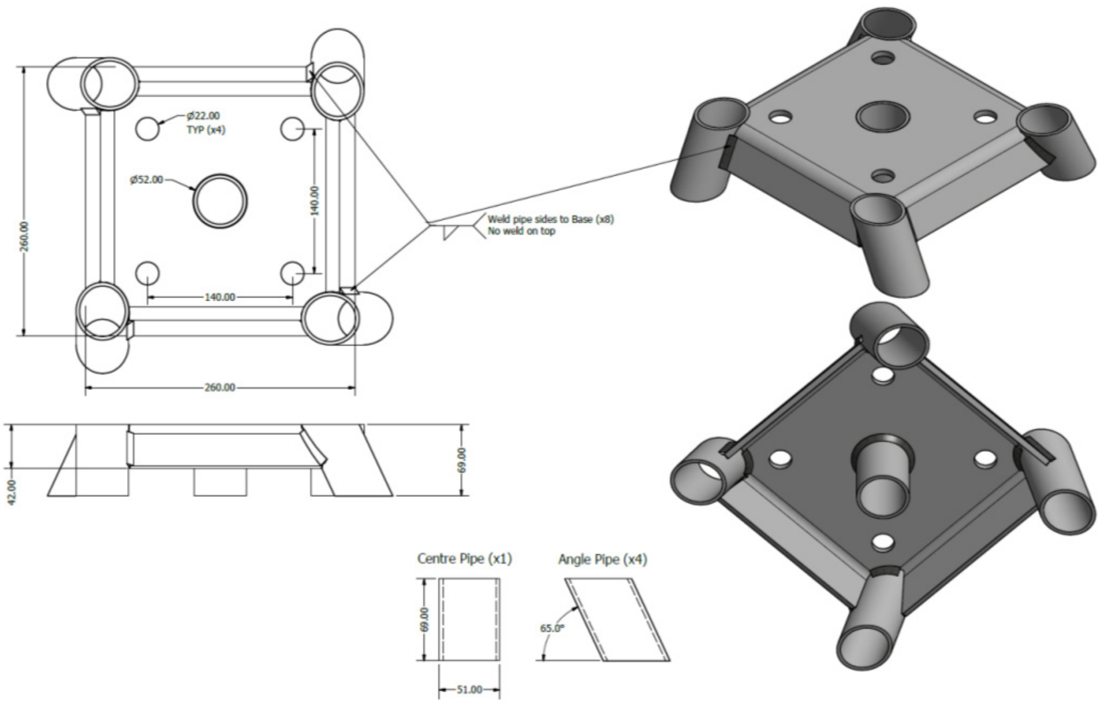


Figure 2: Surefoot SF100 dimensions (in mm) and details

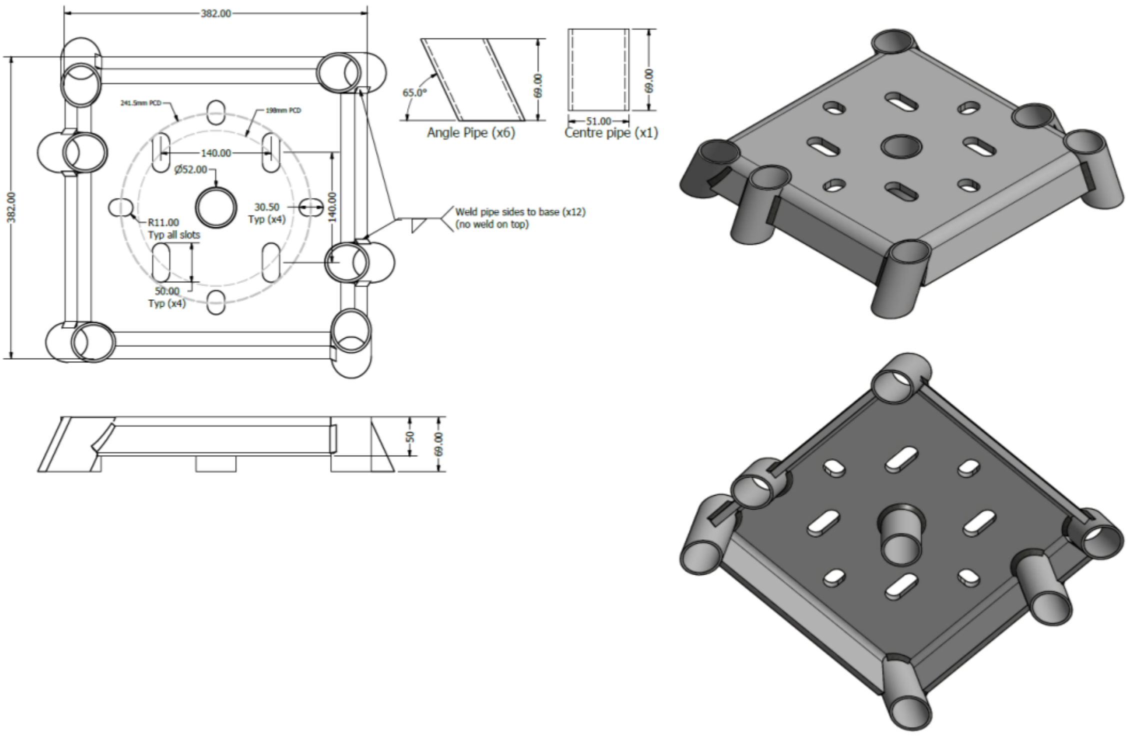


Figure 3: Surefoot SF300 dimensions (in mm) and details

Upon completion of the field testing, all field and laboratory results were analysed with two main objectives. The first objective was to obtain the maximum bearing capacity of the Surefoot footing system in compression and pull-out. The second objective was to review the current design procedure and contrast the design assumptions with field data. Figure 4 shows a general overview of the project.

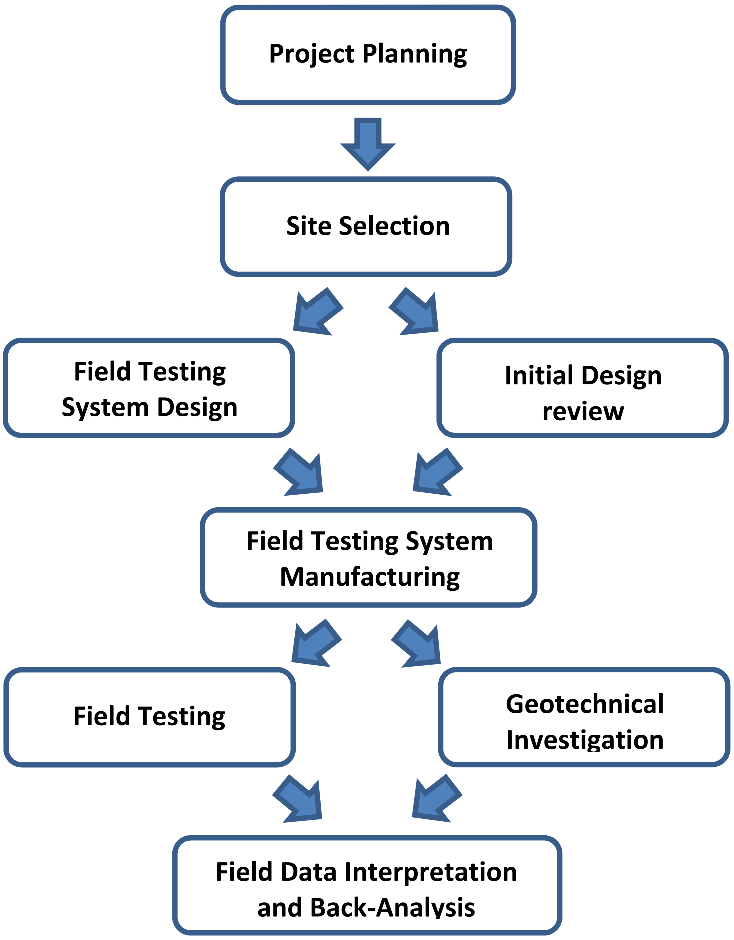


Figure 4: The flow chart of the project

Site Description and Geotechnical Investigation

The geotechnical investigation is an important part of each construction project. Strength parameters of the soil and evaluation of bearing capacity are directly related to the foundation response. Without a clear understanding of the soil properties, a safe and economic design of any footing system is unlikely.

The selected site was located at Braybrook, Victoria. Figure 5 shows aerial photographs of site at different times during 2010. It can be seen that the site is divided into three blocks with one house on each. Between October and December in 2010, the houses were demolished and the ground levelled. These photos, combined with visual observation of the disturbed samples gathered (using hand and powered augers) suggest the presence of 300 to 700 mm of fill material. The geological and geotechnical investigation carried out on site confirmed that the soil layer below the fill material was Quaternary basaltic clay.

Figure 5: Aerial photos of project site at various historical dates

Due to access issues and existence of delicate instrumentation on the site (due to another parallel research project being undertaken), the two highlighted locations in Figure 6 were selected for this project as option 1 and 2. After much evaluation of the site, option 1 was selected for testing. This was mainly due to crane and truck accessibility needed to move the loading beams between tests vs. current instrumentation on the site.

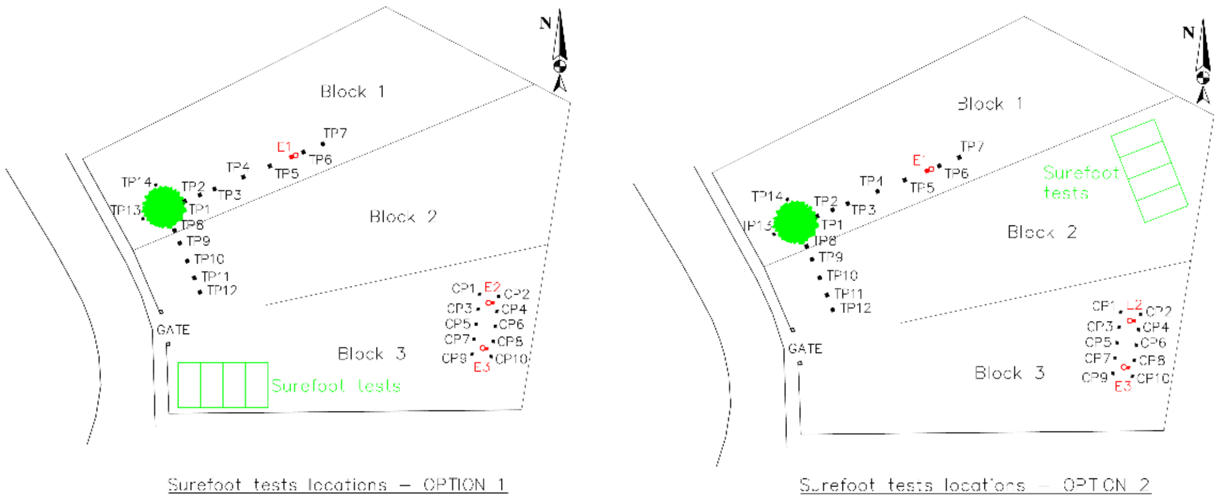


Figure 6: Initial field testing location options

Once the location on the test site was confirmed, 14 Surefoot footings of various size were installed to perform static compression and pull-out load tests. Table 1 shows the specification of the installed footings. It is important to note that every possible effort was made to satisfy the minimum distance required between test footings and reaction footings. This was measured in terms of influence radius of each system during installation according to ASTM 1143-1994 (Figure 7).

The geotechnical investigation of this project included DCP (Dynamic Cone Pentrometer) tests, UU (Unconsolidated Undrained) and CU (Consolidated Undrained) triaxial tests from undisturbed specimens obtained by a professional registered driller. Six UU tests and a series of four CU tests were performed to estimate the undrained and drained shear strength parameters of the soil at a depth of between 500 mm and 1500 mm. In addition, a total of seven DCPs were performed from the ground surface down to a maximum depth of 1700 mm in the centre of each Surefoot, as well as at other locations around the tested footings.

The depth of the undisturbed samples chosen for laboratory strength testing was based on the depth of influence of the Surefoot systems. The location of the bore holes and thus the samples are shown in Figure 7 and Figure 8.

Table 1: Specification of the installed footings

Number	Type	Number of micropiles	Embedment Depth (mm)	Type
R1	SF400	9	1600	Reaction Pile
R2	SF400	9	1600	Reaction Pile
R4	SF400	9	1600	Reaction Pile
R5	SF400	9	1600	Reaction Pile
R6	SF400	9	1600	Reaction Pile
R7	SF400	9	1600	Reaction Pile
R8	SF400	9	1600	Reaction Pile
R9	SF400	9	1600	Reaction Pile
R10	SF400	9	1600	Reaction Pile
R11	SF400	9	1600	Reaction Pile
T1	SF300	6	1500	Test Pile
T2	SF300	6	1200	Test Pile
T3	SF100	4	1500	Test Pile
T4	SF100	4	1200	Test Pile

The results of the DCP tests, UU triaxial tests and CU triaxial tests are presented in Figure 9, Figure 10 and Figure 11, Table 2 and Table 3.

Figure 9 and Table 2 show that the average undrained shear strength (Su_{ave}) of fill material is around 12 kPa. For Braybrook clay, the undrained shear strength is around 23 kPa and shows some variations with depth. However, site observation showed that the organic material such as root plants spread through a deeper layer down to 1 m. The in-situ moisture content of soil samples was measured in the laboratory as a field index with results varying from 13% to 23%.

Figure 11 shows the results of CU tests. The stress-strain curves of Braybrook clay suggest softening behaviour for confining pressures above 50 kPa. However, for confining pressures below 50 kPa the behaviour is stress-hardening; typical of over-consolidated clays. Assuming a nominal depth of 0.75 m for the soil samples and an average density of 17.4 kN/m^3, the Over-Consolidation Ratio (OCR) for Braybrook clay would be around 3.8.

Comparing the undrained shear strength values reported in Table 2 with Table 5 of AS 1726 (Standards Australia, 1993) suggests that the fill material can be described as “Very Soft” while the underneath clay is described as “Soft”.

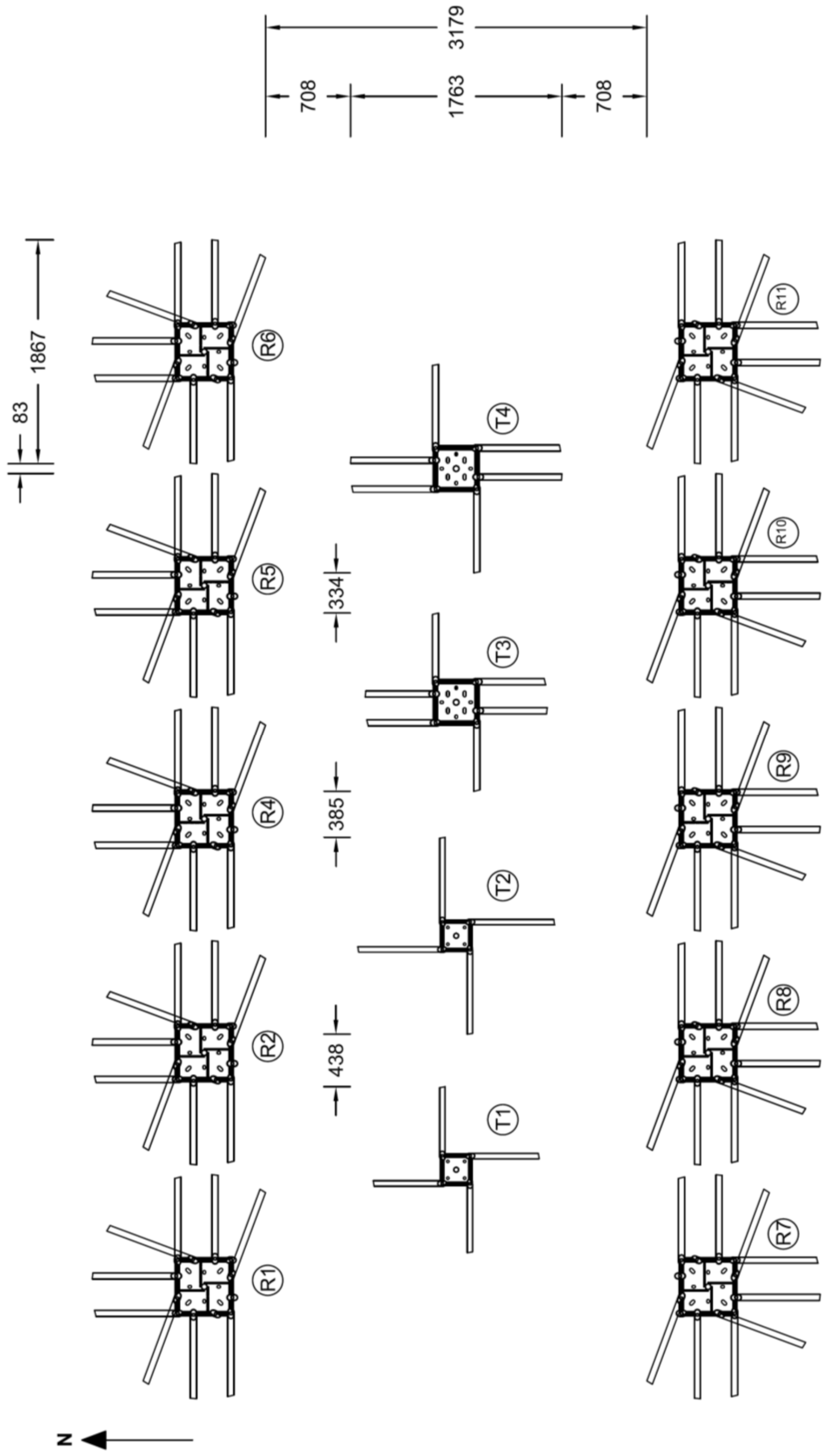


Figure 7: Layout of Surefoot footings and orientation of micropiles (dimensions in mm)

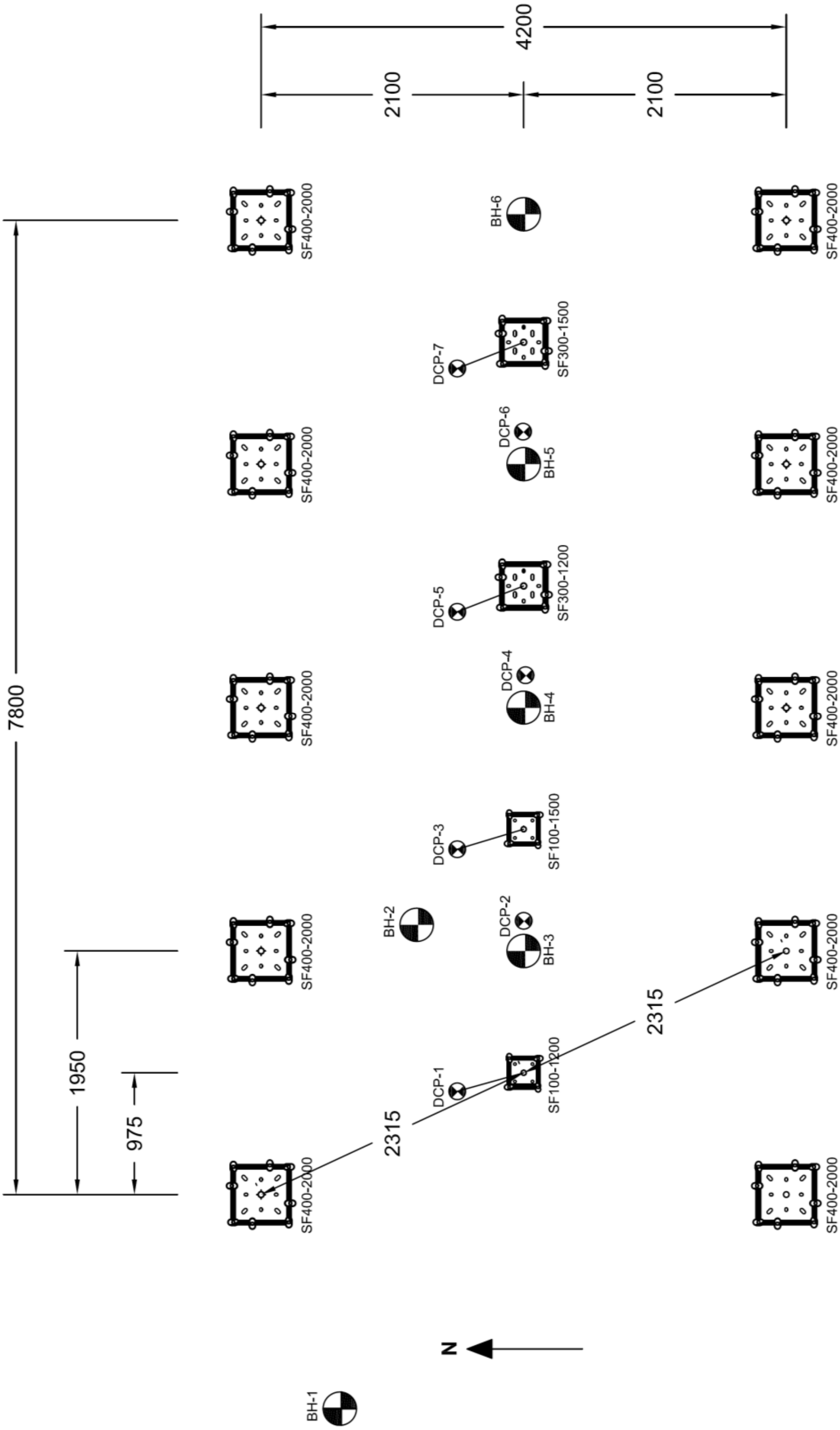


Figure 8: Layout of Surefoot footings – top plate only (dimensions in mm)

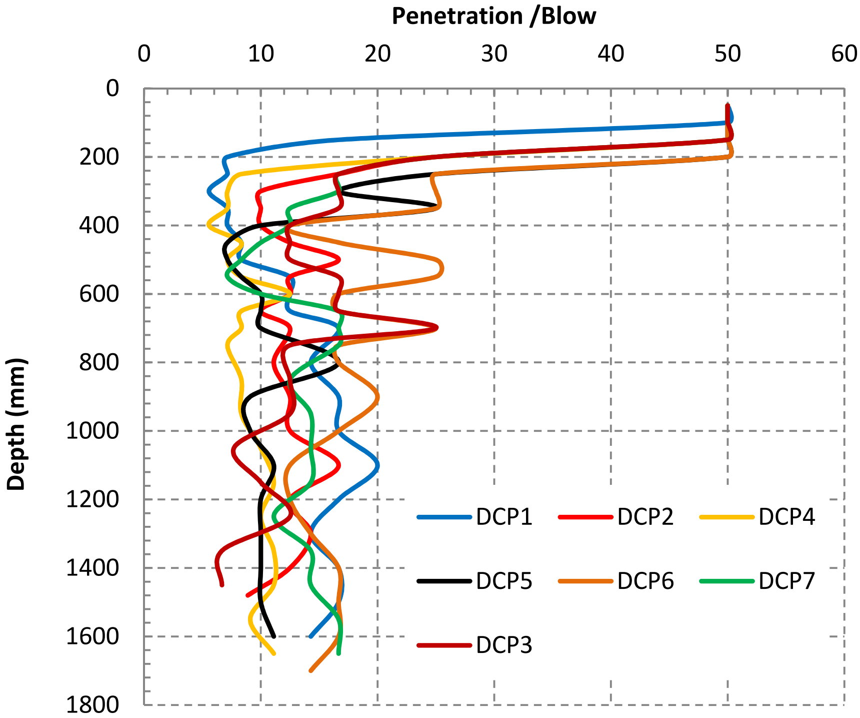


Figure 9: DCP results in terms of penetration (mm) per blow against depth

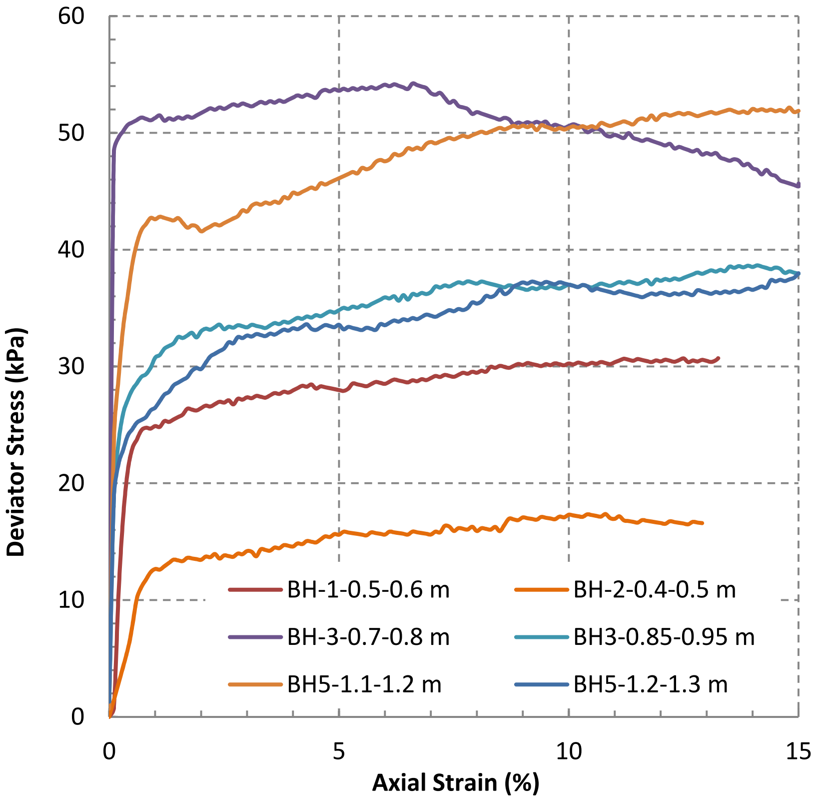


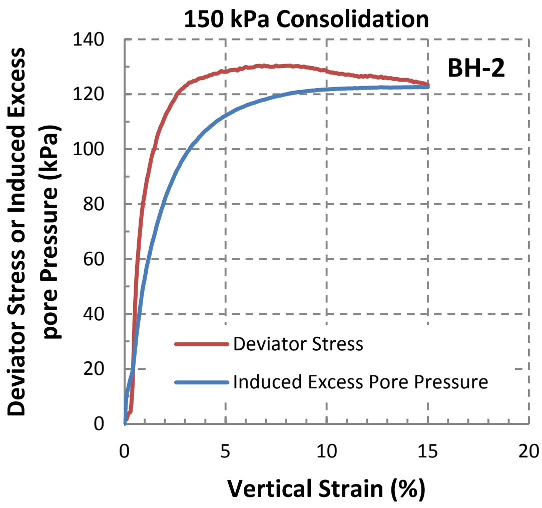
Figure 10: Deviator stress vs axial strain from UU triaxial tests

Table 2: Triaxial UU tests results

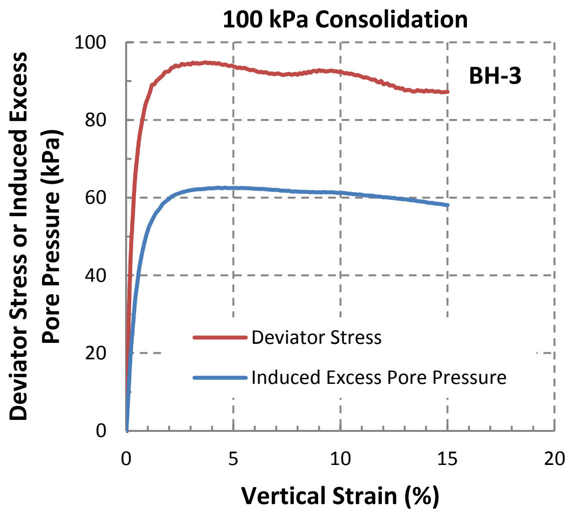
BH	Depth (mm)	Undrained Shear Strength (kPa)	Layer
1	500-600	16	Fill
2	400-500	8.5	Fill
3	700-800	27	Clay
3	850-950	19.5	Clay
5	1100-1200	26	Clay
5	1200-1300	18.5	Clay

Table 3: Triaxial CU tests results for samples at a depth of 500 to 1000 mm.

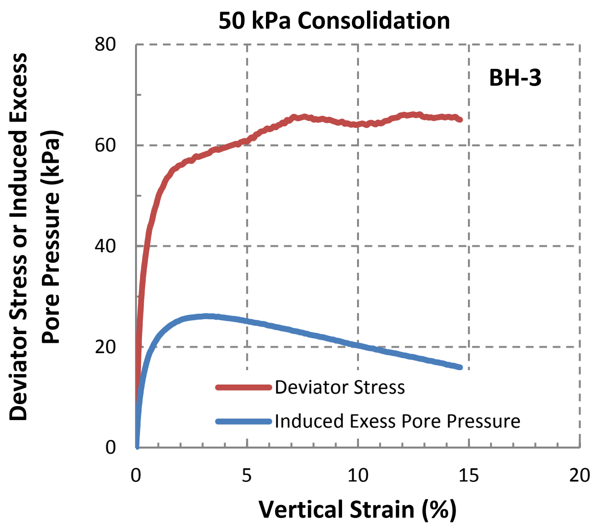
	Cohesion (kPa)	Internal Friction Angle (^{o})	Modulus of Elasticity, E_{50} (MPa)
Effective Strength Parameters	0	34	9 - 19
Total Strength Parameters	13	14	



(a)



(b)



(c)

Figure 11: Deviator stress and induced excess pore pressure from the CU triaxial test for (a) BH-2, 0.9-1 m, (b) BH-3, 0.5-0.6 m and (c) BH-3, 0.8-0.9 m

Field Test Program

The field loading test procedure used in this project conforms to the requirements of FHWA (2005), ASTM 1143 (1994) and D3689 (1990) for testing individual piles and micropiles under static axial compression and tension loads, with some modifications to suit the innovative and non-conventional aspects of the new Surefoot footing systems.

Pile design in terms of load capacity and settlement under service loads is usually based on empirical and semi-empirical methods using the results of a geotechnical investigation. These estimated values should then be confirmed by field pile load tests.

Since the primary goal of this project was to evaluate the ultimate bearing and pull-out capacities of the Surefoot footing system, the Quick Maintained Load Test Method (QM Test) procedure with some modification was selected as the most appropriate. This test method is fast and economical and only requires 3 to 5 hours for each test. It is important to note that this test method represents almost pure undrained conditions in the soil during failure and it cannot be used for estimating settlements.

The Quick Maintained Load Test Method (QM Test), as recommended by FHWA (2005) and ASTM 1143 (1994), consists of the following main steps:

(i) Load the pile in 20 increments to 300 per cent of the design load (i.e. each increment is equal to 15 per cent of the design load assuming a factor of safety of 3).

(ii) Maintain each load for a period of 5 minutes with readings taken every 2.5 minutes.

(iii) Add load increments until continuous jacking is required to maintain the test load (Failure Criteria).

(iv) After a 5 minute interval, remove the full load from the pile in four equal decrements with 5 minute intervals between decrements.

The slight modifications applied to this method for this project were (i) the increments of loading were around 10 per cent and each loading step was held for 15 minutes, and (ii) an additional creep stage of 10 minutes was added to the final stage of loading to investigate the soil/system sensitivity to the creep.

The ultimate failure load is defined when a sustained load causes the pile to plunge or settle rapidly. However, to achieve true plunging (i.e. ultimate failure) the vertical movements required may exceed the allowable recordable settlement of the system. Many engineers define the failure load mathematically as being at the point of intersection of the initial tangent to the load-settlement curve and the tangent to the extension of the final portion of the curve. These definitions for defining failure rely on engineering judgment of project engineers. The following interpretation methods to evaluate failure have been used in the past for analysing various pile load tests.

(i) Vander Veen's method (1953)
(i) Brinch Hansen's 90 per cent criterion (1963)
(ii) Brinch Hansen's 80 per cent criterion (1963)
(iii) De Beer's method (1967)
(iv) Fuller and Hoy's method (1970)
(v) Chin's method (1970, 1971)
(vi) Davisson's method (1972)
(vii) De Beer and Wallays' method (1972)
(viii) Mazurkiewicz's method (1972)
(ix) Butler and Hoy's method (1977)

It is worth mentioning that some of these methods are not applicable to the Surefoot system. However, the next section will discuss and analyse the test results and illustrate the ultimate capacity of the Surefoot footing system.

Creep tests are normally conducted as part of the ultimate, verification and/or proof tests. Creep is defined as a time dependent deformation of the soil/structure under a sustained constant loading. It could be considerable in organic and soft soils such as clays and young fine deposits. The creep test consists of measuring the movement of the pile under constant loading over a specified period of time. This test ensures that the footing system will maintain the service load throughout the life of the project without causing damage or failure. Creep-displacement criterion is usually defined as an allowable displacement of 2 mm per log cycle of time in minutes.

Micropiles are often designed to support tension and compression loads. In this condition, both loading condition should be tested. It is suggested that the tension test be performed prior to the compression test (FHWA, 2005). This will allow the system to reseat during early stages of compression testing in the event some net upward residual movement occurred during tension test.

Load-hold duration is another important consideration. If soil is not sensitive to creep such as sand, gravel or rock, the maximum test load may be held for only ten minutes. For piles in creep-sensitive soils, the maximum load hold duration may increase up to 100 minutes or even 24 hours depending on the type and magnitude of design loading, nature of the soil and type of the super-structure.

Appendix I provides details of the loading system.

Test Results

This project included four compression and four pull-out tests on four different Surefoot footings. Table 4 shows the program and details of the Surefoot systems tested.

Table 4: Details and testing program

Order Tested	Test Pile ID	Surefoot Description	No. of Micropiles	Length of Micropiles	Test Type
1	T1	SF100-1200	4	1200	Compression
2	T1	SF100-1200	4	1200	Pull-out
3	T2	SF100-1500	4	1500	Pull-out
4	T2	SF100-1500	4	1500	Compression
5	T3	SF300-1200	6	1200	Pull-out
6	T3	SF300-1200	6	1200	Compression
7	T4	SF300-1500	6	1500	Pull-out
8	T4	SF300-1500	6	1500	Compression

Note: Length of the micropiles listed is the total inclined length

First, the maximum bearing capacity and pull-out resistance of each system were predicted based on available design theory and results of the geotechnical investigation. From this, the loading increments were calculated. After reaching the ultimate load, a creep stage of 10 minutes was conducted to ascertain the system performance under sustained loading. Finally the system was unloaded in four steps.

It is common to conduct a compression and pull-out test on the one footing system. However, it is important to allow the soil to relax and reset between pull-out and compression test. This relaxation time depends on the type of soil, degree of saturation, water table level and the effective stress situation. Apart from the first Surefoot system (SF100-1200), all Surefoot systems were subjected to the pull-out test first and then the compression test according to FHWA (2005). This allowed the system to reseat during early stages of the compression testing in the event some net upward residual movement occurred during tension test. For this project with the consideration that the lengths of the micropiles were less than 2 m, it was decided that 2 to or 3 days would be sufficient time for the excess pore pressures to dissipate and the soil to reset.

All data sheets from the tests are provided in Appendix III.

Although it was mentioned previously that there are different failure criteria available for interpreting the field test results, the results showed that continuous jacking to maintain the test load was the best way to capture the ultimate capacity of the system. It is also worth mentioning that during the first compression test on the SF100-1200 Surefoot system, the screws that joined the surface plate to the pins failed first before the system reached its maximum bearing capacity. This issue was fixed by driving new screws with a 24 kN shearing capacity for the remaining Surefoot systems. After this remedial fix, the contact between the cap plate and pipes remained rigid and no further problems were observed for the following six tests. It should be also noted that all Surefoot top cap plates were place well above the ground level to avoid any contact between them and soil during the loading. This assures that the load applied is purely transferred to the soil through the micropiles

The settlement or upward movement of each main Surefoot system under load was measured using four digital Linear Variable Differential Transducers (LVDTs) with a travel of 50 mm located at 4 corners of the top cap. The support for each compression test was provided by four reaction Surefoot systems. To ensure that the reaction footings did not move significantly or experience pull-out failure, the movement of each reaction pile was also monitored using one LVDT. To limit any equipment or human error, an automatic backup system was employed to monitor the deformations in parallel to the primary measurements. This backup system consisted of five digital LVDTs connected to a GDS data logger. Applied loads to the system were measured by a 500 kN load cell with a portable readout unit. All measuring instruments were calibrated before starting the first test. Appendix II shows the detail of the load testing for each stage through a range of photos.

Figure 12 to Figure 19 show the load-settlement and creep plots for each test. These plots were used to determine the ultimate capacity of Surefoot system based on methods mentioned in previous section.

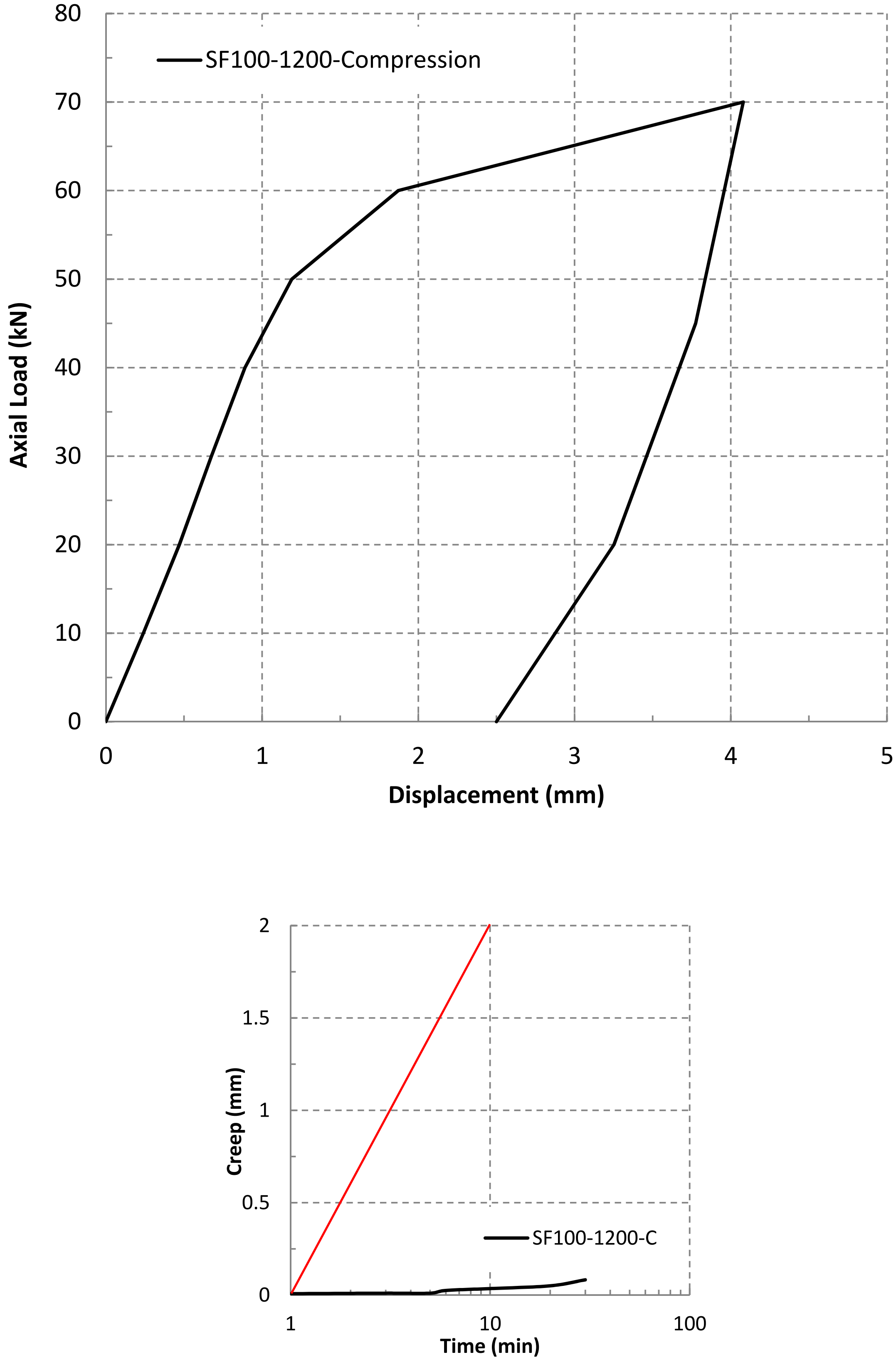


Figure 12: Compression test result for SF100-1200

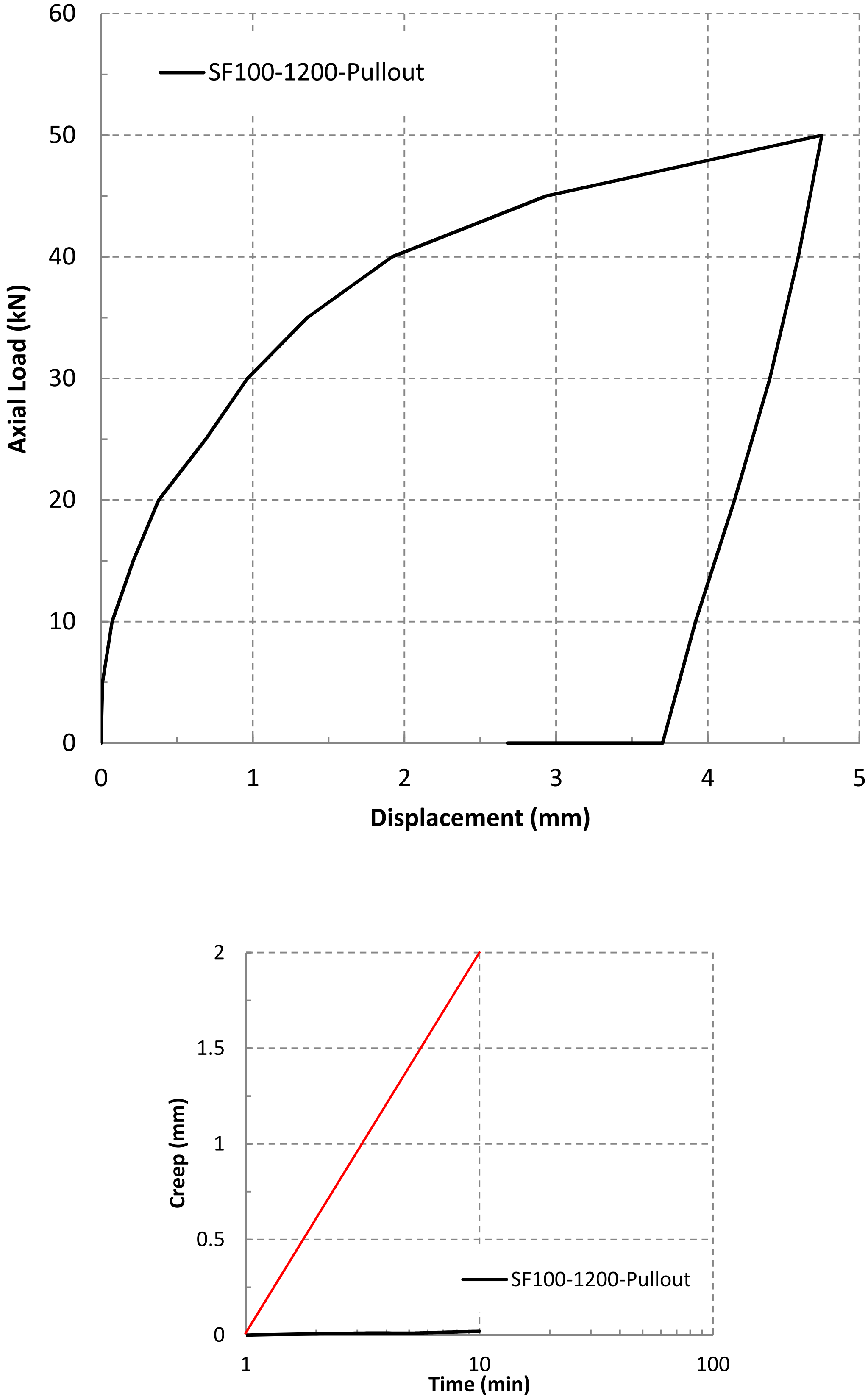
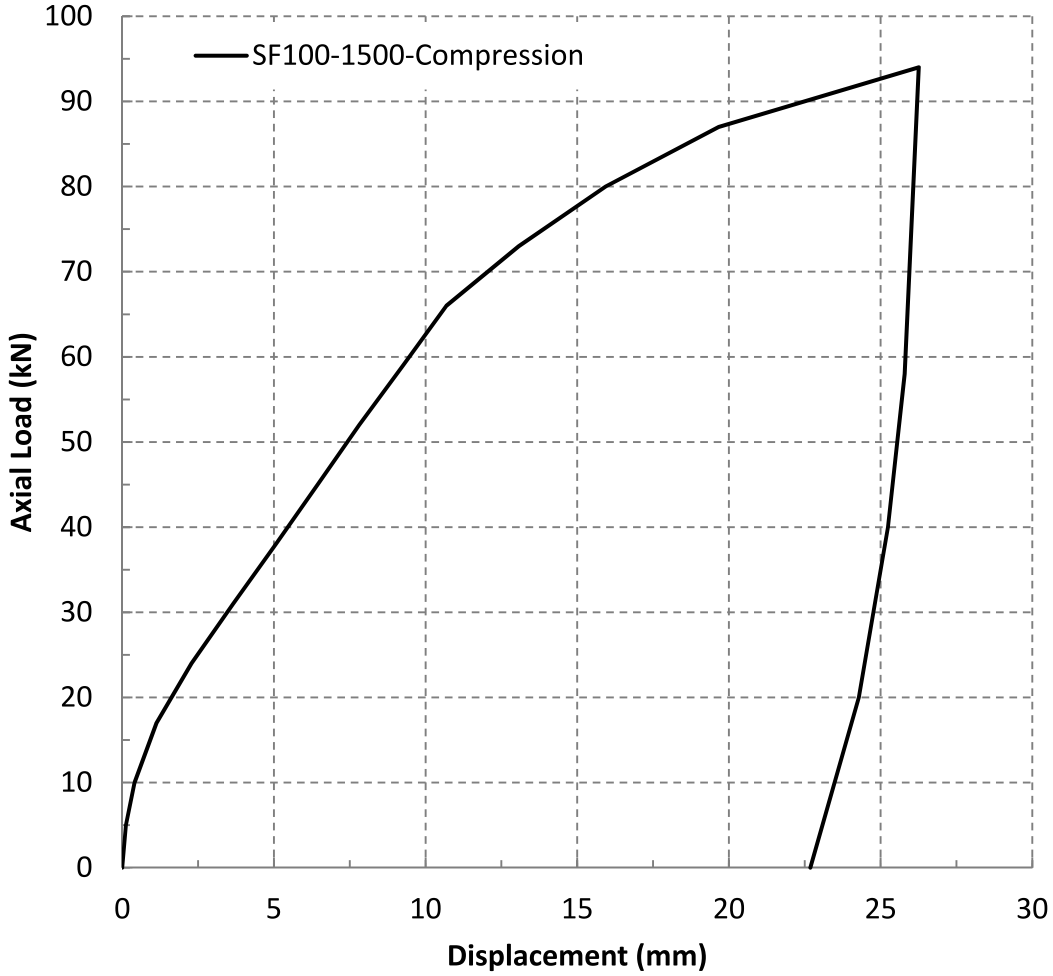


Figure 13: Pullout test result for SF100-1200



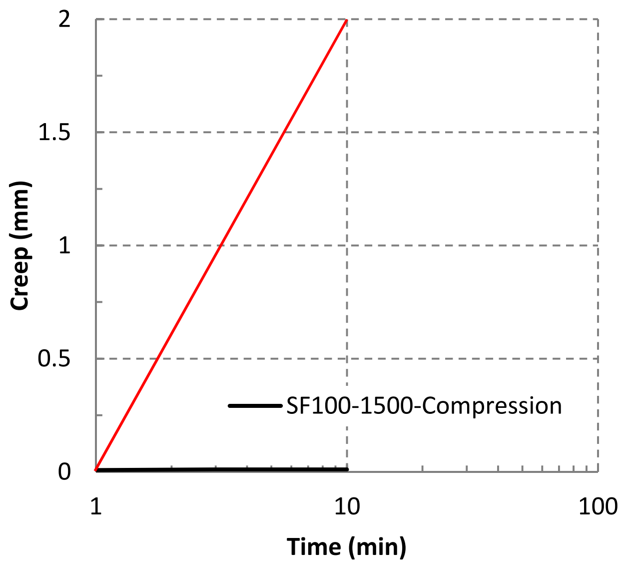
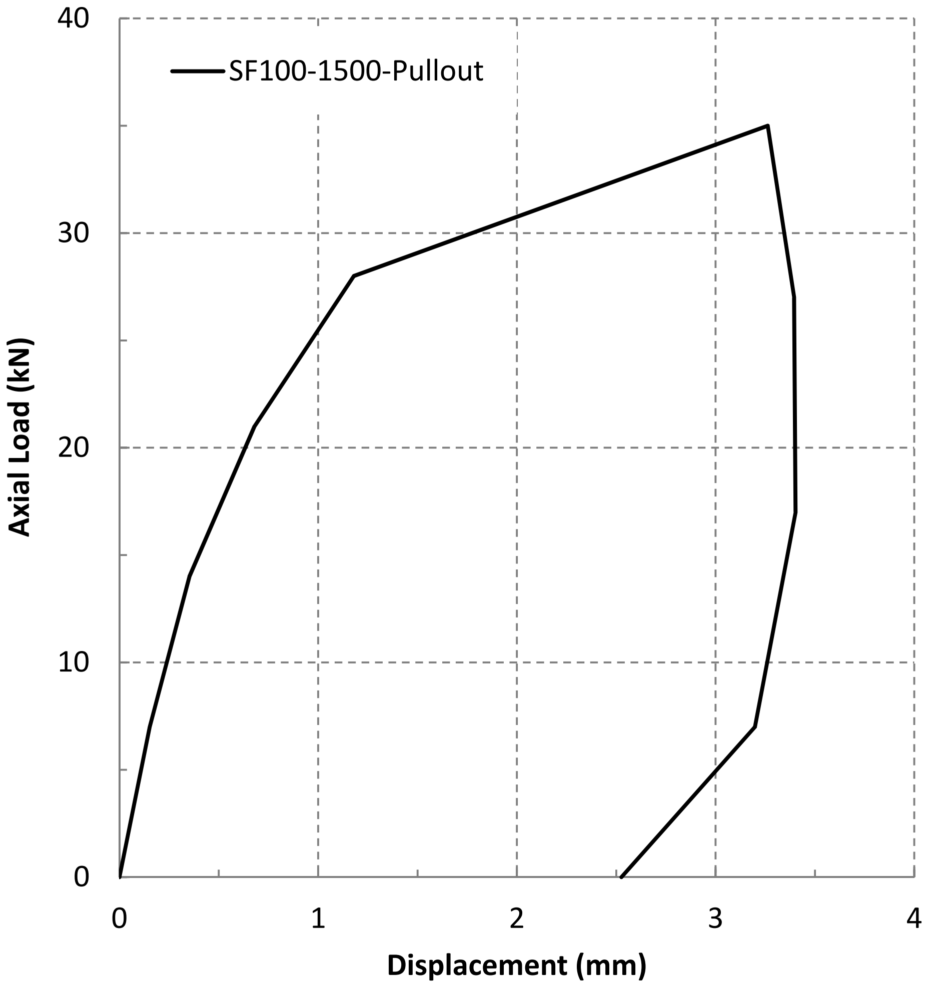


Figure 14: Compression test result for SF100-1500



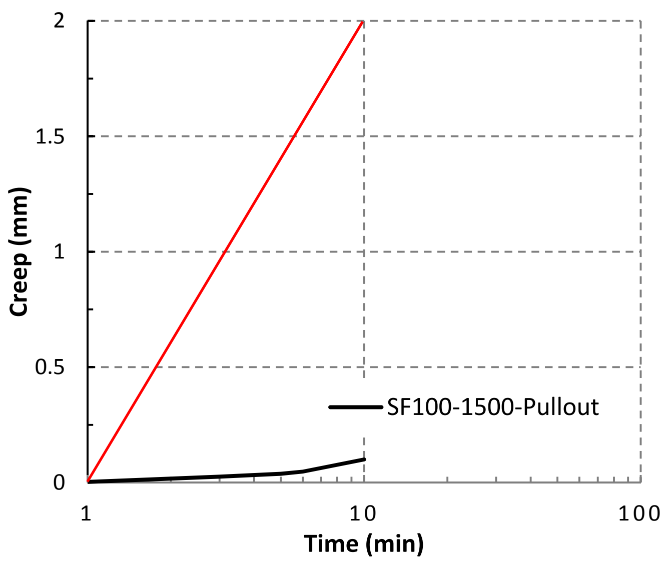


Figure 15: Pullout test result for SF100-1500

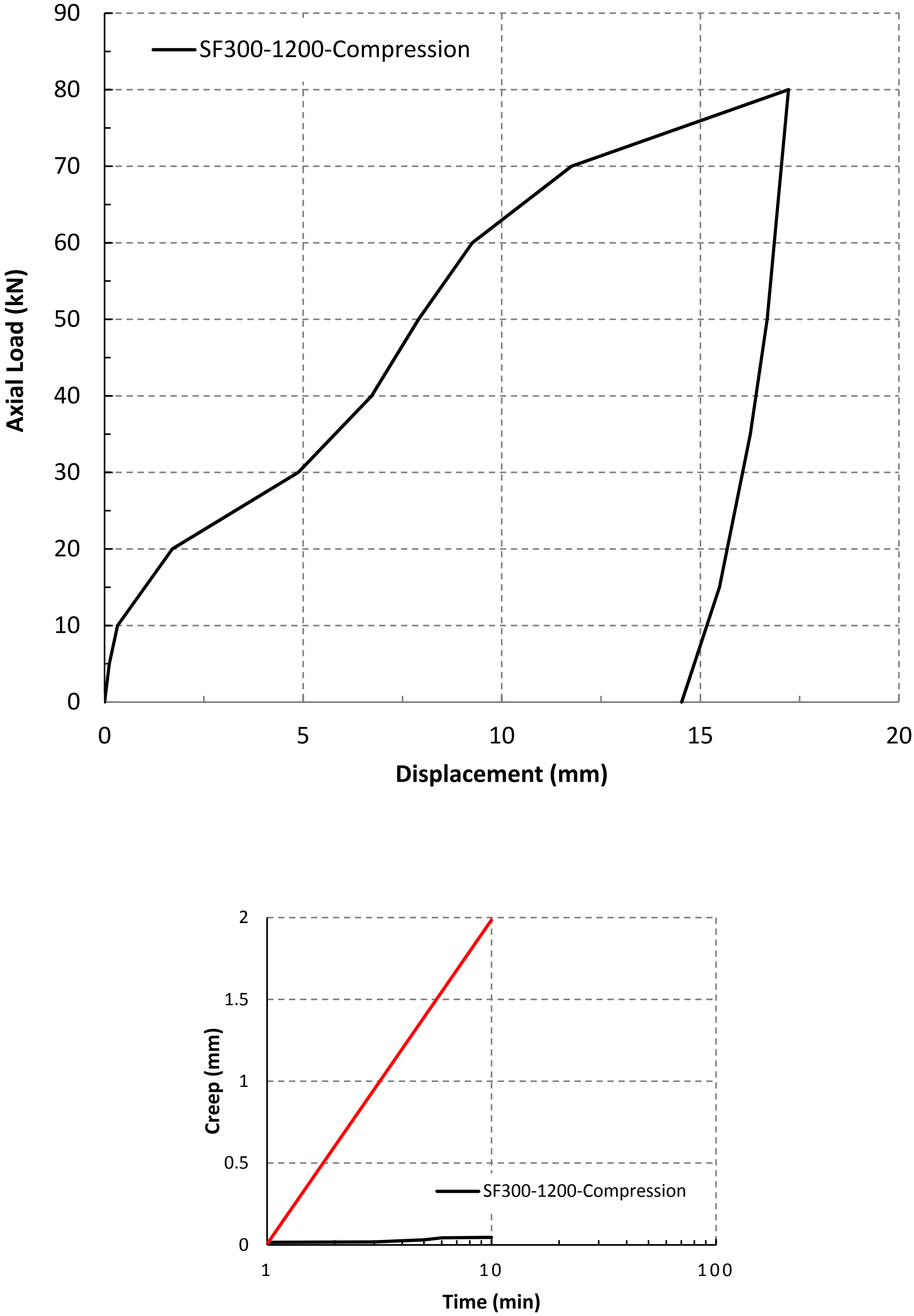
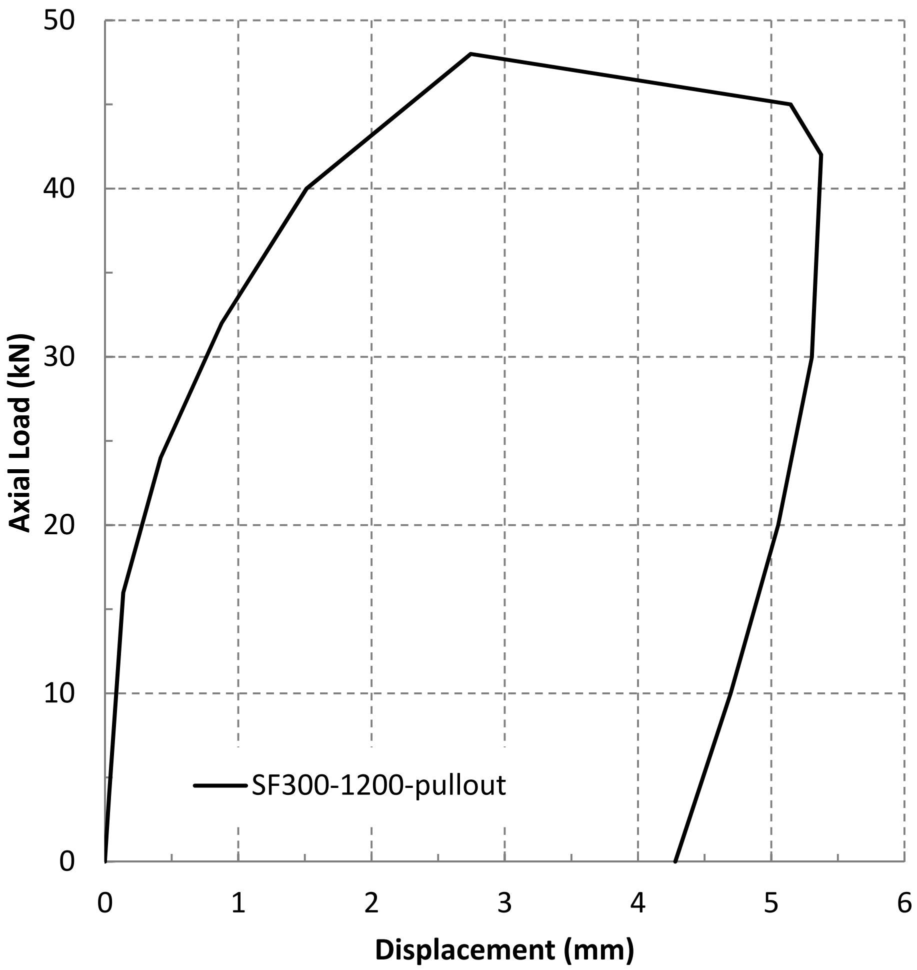


Figure 16: Compression test result for SF300-1200



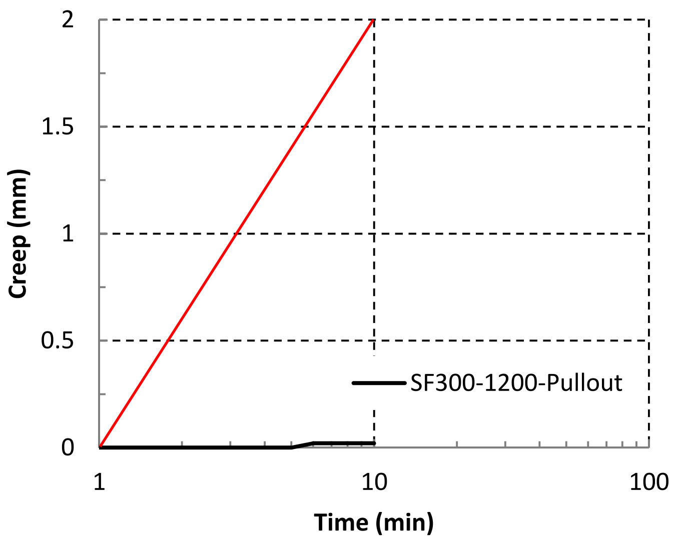


Figure 17: Pullout test result for SF300-1200

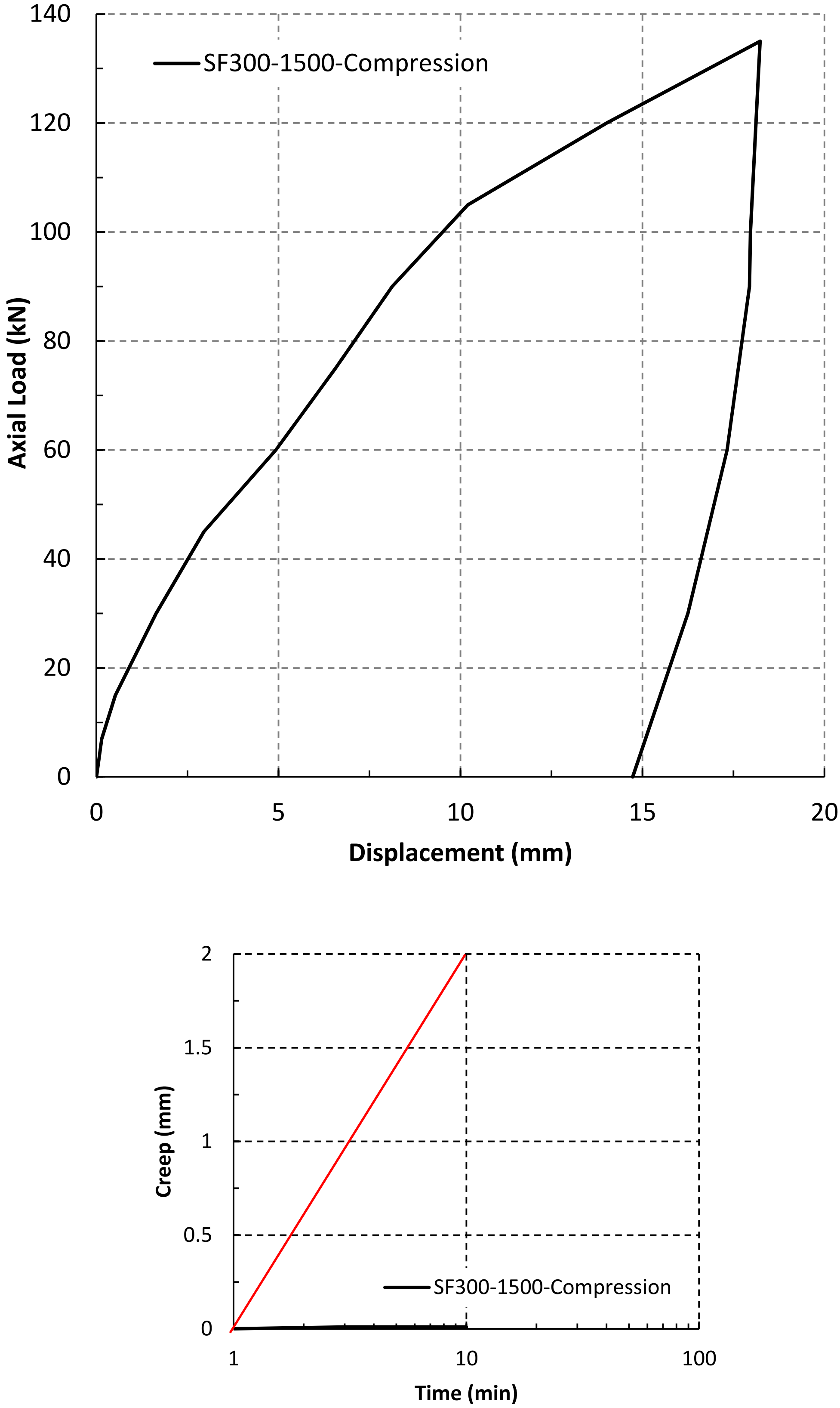
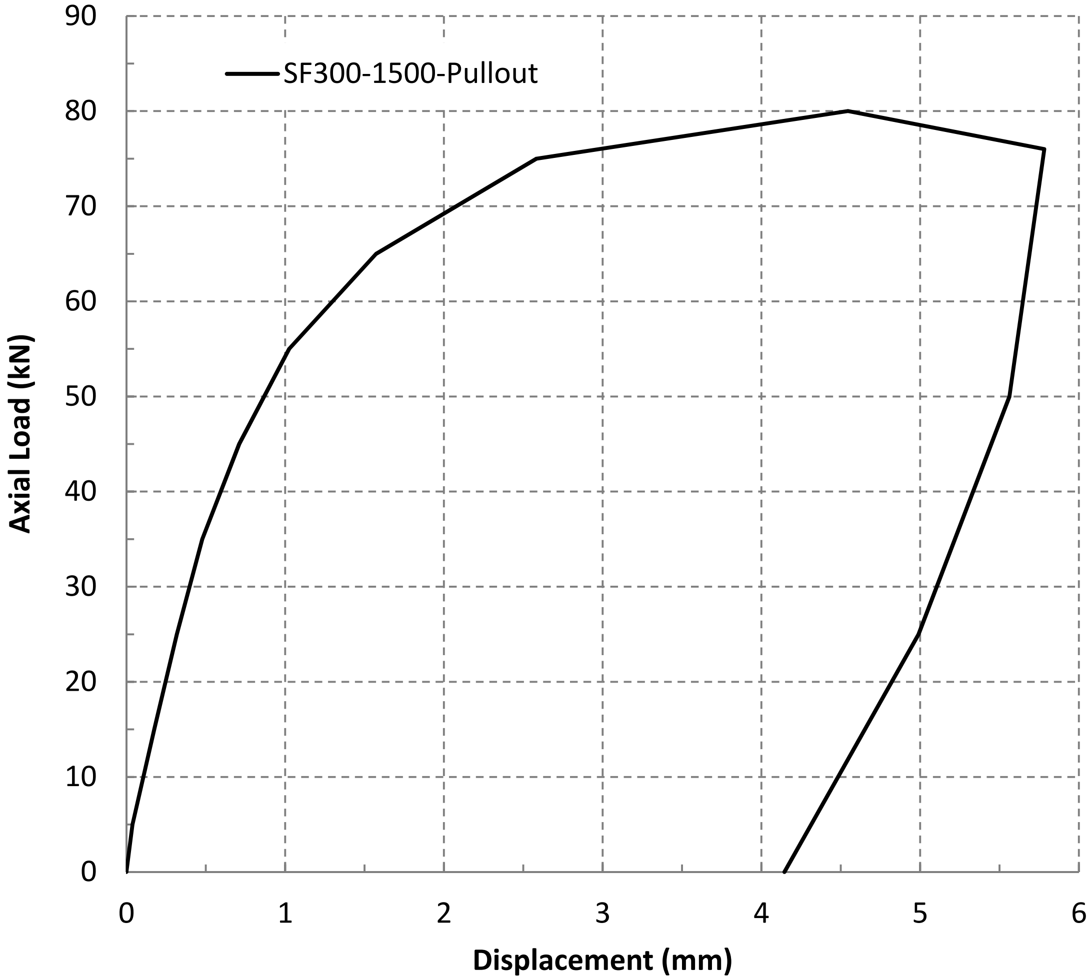


Figure 18: Compression test result for SF300-1500



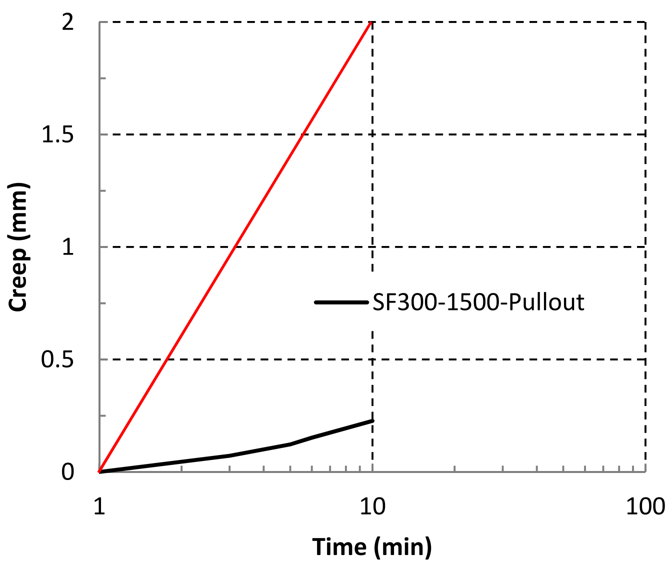


Figure 19: Pullout test result for SF300-1500

These test results show the identification of three distinct zones during compression loading for each test, except for the first one (SF100-1200-C). The first zone is related to reseating the system to compensate for the upward displacements due to the initial pull-out test. After this, the system shows greater strength and the slope of the loading zone increases. In the last zone, deformations start to increase again until the system reaches the ultimate capacity and eventual failure.

It was observed that 57 to 84 per cent of displacements were permanent after unloading which shows a considerable plastic deformation in the soil when ultimate bearing capacity was reached. In addition, measured creep settlements were well below the creep criteria.

Table 5 and Table 6 present the maximum and average ultimate bearing and pull out capacities of each tested system obtained using different methods. It is important to note that these ultimate bearing capacities are calculated for these Surefoot systems based on loading and soil conditions for this particular project.

Table 5: Analysis of ultimate bearing capacities

No.	Method	SF100 1200	SF100 1500	SF300 1200	SF300 1500
		Q (kN)	Q (kN)	Q (kN)	Q (kN)
1	Mazurkiewics (1972)	68	102	84	140
2	Fuller and Hoy's (1977)	60	-	50	90
3	Butler and Hoy's (1977)	58	-	45	75
4	Brinch Hansen's 80% Criterion (1963)	73	108	108	-
5	Chin-Konder Extrapolation (1971)	83	123	80	-
6	DeBeer (1968)	50	80	70	100

Table 6: Analysis of ultimate pull-out capacities

No.	Method	SF100 1200	SF100 1500	SF300 1200	SF300 1500
		Q (kN)	Q (kN)	Q (kN)	Q (kN)
1	Mazurkiewics (1972)	52	32	52	80
2	Fuller and Hoy's (1977)	40	28	40	75
3	Butler and Hoy's (1977)	32	23	32	62
4	Brinch Hansen's 80% Criterion (1963)	55	35	55	83
5	Chin-Konder Extrapolation (1971)	60	42	55	93
6	De Beer (1968)	40	28	20	65

Table 7 and Table 8 show the bearing and pull-out capacities of Surefoot system per number of micropiles and unit length of each micropile.

Table 7. Ultimate bearing and pull-out capacities of Surefoot system per number of pipe in Braybrook clay

(a) SF100 & SF300 (1200 mm embedment depth)

Surefoot Type	Number of micropiles (n)	Ultimate Bearing Capacity (Q) (kN)	Q/n (kN)
SF100-1200	4	73	18.25
SF300-1200	6	70	11.7
Surefoot Type	**Number of micropiles (n)**	**Ultimate Pull-out Capacity (Q) (kN)**	**Q/n (kN)**
SF100-1200	4	48	12
SF300-1200	6	43	7.2

(b) SF100 & SF300 (1500 mm embedment depth)

Surefoot Type	Number of micropiles (n)	Ultimate Bearing Capacity (Q) (kN)	Q/n (kN)
SF100-1500	4	95	23.75
SF300-1500	6	120	20
Surefoot Type	**Number of micropiles (n)**	**Ultimate Pull-out Capacity (Q) (kN)**	**Q/n (kN)**
SF100-1500	4	35	8.75
SF300-1500	6	78	13

Table 8. Ultimate bearing and pull-out capacities of Surefoot system per length of micropiles for 1200 & 1500 mm embedment depth in Braybrook clay

Surefoot Type	Total Length of micropiles (L) (m)	Ultimate Bearing Capacity (Q) (kN)	Q/L (kN/m)	Trend
SF100-1200	4.8	73	15.2	↑
SF100-1500	6	95	15.8	
SF300-1200	7.2	70	9.7	↑
SF300-1500	9	120	13.3	
Ave.	**6.75**	**89.5**	**13.25**	
Surefoot Type	**Total Length of micropiles (L) (m)**	**Ultimate Pullout Capacity (Q) (kN)**	**Q/L (kN/m)**	**Trend**
SF100-1200	4.8	48	10	↓
SF100-1500	6	35	5.8	
SF300-1200	7.2	43	6	↑
SF300-1500	9	78	8.7	
Ave.	**6.75**	**51**	**7.55**	

The results of the pull-out test on Surefoot footings SF100-1500 and SF300-1200 were below the expectation with respect to the other results. This was also the case for the compression test on footing SF300-1200. This may be due to variation in soil properties for that particular location or existence of an old structural element (i.e. a stump or part of an old footing) from the demolished building. Based on the limited test results, the following conclusions can be drawn.

- Although increasing the number of micropiles increases the overall ultimate capacity of the system, it seems that the ultimate capacity of each micropile decreases. This may be due to the group effect of reticulated micropiles, which needs further investigation.

- Overall, the ultimate pull-out capacity of the Surefoot system in Braybrook clay was around 57 per cent of the ultimate bearing capacity. This may change under different soil conditions. The ultimate bearing and pull-out capacities of each micropile with an embedment depth of 1.2 to 1.5 m in soils similar to Braybrook are about 13 and 7 kN/m length of micropile, respectively.

Design Philosophy

The Surefoot system does not fall into the conventional footing categories of shallow foundation; semi-deep or deep foundation. The unique shape of each Surefoot which contains four to ten inclined micropiles, makes the interaction of the system with surrounding soil complicated. This section provides a review of the current assumption and theory for designing Surefoot systems.

It is important to note that the concept presented here is solely developed to explain the noticeable bearing resistance experienced in the field testing of the Surefoot system in Braybrook Clay. Other phenomena such as the arching effect of soil, reinforcing effects of micropiles and the increased stiffness of soil confined by Surefoot micropiles has not been considered in this report. Due to the layout of micropiles in the Surefoot system, including spacing, orientation and group effects, they may behave like reticulated micropiles.

Gravity Forces:

It seems that the combination of bearing capacity and skin friction of micropiles resist the gravity forces imposed on Surefoot system (Figure 20). The bearing capacity of each micropile can be estimated based on the bearing capacity of shallow foundations using methods developed by Terzaghi or Meyerhof. Skin friction (only on the outer wall of the pipes) can be estimated using available deep foundation or pull-out theory. Another resisting force is bearing capacity at the micropile tip. However, due to the small diameter of the micropiles, this capacity was not considered, which in turn provides some minor additional margin of safety.

Uplift or Pull-out Forces:

Surefoot systems may experience uplift or pull-out forces under wind loading. The resisting forces against upward active forces are believed to be the skin friction of each micropile plus the passive force (Figure 21).

Horizontal Forces:

When a Surefoot system experiences horizontal active forces, some micropiles act in compression and some in tension.

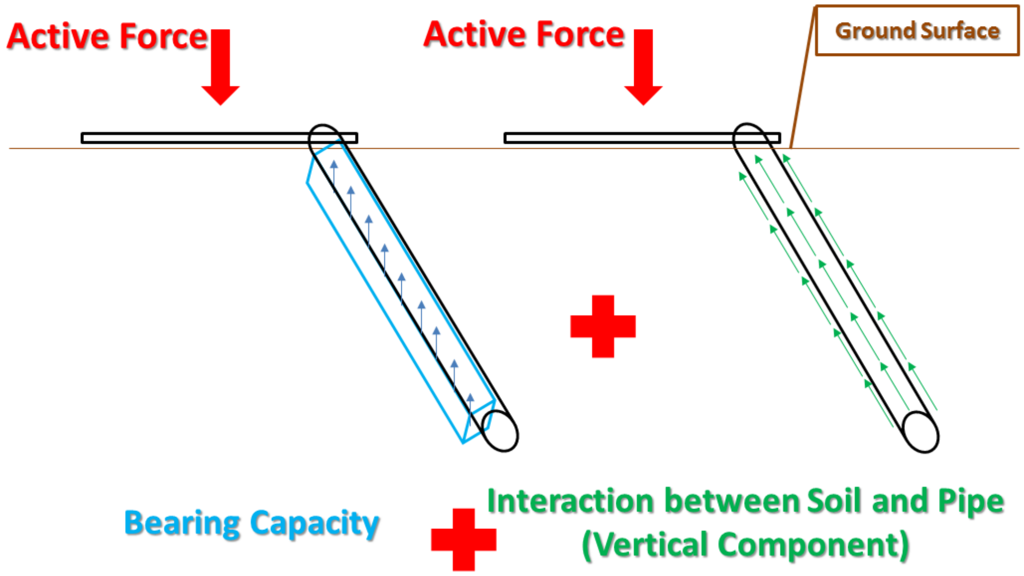


Figure 20: Resisting forces against the gravity active forces

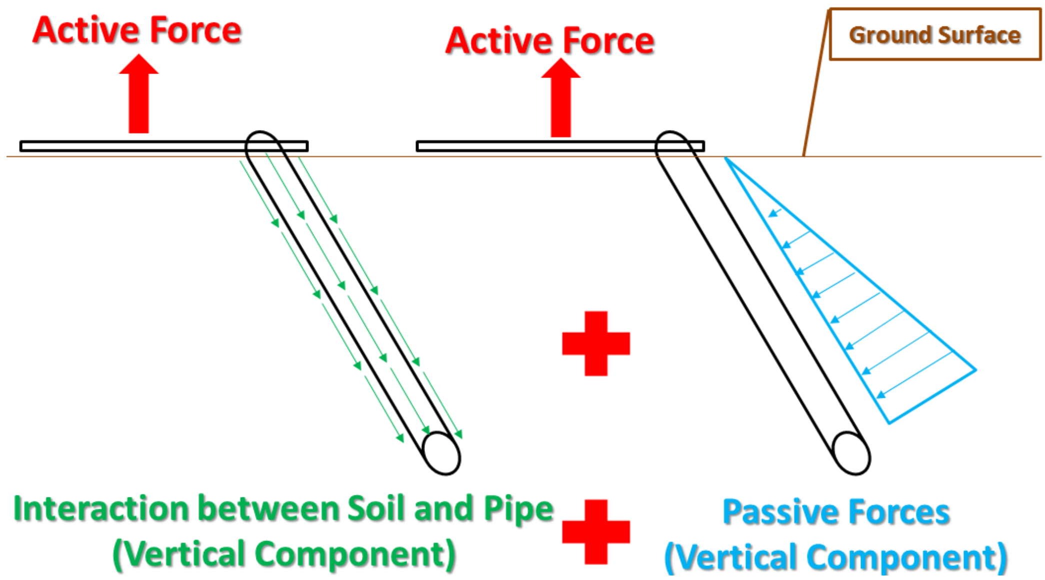


Figure 21: Resisting forces against the uplift or pull-out forces

To investigate the accuracy of the current theory, the ultimate bearing and pullout capacities of SF300-1500 under compression and tension loads are calculated and compared with the field results.

The bearing capacity, friction resistance and passive force of each micropile are calculated using Terzaghi, Meyerhof, λ and Rankine methods, respectively, considering two soil layers of fill (400 mm) and Braybrook clay with 12 and 22 kPa undrained shear strain respectively regardless of the local failure effects.

A) Terzaghi's Ultimate Bearing Capacity Equations:

$$q_{ult} = cN_c + qN_qS_qd_q + 0.5\gamma BN_\gamma \qquad (1)$$

where N_c, N_q and N_Υ are bearing capacity factors derived from earth pressure coefficients, which are dependent on the soil's friction angle, ϕ.

B) Meyerhof's Ultimate Bearing Capacity Equations (1963):

$$q_{ult} = cN_cS_cd_c + qN_qS_qd_q + 0.5\gamma B'N_\gamma S_\gamma d_\gamma \qquad (2)$$

Where: c is soil cohesion, $q = D_f$, D_f is embedment depth, B or B' is footing width and L is footing length.

$$N_q = e^{\pi tan\emptyset} tan^2\left(45 + {}^{\emptyset}/_{2}\right)$$

$$N_c = \left(N_q - 1\right)cot\emptyset$$

$$N_\gamma = \left(N_q - 1\right)\tan(1.4\emptyset)$$

$S_c = 1 + 0.2K_p\frac{B}{L}$; and $K_p = \frac{1+sin\emptyset}{1-sin\emptyset}$

$S_q = S_\gamma = 1 + 0.1K_p\frac{B}{L}$; $\quad S_q = S_\gamma = 1$ for $\emptyset = 0$

$$d_c = 1 + 0.2\sqrt{K_p}\frac{D}{B}$$

$d_q = d_\gamma = 1 + 0.1\sqrt{K_p}\frac{D}{B}$; $\quad d_q = d_\gamma = 1$ for $\emptyset = 0$

C) λ Method for Determining Frictional Resistance:

$$Q_{Shaft} = \sum f \times A_{Shaft} \qquad (3)$$

$$f = \lambda(\overline{\sigma'_{\mathrm{v}}} + 2c_u) \qquad (4)$$

Where: $\overline{\sigma'_{\mathrm{v}}}$ is mean effective vertical stress for the entire embedment length and λ is factor that varies with the length of pile. λ can be chosen from Figure 22.

D) Rankine's Passive Earth Pressure – Cohesive Soils:

$$\sigma_p = K_p\sigma_p + 2c\sqrt{K_p} \qquad (5)$$

Where: $K_p = \frac{1+sin\emptyset}{1-sin\emptyset}$

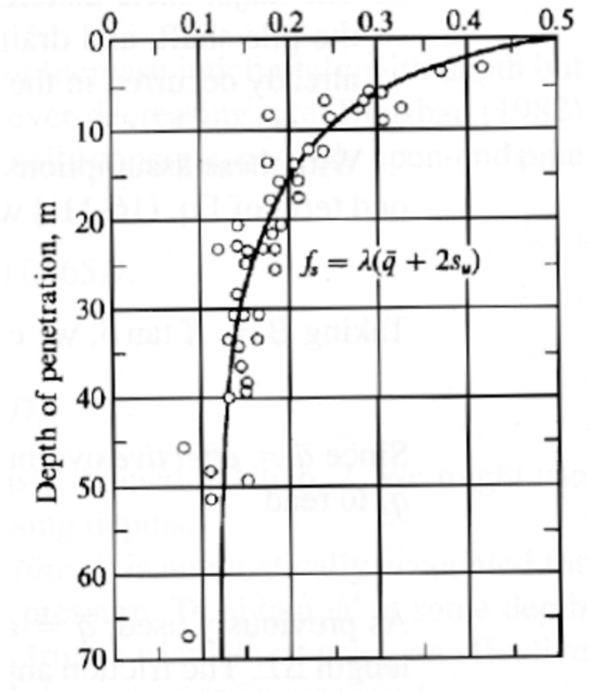


Figure 22. Variation of λ with pile embedment length (Das, 1995)

Table 9 shows the ultimate bearing and pullout capacities determined based on the current theory and the explained methods. It can be seen that Terzaghi's method is conservative while Meyerhof's method determine the ultimate bearing capacity higher than the measured value in the field. In this analysis, the ultimate capacity of Surefoot footing was determined based on the contribution of each micropile individually. It seems if the confining effect of micropiles as a group is also considered, the accuracy of calculation increases. Table 10 presents input parameters used for calculating the bearing capacities in this example.

Table 9. Ultimate bearing and pullout capacities of SF300-1500 based on the field data and design approach

				Determined Value		Measured Value	
Bearing Capacity Method	**Bearing Capacity (kN)**	**Skin Friction (kN)**	**Passive Forces (kN)**	**Ultimate Bearing Capacity (kN)**	**Ultimate Pullout Capacity (kN)**	**Field Bearing Capacity (kN)**	**Field Pullout Capacity (kN)**
Terzaghi	47.5	27.7	19.31	75.2	47.01	101	76
Meyerhof	182			209.7			

Table 10. Input soil properties for calculation of ultimate bearing and pullout capacities

Soil Layer	Thickness (m)	Internal Friction (ϕ), (˚)	Undrained Shear Strain (Su), (kPa)	Density (kN/m^3)	λ
Fill	0.4	0	12	17.4	0.45
Clay	0.4-1.36	0	23	17.4	0.45

Conclusion

The main aim of this research was to better understand the behaviour of the Surefoot system under vertical loading. Four compression and four pull-out tests were performed to evaluate the bearing capacity and pull-out resistance of two different sized Surefoot systems with different embedment depths. The results of the static tests were used to back analyse the ultimate capacity for each system using various methods.

The following points are of particular importance in terms of Surefoot performance:

- The significant resistance of Surefoot system against imposed loads obtained in the field tests is believed to come from a combination of skin friction of individual pipes, bearing resistance of soil underneath the piles and the passive resistance of soil under pull-out forces.
- Field test results revealed the identification of three distinct zones during compression loading for each test (except for the first load test where compression was performed before pull-out (SF100-1200-C). The first zone is related to reseating the system to compensate for the upward displacements due to the initial pull-out test. After this, the system showed greater strength and the slope of the loading zone increased. In the last zone, deformations increased again until the system reached ultimate capacity and eventual failure.
- Field results suggested that 57 to 84 per cent of displacements were permanent after unloading, which showed a considerable plastic deformation in the soil when ultimate bearing capacity was reached.
- Measured creep settlements were well below the creep criteria.
- Comparing field results of SF100 and SF300 suggest that although increasing the number of micropiles increases the overall ultimate capacity of the system, the ultimate capacity of each micropile seems to decrease. This may be due to the group effect of reticulated micropiles, which needs further investigation.
- Overall, the ultimate pull-out capacity of the Surefoot system in Braybrook clay was around 57 per cent of the ultimate bearing capacity. The ultimate bearing and pull-out capacities of each micropile with an embedment depth of 1.2 to 1.5 m in soils similar to Braybrook are about 13 and 7 kN/m length of micropile, respectively.
- Applying a reasonable factor of safety to the calculated ultimate bearing capacity of Surefoot is a viable alternative to assure safe performance of structures and limiting the settlement.

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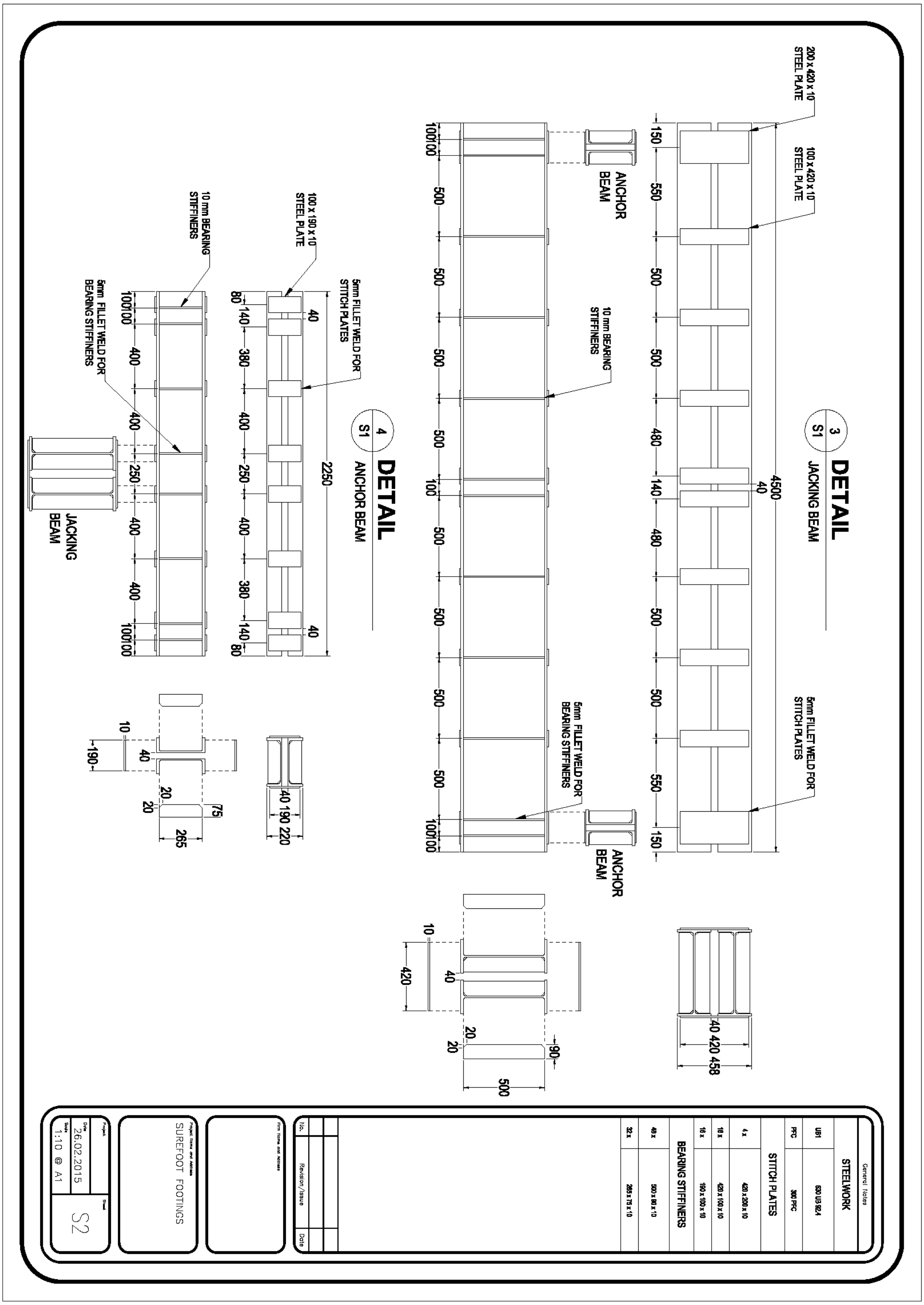
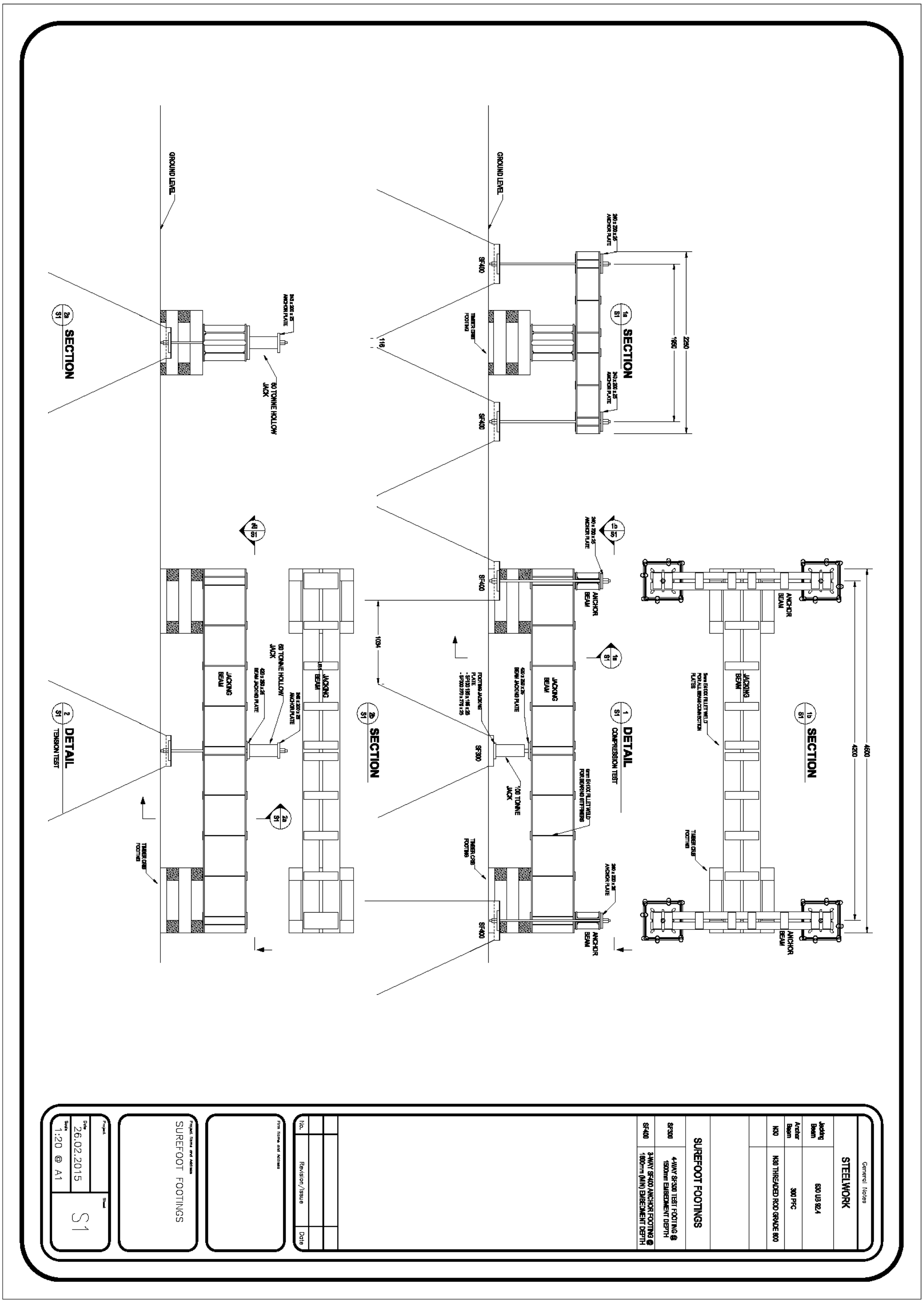
Appendix I. Field Test System Details

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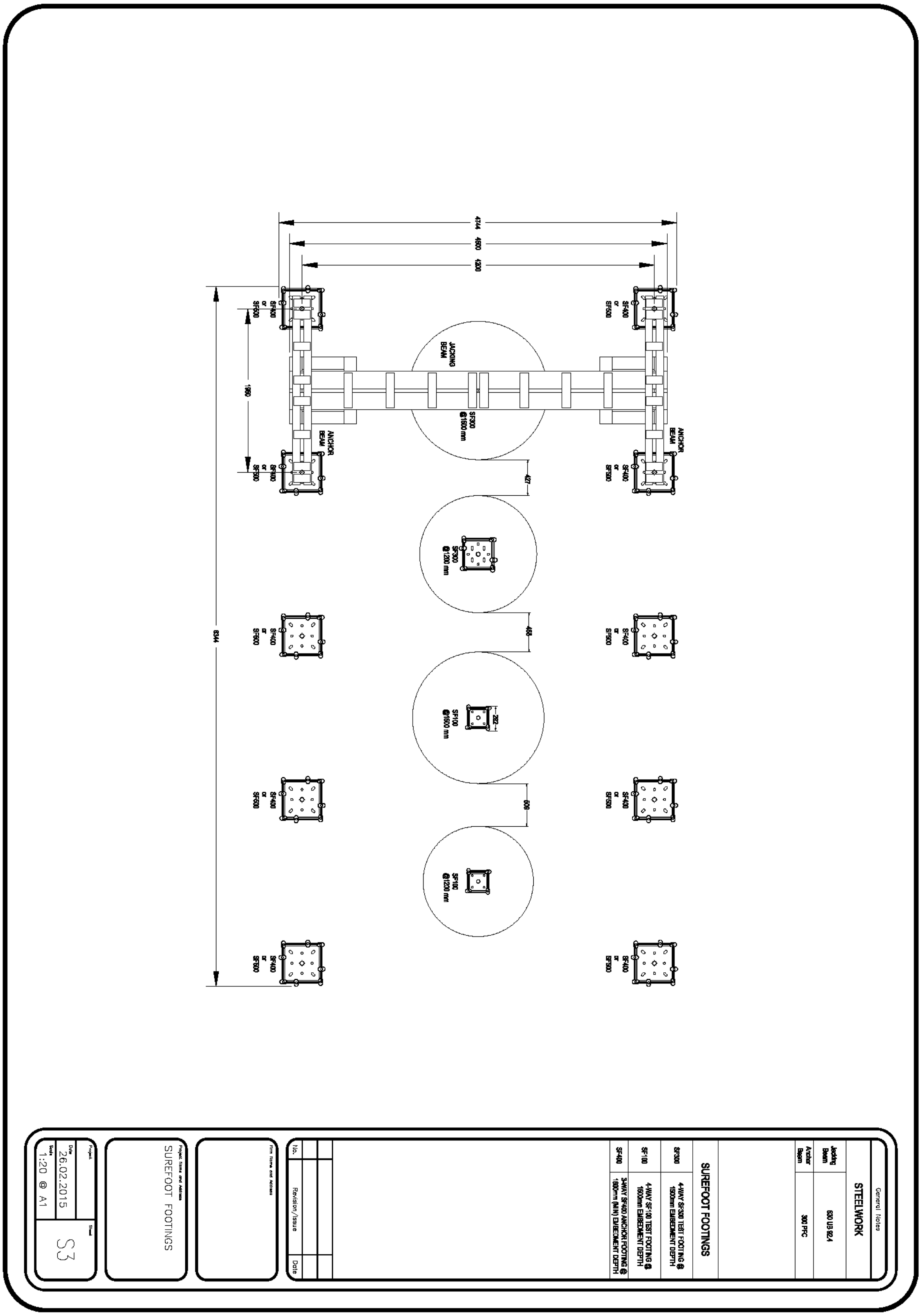
DETAIL
COMPRESSION TEST
TENSION TEST
GROUND LEVEL
STEELWORK
SUREFOOT FOOTINGS
26.02.2015
1:20 @ A1
S1


STEELWORK
SUREFOOT FOOTINGS
SUREFOOT FOOTINGS
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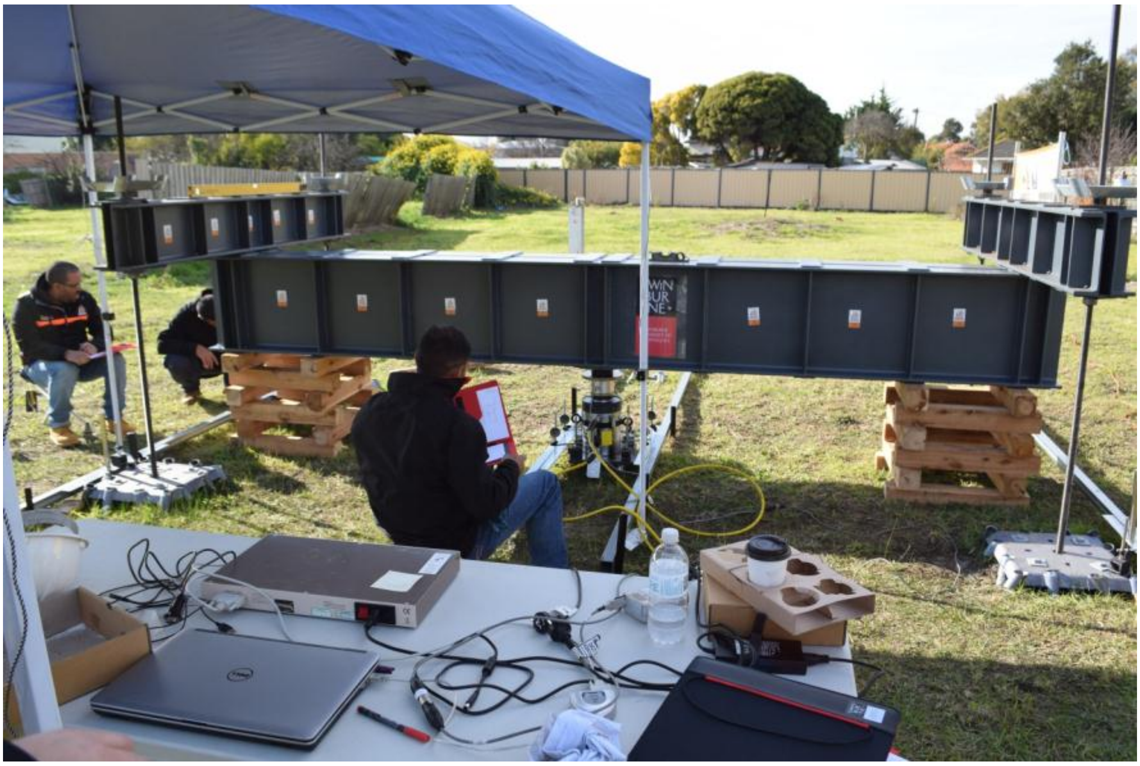
S3

Appendix II. Photos Album

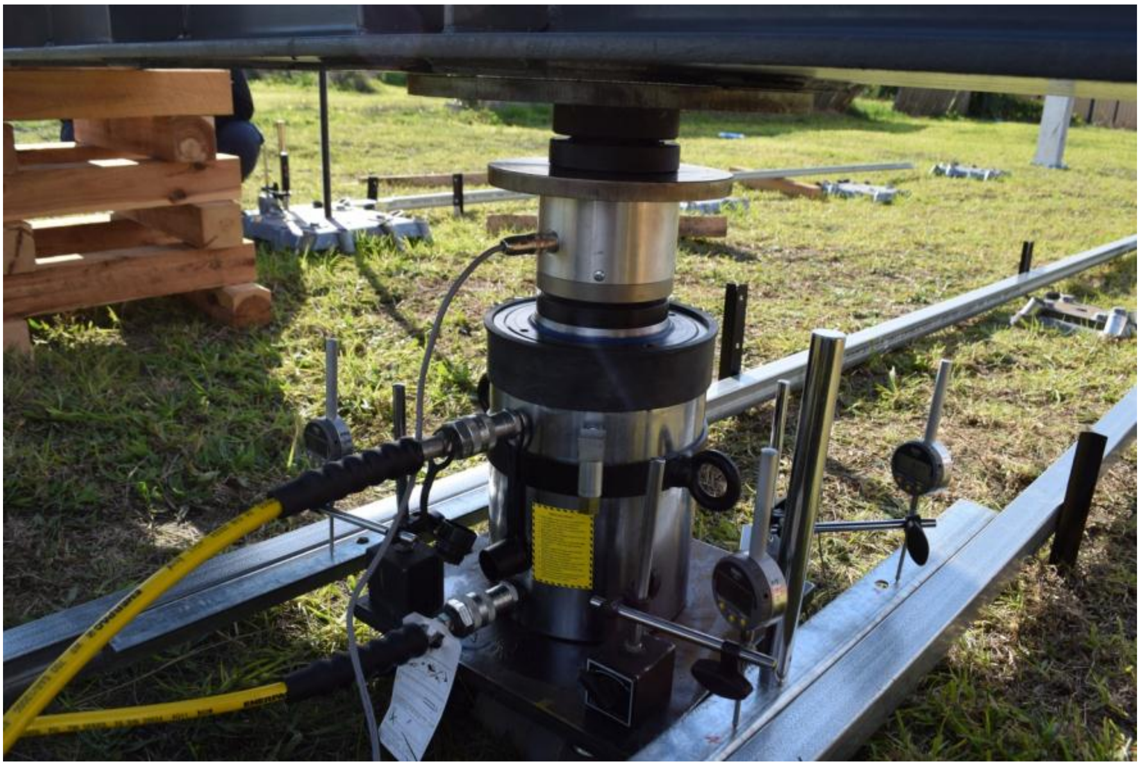
Site preparation prior to installation

Installation of reaction piles for field testing

Installation of reaction piles for field testing



Compression test in progress



Hydraulic jack, load cell, ball bearing and LVDTs

Reading reaction piles movement on each side

Hydraulic loading system and LVDTs mounting beams

Beams to mount LVDTs on

Hydraulic loading system and load cell screen

General view of test set-up in progress

Pull-out test set-up

Beam seating on timber cribs for pull-out test

LVDTs and the mounting beams for pull-out tests

Data logger and desktop used for data acquisition

Calcareous in the top layer of soil

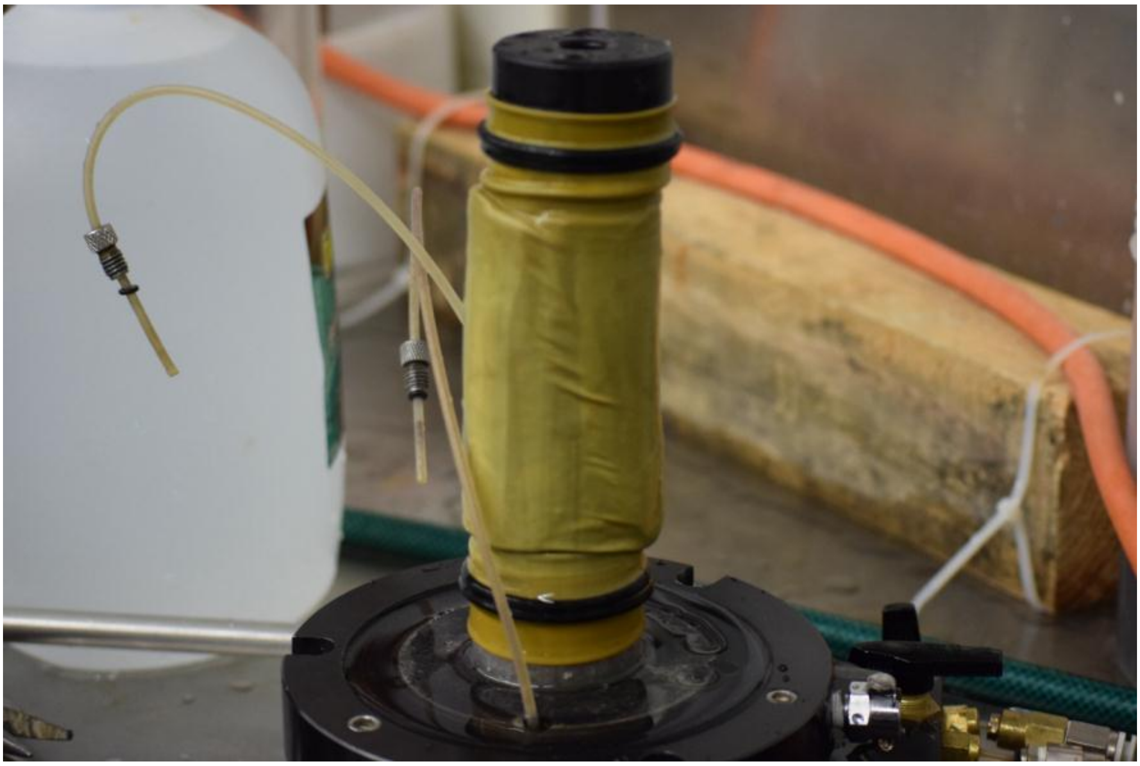
Braybrook clay

Shelby tubes and extracted specimen

Presence of organic matter in extracted clay specimen

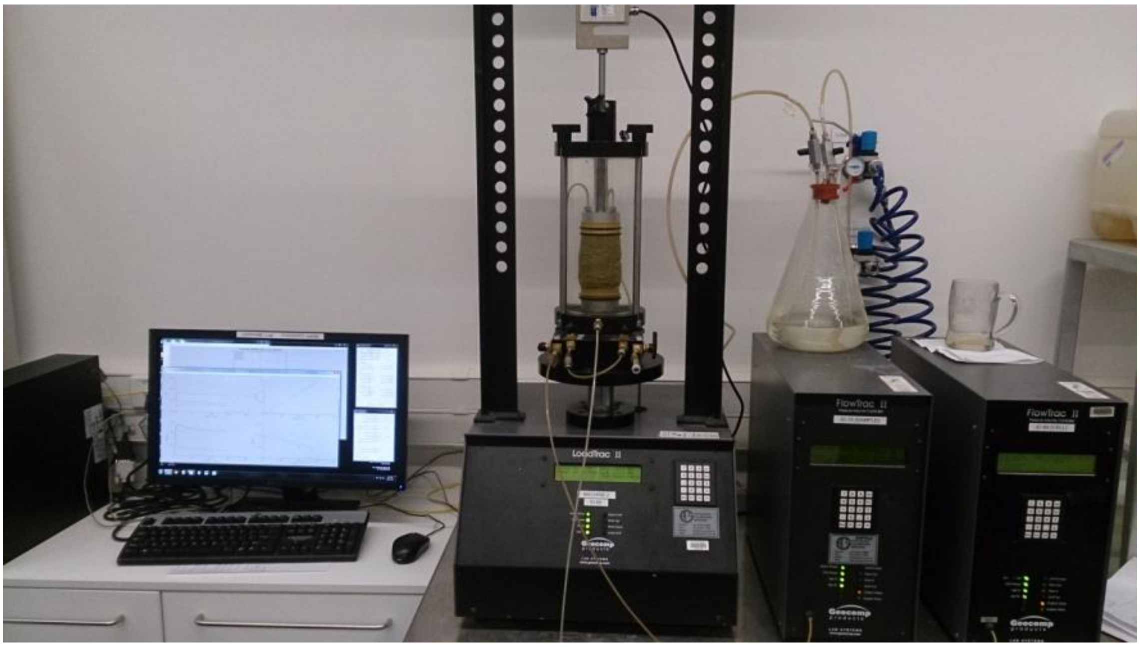
Extracted clay specimen from Shelby tubes

Extracted clay specimen from Shelby tubes



Braybrook clay specimen after triaxial shear strength test

Failure band on triaxial specimen of Braybrook clay



Automatic triaxial system during testing

Project team (Surefoot and Swinburne University of Technology staff)

Appendix III. Data Sheets

SWINBURNE UNIVERSITY OF TECHNOLOGY

Surefoot Footing Under Static Axial Compression Load

Quick Load Test Method :D3689/D3689M (Modified) **Supervisor:**

Date: **Start Time:** **Finish time:**

Footing System: SF 100 **Embedment Depth (m):** 1.3

Anticipated Failure Load (AFL) (kN): 100 **Weather:**

Hydraulic Jack: **Remarks:**

Anticipated Duration of Test Time(min): 180

Test Stage	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
1	5 (AL)	5		15 sec	0.08	0.1	0.17	0.11	0.115
2	10	10		0	0.15	0.2	0.32	0.21	0.22
2				2.5	0.15	0.21	0.32	0.21	0.2225
2				5	0.15	0.21	0.33	0.22	0.2275
2				7.5	0.15	0.21	0.33	0.21	0.225
2				10	0.16	0.22	0.35	0.23	0.24
3	10	20		0	0.35	0.43	0.6	0.42	0.45
3				2.5	0.36	0.43	0.61	0.43	0.4575
3				5	0.36	0.44	0.63	0.44	0.4675
3				7.5	0.37	0.44	0.63	0.44	0.47
3				10	0.37	0.44	0.63	0.44	0.47
4	10	30		0	0.5	0.61	0.81	0.58	0.625
4				2.5	0.52	0.63	0.84	0.6	0.6475
4				5	0.55	0.66	0.87	0.62	0.675
4				7.5	0.52	0.65	0.87	0.63	0.6675
4				10	0.55	0.66	0.87	0.62	0.675
5	10	40		0	0.7	0.84	1.08	0.78	0.85
5				2.5	0.73	0.88	1.11	0.8	0.88
5				5	0.74	0.89	1.12	0.81	0.89
5				7.5	0.74	0.89	1.12	0.82	0.8925
5				10	0.74	0.89	1.12	0.81	0.89
6	10	50		0	0.93	1.11	1.35	0.99	1.095
6				2.5	0.95	1.12	1.4	1.03	1.125
6				5	1	1.18	1.43	1.06	1.1675
6				7.5	1.02	1.2	1.46	1.08	1.19
6				10	1.02	1.2	1.46	1.08	1.19
7	10	60		0	1.32	1.66	1.98	1.47	1.6075
7				2.5	1.43	1.87	2.21	1.63	1.785
7				5	1.44	1.9	2.26	1.66	1.815
7				7.5	1.45	1.91	2.3	1.69	1.8375
7				10	1.48	1.95	2.34	1.72	1.8725
8	10	70		0	1.8	2.44	3	2.24	2.37
8				2.5	2.09	2.81	3.4	2.6	2.725
8				5	2.18	2.9	3.51	2.71	2.825
8				7.5	2.27	2.99	6.62	2.79	3.6675
8				10	2.32	3.05	3.68	2.84	2.9725

Surefoot Footing Under Static Axial Tension Load

Quick Load Test Method :D3689/D3689M (Modified)	**Supervisor:**
Date:	**Start Time:** **Finish time:**
Footing System: SF 100	**Embedment Depth (m):** 1.3
Anticipated Failure Load (AFL) (kN): 80	**Weather:**
Hydraulic Jack:	**Remarks:**
Anticipated Duration of Test Time(min): 180	

Test Stage	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
1	5 (AL)	5		40 sec	0.02	0	0.02	0	0.01
2	10	10		0	0.05	0.01	0.04	0.03	0.0325
2				2.5	0.06	0.01	0.05	0.04	0.04
2				5	0.06	0.01	0.05	0.04	0.04
2				7.5	0.06	0.03	0.08	0.04	0.0525
2				10	0.06	0.07	0.1	0.04	0.0675
2				15	0.06	0.07	0.11	0.05	0.0725
3	10	15		0	0.12	0.12	0.17	0.1	0.1275
3				2.5	0.15	0.14	0.2	0.11	0.15
3				5	0.16	0.16	0.22	0.13	0.1675
3				7.5	0.17	0.16	0.22	0.15	0.175
3				10	0.18	0.16	0.22	0.17	0.1825
3				15	0.25	0.15	0.22	0.23	0.2125
4	10	20		0	0.32	0.23	0.28	0.29	0.28
4				2.5	0.42	0.25	0.03	0.41	0.2775
4				5	0.42	0.26	0.32	0.41	0.3525
4				7.5	0.43	0.26	0.32	0.41	0.355
4				10	0.44	0.27	0.33	0.41	0.3625
4				15	0.44	0.3	0.35	0.43	0.38
5	10	25		0	0.56	0.41	0.46	0.54	0.4925
5				2.5	0.63	0.5	0.54	0.62	0.5725
5				5	0.65	0.5	0.54	0.65	0.585
5				7.5	0.71	0.53	0.56	0.68	0.62
5				10	0.7	0.69	0.66	0.69	0.685
5				15	0.72	0.69	0.66	0.69	0.69
6	10	30		0	0.82	0.74	0.73	0.77	0.765
6				2.5	0.91	0.81	0.8	0.85	0.8425
6				5	0.98	0.87	0.85	0.91	0.9025
6				7.5	1.02	0.91	0.88	0.93	0.935
6				10	1.03	0.91	0.9	0.96	0.95
6				15	1.03	0.93	0.93	0.97	0.965
7	10	35		0	1.17	1.07	1.05	1.1	1.0975
7				2.5	1.28	1.19	1.15	1.22	1.21
7				5	1.35	1.26	1.2	1.29	1.275
7				7.5	1.37	1.29	1.24	1.31	1.3025
7				10	1.41	1.31	1.25	1.35	1.33
7				15	1.46	1.32	1.27	1.39	1.36

Surefoot Footing Under Static Axial Tension Load

Quick Load Test Method :D3689/D3689M (Modified) **Supervisor:**

Date: **Start Time:** **Finish time:**

Footing System: SF 100 **Embedment Depth (m):** 1.3

Anticipated Failure Load (AFL) (kN): 80 **Weather:**

Hydraulic Jack: **Remarks:**

Anticipated Duration of Test Time(min): 180

Test Stage	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
8	10	40		0	1.63	1.49	1.43	1.56	1.5275
8				2.5	1.8	1.62	1.56	1.63	1.6525
8				5	1.94	1.67	1.61	1.88	1.775
8				7.5	1.97	1.72	1.65	1.91	1.8125
8				10	1.98	1.76	1.69	1.93	1.84
8				15	2.11	1.8	1.73	2.04	1.92
9	**10**	**45**		**0**	**2.29**	**1.98**	**1.9**	**2.24**	**2.1025**
9				**2.5**	**2.54**	**2.22**	**2.17**	**2.54**	**2.3675**
9				**5**	**2.77**	**2.39**	**2.35**	**2.72**	**2.5575**
9				**7.5**	**2.95**	**2.56**	**2.47**	**2.87**	**2.7125**
9				**10**	**3.04**	**2.65**	**2.55**	**2.97**	**2.8025**
9				**15**	**3.19**	**2.77**	**2.67**	**3.11**	**2.935**
10	10	50		0	3.6	3.15	3.06	3.56	3.3425
10				2.5	4.4	3.87	3.75	4.35	4.0925
10				5	4.68	4.11	3.99	4.61	4.3475
10				7.5	4.82	4.25	4.15	4.75	4.4925
10				10	4.88	4.36	4.26	4.84	4.585
10				15	5.06	4.5	4.41	5.04	4.7525
11	**10**	**55**		**0**					
11				**2.5**					
11				**5**					
11				**7.5**					
11				**10**					
11				**15**					
12	10	60		0					
12				2.5					
12				5					
12				7.5					
12				10					
12				15					
13	**10**	**65**		**0**					
13				**2.5**					
13				**5**					
13				**7.5**					
13				**10**					
13				**15**					

Surefoot Footing Under Static Axial Compression Load

Quick Load Test Method :D3689/D3689M (Modified)	**Supervisor:**	
Date:	**Start Time:**	**Finish time:**
Footing System: SF 100	**Embedment Depth (m):** 1.6	
Anticipated Failure Load (AFL) (kN): 150	**Weather:**	
Hydraulic Jack:	**Remarks:**	
Anticipated Duration of Test Time(min): 180		

Test Stage	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
1	5 (AL)	5		40 sec	0.08	0.12	0.18	0.11	0.1225
2	10	10		0	0.26	0.33	0.39	0.27	0.3125
2				2.5	0.31	0.39	0.44	0.3	0.36
2				5	0.32	0.4	0.45	0.31	0.37
2				7.5	0.32	0.4	0.46	0.33	0.3775
2				10	0.33	0.41	0.47	0.33	0.385
2				15	0.34	0.42	0.5	0.36	0.405
3	10	17		0	0.88	0.96	1	0.83	0.9175
3				2.5	1.03	1.09	1.13	0.96	1.0525
3				5	1.05	1.11	1.15	0.98	1.0725
3				7.5	1.06	1.12	1.16	0.99	1.0825
3				10	1.07	1.14	1.17	1	1.095
3				15	1.11	1.16	1.2	1.04	1.1275
4	10	24		0	1.85	1.9	2	1.83	1.895
4				2.5	2.06	2.08	2.2	2.04	2.095
4				5	2.13	2.14	2.26	2.1	2.1575
4				7.5	2.16	2.17	2.3	2.14	2.1925
4				10	2.18	2.19	2.32	2.16	2.2125
4				15	2.2	2.4	2.35	2.18	2.2825
5	10	31		0	3.08	3.1	3.29	3.17	3.16
5				2.5	3.45	3.44	3.63	3.5	3.505
5				5	3.52	3.51	3.69	3.57	3.5725
5				7.5	3.55	3.54	3.75	3.6	3.61
5				10	3.59	3.57	3.73	3.62	3.6275
5				15	3.62	3.6	3.76	3.65	3.6575
6	10	38		0	4.67	4.58	4.67	4.63	4.6375
6				2.5	4.97	4.87	4.93	4.89	4.915
6				5	5.04	4.92	4.99	4.97	4.98
6				7.5	5.09	4.97	5.02	5	5.02
6				10	5.1	4.98	5.03	5.01	5.03
6				15	5.14	5	5.06	5.05	5.0625
7	10	45		0	6.06	5.87	5.83	5.87	5.9075
7				2.5	6.47	6.23	6.14	6.19	6.2575
7				5	6.56	6.31	6.2	6.25	6.33
7				7.5	6.62	6.35	6.23	6.29	6.3725
7				10	6.64	6.37	6.25	6.32	6.395
7				15	6.7	6.44	6.28	6.35	6.4425

Surefoot Footing Under Static Axial Compression Load

Quick Load Test Method :D3689/D3689M (Modified) **Supervisor:**
Date: **Start Time:** **Finish time:**
Footing System: SF 100 **Embedment Depth (m):** 1.6
Anticipated Failure Load (AFL) (kN): 150 **Weather:**
Hydraulic Jack: **Remarks:**
Anticipated Duration of Test Time(min): 180

Test Stage	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
8	10	52		0	7.43	7.18	6.92	7.02	7.1375
8				2.5	7.89	7.59	7.22	7.34	7.51
8				5	8.01	7.7	7.31	7.42	7.61
8				7.5	8.08	7.77	7.37	7.49	7.6775
8				10	8.14	7.82	7.42	7.55	7.7325
8				15	8.23	7.92	7.49	7.62	7.815
9	10	59		0	8.88	8.59	8.13	8.29	8.4725
9				2.5	9.54	9.16	8.57	8.77	9.01
9				5	9.68	9.29	8.7	8.91	9.145
9				7.5	9.74	9.33	8.73	8.96	9.19
9				10	9.77	9.36	8.76	8.98	9.2175
9				15	9.82	9.4	8.79	9.02	9.2575
10	10	66		0	10.27	9.85	9.28	9.54	9.735
10				2.5	10.82	10.32	9.71	10.03	10.22
10				5	10.99	10.47	9.84	10.16	10.365
10				7.5	11.21	10.66	10.07	10.4	10.585
10				10	11.24	10.68	10.08	10.42	10.605
10				15	11.34	10.78	10.14	10.49	10.6875
11	10	73		0	12.07	11.49	10.81	11.26	11.4075
11				2.5	12.87	12.25	11.53	11.92	12.1425
11				5	13.12	12.49	11.77	12.16	12.385
11				7.5	13.27	12.64	11.95	12.35	12.5525
11				10	13.36	12.73	12.02	12.41	12.63
11				15	13.58	13.94	12.19	12.59	13.075
12	10	80		0	14.49	14.15	13.4	13.84	13.97
12				2.5	15.66	14.97	14.25	14.71	14.8975
12				5	16.12	15.4	14.62	15.09	15.3075
12				7.5	16.37	15.64	14.9	15.39	15.575
12				10	16.5	15.75	15.07	15.55	15.7175
12				15	16.75	15.97	15.26	15.77	15.9375
13	10	87		0	18.13	17.19	16.71	17.25	17.32
13				2.5	19.03	17.42	17.74	18.32	18.1275
13				5	19.66	17.56	18.44	19.04	18.675
13				7.5	20.28	17.68	19.23	19.85	19.26
13				10	20.79	17.78	19.71	20.36	19.66
13				15	20.79	17.78	19.71	20.36	19.66

Surefoot Footing Under Static Axial Compression Load

Quick Load Test Method : D3689/D3689M (Modified) | **Supervisor:**
Date: | **Start Time:** | **Finish time:**
Footing System: SF 100 | **Embedment Depth (m):** 1.6
Anticipated Failure Load (AFL) (kN): 150 | **Weather:**
Hydraulic Jack: | **Remarks:**
Anticipated Duration of Test Time(min): 180

Test Stage	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
14	10	94		0	22.79	21.63	22.91	22.58	22.4775
14				2.5	25.52	22.96	23.79	24.53	24.2
14				5	26.62	23.04	24.81	25.58	25.0125
14				7.5	27.4	23.8	25.56	26.31	25.7675
14				10	27.89	24.28	26.06	26.82	26.2625
14				15					
15				0					
15				2.5					
15				5					
15				7.5					
15				10					
15				15					
16				0					
16				2.5					
16				5					
16				7.5					
16				10					
16				15					
11				0					
11				2.5					
11				5					
11				7.5					
11				10					
11				15					
12				0					
12				2.5					
12				5					
12				7.5					
12				10					
12				15					
13				0					
13				2.5					
13				5					
13				7.5					
13				10					
13				15					

Surefoot Footing Under Static Axial Tension Load

Quick Load Test Method :D3689/D3689M (Modified) **Supervisor:**
Date: **Start Time:** **Finish time:**
Footing System: SF 100 **Embedment Depth (m):** 1.6
Anticipated Failure Load (AFL) (kN): 100 **Weather:**
Hydraulic Jack: **Remarks:**
Anticipated Duration of Test Time(min): 180

Test Stage	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
1	5 (AL)	3.5		40 sec	0	0	0	0	0
2	10	7		0	0.18	0.1	0.11	0.13	0.13
2				2.5	0.17	0.17	0.15	0.1	0.1475
2				5	0.17	0.17	0.15	0.13	0.155
2				7.5	0.18	0.16	0.15	0.13	0.155
2				10	0.18	0.16	0.15	0.13	0.155
2				15	0.18	0.16	0.14	0.13	0.1525
3	10	14		0	0.31	0.23	0.23	0.23	0.25
3				2.5	0.37	0.27	0.27	0.26	0.2925
3				5	0.40	0.3	0.29	0.3	0.3225
3				7.5	0.40	0.30	0.29	0.30	0.3225
3				10	0.41	0.30	0.29	0.31	0.3275
3				15	0.44	0.33	0.31	0.33	0.3525
4	10	21		0	0.61	0.53	0.48	0.51	0.5325
4				2.5	0.69	0.61	0.55	0.57	0.605
4				5	0.71	0.65	0.59	0.59	0.635
4				7.5	0.71	0.65	0.59	0.59	0.635
4				10	0.75	0.65	0.61	0.62	0.6575
4				15	0.76	0.69	0.63	0.64	0.68
5	10	28		0	0.96	0.91	0.82	0.82	0.8775
5				2.5	1.13	1.1	0.97	0.94	1.035
5				5	1.17	1.17	1.03	0.98	1.0875
5				7.5	1.22	1.2	1.06	1.03	1.1275
5				10	1.24	1.23	1.08	1.05	1.15
5				15	1.27	1.26	1.11	1.08	1.18
6	10	35		0	1.58	1.58	1.42	1.36	1.485
6				2.5	2.52	2.46	2.11	2	2.2725
6				5	3.29	3.1	3.76	2.9	3.2625
6				7.5					
6				10					
6				15					
7	10			0					
7				2.5					
7				5					
7				7.5					
7				10					
7				15					

Surefoot Footing Under Static Axial Tension Load

Quick Load Test Method :D3689/D3689M (Modified) **Supervisor:**

Date: **Start Time:** **Finish time:**

Footing System: SF 100 **Embedment Depth (m):** 1.6

Anticipated Failure Load (AFL) (kN): 100 **Weather:**

Hydraulic Jack: **Remarks:**

Anticipated Duration of Test Time(min): 180

Load Cycle	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
		27		0	3.29	3.1	3.76	2.9	3.2625
				1	3.29	3.11	3.76	2.9	3.265
				3	3.3	3.15	3.8	3	3.3125
				5	3.5	3.21	3.86	3.01	3.395
				6	3.8	3.28	3.93	3.03	3.51
				10	4.89	3.45	4.26	3.09	3.9225
				15					
				20					
	25	17		0	3.39	4.27	3.09	3.1	3.4625
				2.5	3.32	4.19	3.09	3.02	3.405
				5	3.31	4.19	3.09	3.02	3.4025
	25	7		0	3.01	3.9	3.09	2.69	3.1725
				2.5	2.92	4	3.09	2.9725	3.198125
				5	2.92	3.81	3.09	2.9725	3.198125
	25	0		0	2.12	2.95	3.09	2.2825	2.610625
				2.5	2.06	2.88	3.09	2.2425	2.568125
				5	2.03	2.86	3.09	2.2225	2.550625
				10	2.14	2.78	3.09	2.0925	2.525625

Surefoot Footing Under Static Axial Compression Load

Quick Load Test Method :D3689/D3689M (Modified)	**Supervisor:**
Date:	**Start Time:** **Finish time:**
Footing System: SF 300	**Embedment Depth (m):** 1.3
Anticipated Failure Load (AFL) (kN): 110	**Weather:**
Hydraulic Jack:	**Remarks:**
Anticipated Duration of Test Time(min): 180	

Test Stage	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
1	5 (AL)	5		30 sec	0.22	0.17	0.02	0.07	0.12
2	10	10		0	0.47	0.39	0.09	0.21	0.29
2				2.5	0.52	0.43	0.1	0.22	0.3175
2				5	0.53	0.45	0.1	0.22	0.325
2				7.5	0.54	0.42	0.1	0.23	0.3225
2				10	0.55	0.42	0.1	0.23	0.325
2				15	0.55	0.43	0.1	0.23	0.3275
3	10	20		0	1.69	1.43	1.17	1.32	1.4025
3				2.5	1.92	1.63	1.36	1.5	1.6025
3				5	1.96	1.66	1.4	1.54	1.64
3				7.5	1.99	1.68	1.42	1.56	1.6625
3				10	2.01	1.7	1.44	1.58	1.6825
3				15	2.03	1.72	1.46	1.61	1.705
4	10	30		0	4.45	4.12	4.1	4.12	4.1975
4				2.5	5.06	4.76	4.55	4.58	4.7375
4				5	5.12	4.81	4.6	4.64	4.7925
4				7.5	5.17	4.85	4.66	4.7	4.845
4				10	5.18	4.86	4.48	4.71	4.8075
4				15	5.2	4.88	4.7	4.73	4.8775
5	10	40		0	6.86	6.5	6.01	6.02	6.3475
5				2.5	7.2	6.78	6.19	6.23	6.6
5				5	7.26	6.83	6.22	6.27	6.645
5				7.5	7.3	6.86	6.25	6.31	6.68
5				10	7.32	6.88	6.28	6.34	6.705
5				15	7.35	6.91	6.29	6.35	6.725
6	10	50		0	8.23	7.8	7.04	7.09	7.54
6				2.5	8.45	8	7.25	7.28	7.745
6				5	8.5	8.05	7.31	7.33	7.7975
6				7.5	8.52	8.07	7.36	7.37	7.83
6				10	8.54	8.09	7.38	7.4	7.8525
6				15	8.58	8.13	7.45	7.46	7.905
7	10	60		0	9.26	8.88	8.26	8.2	8.65
7				2.5	8.52	9.16	8.62	8.51	8.7025
7				5	9.63	9.26	8.75	8.63	9.0675
7				7.5	9.69	9.31	8.82	8.71	9.1325
7				10	9.75	9.37	8.89	8.77	9.195
7				15	9.79	9.43	8.96	8.85	9.2575

Surefoot Footing Under Static Axial Compression Load

Quick Load Test Method :D3689/D3689M (Modified) **Supervisor:**
Date: **Start Time:** **Finish time:**
Footing System: SF 300 **Embedment Depth (m):** 1.3
Anticipated Failure Load (AFL) (kN): 110 **Weather:**
Hydraulic Jack: **Remarks:**
Anticipated Duration of Test Time(min): 180

Test Stage	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
8	10	70		0	10.57	10.34	9.94	9.8	10.1625
8				2.5	11.47	11.14	10.79	10.62	11.005
8				5	11.75	11.4	11.1	10.91	11.29
8				7.5	11.89	11.53	11.25	11.06	11.4325
8				10	12.01	11.66	11.37	11.19	11.5575
8				15	12.21	11.85	11.57	11.39	11.755
9	**10**	**80**		**0**	**13.93**	**13.63**	**13.47**	**13.42**	**13.6125**
9				**2.5**	**15.98**	**15.59**	**15.37**	**15.2**	**15.535**
9				**5**	**16.52**	**16.15**	**15.97**	**15.8**	**16.11**
9				**7.5**	**16.89**	**16.49**	**16.34**	**16.14**	**16.465**
9				**10**	**17.2**	**16.81**	**16.66**	**16.47**	**16.785**
9				**15**	**17.64**	**17.22**	**17.1**	**16.91**	**17.2175**
10				0					
10				2.5					
10				5					
10				7.5					
10				10					
10				15					
11				**0**					
11				**2.5**					
11				**5**					
11				**7.5**					
11				**10**					
11				**15**					
12				0					
12				2.5					
12				5					
12				7.5					
12				10					
12				15					
13				**0**					
13				**2.5**					
13				**5**					
13				**7.5**					
13				**10**					
13				**15**					

Surefoot Footing Under Static Axial Compression Load

Quick Load Test Method :D3689/D3689M (Modified)	**Supervisor:**
Date:	**Start Time:** **Finish time:**
Footing System: SF 300	**Embedment Depth (m):** 1.3
Anticipated Failure Load (AFL) (kN): 110	**Weather:**
Hydraulic Jack:	**Remarks:**
Anticipated Duration of Test Time(min): 180	

Load Cycle	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
		70		0	17.55	16.73	17.06	16.86	17.05
				1	17.56	16.74	17.08	16.88	17.065
				3	17.56	16.74	17.08	16.89	17.0675
				5	17.56	16.74	17.11	16.91	17.08
				6	17.57	16.75	17.13	16.92	17.0925
				10	17.57	16.75	17.14	16.92	17.095
				15					
				20					
	25	50		0	17.16	16.37	16.78	16.57	16.72
				2.5	17.14	16.36	16.77	16.56	16.7075
				5	17.13	16.34	16.73	16.53	16.6825
	25	35		0	16.81	16.06	16.41	16.22	16.375
				2.5	16.72	15.92	16.33	16.15	16.28
				5	16.7	15.91	16.3	16.12	16.2575
	25	15		0	16.02	15.23	15.7	15.63	15.645
				2.5	15.92	15.08	15.59	15.53	15.53
				5	15.89	15.04	15.52	15.47	15.48
	25	0		0	14.85	14.03	14.95	14.91	14.685
				5	14.78	13.97	14.83	14.8	14.595
				10	14.72	13.97	14.75	14.68	14.53
				15	14.72	13.97	14.75	14.68	14.53

Surefoot Footing Under Static Axial Tension Load

Quick Load Test Method :D3689/D3689M (Modified) **Supervisor:**
Date: **Start Time:** **Finish time:**
Footing System: SF 300 **Embedment Depth (m):** 1.3
Anticipated Failure Load (AFL) (kN): 80 **Weather:**
Hydraulic Jack: **Remarks:**
Anticipated Duration of Test Time(min): 180

Test Stage	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
1	5 (AL)	4		40 sec	0.08	0	0	0.05	0.0325
2	10	8		0	0.1	0	0	0.06	0.04
2				2.5	0.1	0	0	0.08	0.045
2				5	0.1	-0.02	-0.05	0.08	0.0275
2				7.5	0.11	-0.08	-0.1	0.08	0.0025
2				10	0.11	-0.13	-0.18	0.08	-0.03
2				15	0.11	-0.11	-0.13	0.08	-0.0125
3	10	16		0	0.3	-0.11	-0.12	0.22	0.0725
3				2.5	0.35	-0.1	-0.11	0.26	0.1
3				5	0.39	-0.1	-0.11	0.29	0.1175
3				7.5	0.39	-0.1	-0.11	0.2	0.095
3				10	0.39	-0.1	-0.1	0.3	0.1225
3				15	0.42	-0.1	-0.1	0.33	0.1375
4	10	24		0	0.65	0	0.01	0.55	0.3025
4				2.5	0.69	0.05	0.06	0.58	0.345
4				5	0.7	0.07	0.07	0.6	0.36
4				7.5	0.7	0.07	0.07	0.6	0.36
4				10	0.7	0.08	0.07	0.6	0.3625
4				15	0.79	0.08	0.09	0.71	0.4175
5	10	32		0	1	0.29	0.32	0.92	0.6325
5				2.5	1.07	0.34	0.37	0.99	0.6925
5				5	1.09	0.35	0.37	0.99	0.7
5				7.5	1.1	0.42	0.39	0.999	0.72725
5				10	1.15	0.44	0.45	1.07	0.7775
5				15	1.2	0.58	0.58	1.14	0.875
6	10	40		0	1.55	0.86	0.89	1.46	1.19
6				2.5	1.68	1.01	1.03	1.59	1.3275
6				5	1.72	1.03	1.05	1.63	1.3575
6				7.5	1.8	1.07	1.08	1.64	1.3975
6				10	1.81	1.12	1.1	1.66	1.4225
6				15	1.93	1.19	1.16	1.77	1.5125
7	10	48		0	3.29	2.12	2.21	3.36	2.745
7		45		2.5	5.88	4.65	4.44	5.61	5.145
7		42		5	6.07	4.91	4.73	5.79	5.375
7				7.5					
7				10					
7				15					

Surefoot Footing Under Static Axial Tension Load

Quick Load Test Method :D3689/D3689M (Modified) | **Supervisor:**
Date: | **Start Time:** | **Finish time:**
Footing System: SF 300 | **Embedment Depth (m):** 1.3
Anticipated Failure Load (AFL) (kN): 80 | **Weather:**
Hydraulic Jack: | **Remarks:**
Anticipated Duration of Test Time(min): 180

Load Cycle	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
		27		0	6.07	4.91	4.73	5.79	5.375
				1	6.07	4.91	4.73	5.79	5.375
				3	6.07	4.91	4.73	5.79	5.375
				5	6.07	4.91	4.73	5.79	5.375
				6	6.09	4.93	4.76	5.8	5.395
				10	6.09	4.92	4.77	5.8	5.395
				15					
				20					
	25	27		0	5.98	4.93	4.74	5.74	5.3475
				2.5	5.92	4.92	4.7	5.67	5.3025
				5	5.93	4.92	4.7	5.67	5.305
	25	20		0	5.75	4.76	4.51	5.48	5.125
				2.5	5.66	4.68	4.45	5.42	5.0525
				5	5.66	4.68	4.45	5.42	5.0525
	25	10		0	5.37	4.4	4.17	5.15	4.7725
				2.5	5.29	4.33	4.11	5.08	4.7025
				5	5.31	4.3	4.09	5.08	4.695
	25	0		0	5.02	4.01	3.8	4.76	4.3975
				5	4.93	3.95	3.75	4.71	4.335
				10	4.89	3.91	3.71	4.67	4.295
				15	4.9	3.88	3.67	4.67	4.28

Surefoot Footing Under Static Axial Compression Load

Quick Load Test Method :D3689/D3689M (Modified) **Supervisor:**
Date: **Start Time:** **Finish time:**
Footing System: SF 300 **Embedment Depth (m):** 1.6
Anticipated Failure Load (AFL) (kN): 180 **Weather:**
Hydraulic Jack: **Remarks:**
Anticipated Duration of Test Time(min): 180

Test Stage	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
1	5 (AL)	7		1 min	0.14	0.17	0.13	0.14	0.145
2	10	15		0	0.41	0.48	0.43	0.41	0.4325
2				2.5	0.45	0.53	0.5	0.47	0.4875
2				5	0.46	0.53	0.52	0.48	0.4975
2				7.5	0.47	0.54	0.53	0.49	0.5075
2				10	0.47	0.55	0.53	0.5	0.5125
2				15	0.48	0.55	0.54	0.51	0.52
3	10	30		0	1.33	1.54	1.42	1.35	1.41
3				2.5	1.47	1.67	1.53	1.46	1.5325
3				5	1.53	1.73	1.58	1.51	1.5875
3				7.5	1.53	1.75	1.59	1.52	1.5975
3				10	1.55	1.76	1.6	1.53	1.61
3				15	1.58	1.79	1.63	1.56	1.64
4	10	45		0	2.64	2.92	2.61	2.54	2.6775
4				2.5	2.83	3.11	2.77	2.71	2.855
4				5	2.87	3.15	2.8	2.75	2.8925
4				7.5	2.89	3.17	2.82	2.76	2.91
4				10	2.92	3.2	2.84	2.19	2.7875
4				15	2.94	3.22	2.85	2.8	2.9525
5	10	60		0	4.43	4.5	4.11	4.37	4.3525
5				2.5	4.99	4.87	4.43	4.81	4.775
5				5	5.09	4.96	4.52	4.93	4.875
5				7.5	5.11	4.98	4.54	4.96	4.8975
5				10	5.13	4.99	4.56	4.97	4.9125
5				15	5.14	5.01	4.57	4.99	4.9275
6	10	75		0	6.49	6.29	5.49	6.01	6.07
6				2.5	6.9	6.69	5.72	6.27	6.395
6				5	6.97	6.77	5.77	6.32	6.4575
6				7.5	7.03	6.83	5.82	6.37	6.5125
6				10	7.05	6.86	5.83	6.39	6.5325
6				15	7.09	6.9	5.86	6.41	6.565
7	10	90		0	8.5	8.2	6.59	7.34	7.6575
7				2.5	8.76	8.43	6.83	7.6	7.905
7				5	8.87	8.55	6.92	7.69	8.0075
7				7.5	8.88	8.56	6.95	7.73	8.03
7				10	8.91	8.6	6.99	7.76	8.065
7				15	8.99	8.67	7.02	7.81	8.1225

Surefoot Footing Under Static Axial Compression Load

Quick Load Test Method :D3689/D3689M (Modified) **Supervisor:**
Date: **Start Time:** **Finish time:**
Footing System: SF 300 **Embedment Depth (m):** 1.6
Anticipated Failure Load (AFL) (kN): 180 **Weather:**
Hydraulic Jack: **Remarks:**
Anticipated Duration of Test Time(min): 180

Test Stage	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
8	10	105		0	10.2	9.7	8.06	9.07	9.2575
8				2.5	10.64	10.06	8.44	9.54	9.67
8				5	10.83	10.23	8.62	9.74	9.855
8				7.5	10.92	10.3	8.7	9.84	9.94
8				10	11.02	10.37	8.79	9.94	10.03
8				15	11.4	10.47	8.88	10.06	10.2025
9	10	120		0	13.24	11.67	9.97	12.2	11.77
9				2.5	14.99	12.5	10.71	13.7	12.975
9				5	15.57	12.84	11.03	14.23	13.4175
9				7.5	15.86	13.03	11.23	14.52	13.66
9				10	16.64	13.16	11.35	14.69	13.96
9				15	16.37	13.14	11.57	14.99	14.0175
10	10	135		0	19.99	15.08	12.97	18.51	16.6375
10				2.5	20.81	15.55	13.18	19.2	17.185
10				5	21.16	15.79	13.32	19.5	17.4425
10				7.5	21.45	16.02	13.46	19.73	17.665
10				10	21.76	16.23	13.57	19.97	17.8825
10				15	22.34	16.44	13.75	20.4	18.2325
11				0					
11				2.5					
11				5					
11				7.5					
11				10					
11				15					
12				0					
12				2.5					
12				5					
12				7.5					
12				10					
12				15					
13				0					
13				2.5					
13				5					
13				7.5					
13				10					
13				15					

Surefoot Footing Under Static Axial Compression Load

Quick Load Test Method :D3689/D3689M (Modified) **Supervisor:**

Date: **Start Time:** **Finish time:**

Footing System: SF 300 **Embedment Depth (m):** 1.6

Anticipated Failure Load (AFL) (kN): 180 **Weather:**

Hydraulic Jack: **Remarks:**

Anticipated Duration of Test Time(min): 180

Load Cycle	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
		90		0	21.96	16.79	13.76	19.93	18.11
				1	21.96	16.79	13.76	19.93	18.11
				3	21.93	16.16	13.76	19.92	17.9425
				5	21.93	16.16	13.76	19.92	17.9425
				6	21.93	16.16	13.76	19.92	17.9425
				10	21.92	16.16	13.76	19.91	17.9375
				15					
				20					
	25	90		0	21.96	16.79	13.76	19.93	18.11
				2.5	21.945	16.475	13.76	19.925	18.02625
				5	21.93	16.16	13.76	19.92	17.9425
	25	60		0	21.4	15.61	13.4	19.33	17.435
				2.5	21.34	15.54	13.2	19.27	17.3375
				5	21.33	15.54	13.19	19.25	17.3275
	25	30		0	20.72	14.78	11.62	18.26	16.345
				2.5	20.63	14.7	11.53	18.19	16.2625
				5	20.63	14.69	11.51	18.16	16.2475
	25	0		0	19.74	13.54	9.85	16.44	14.8925
				5	19.63	13.44	9.68	16.27	14.755
				10	19.7	13.5	9.64	16.22	14.765
				15	19.68	13.48	9.59	16.17	14.73

Surefoot Footing Under Static Axial Tension Load

Quick Load Test Method :D3689/D3689M (Modified) | **Supervisor:**

Date: | **Start Time:** | **Finish time:**

Footing System: SF 300 | **Embedment Depth (m):** 1.6

Anticipated Failure Load (AFL) (kN): 150 | **Weather:**

Hydraulic Jack: | **Remarks:**

Anticipated Duration of Test Time(min): 180

Test Stage	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
1	5 (AL)	5		30 sec	0.02	0.04	0.04	0.05	0.0375
2	10	15		0	0.14	0.18	0.15	0.17	0.16
2				2.5	0.15	0.19	0.18	0.18	0.175
2				5	0.15	0.19	0.16	0.18	0.17
2				7.5	0.15	0.19	0.16	0.18	0.17
2				10	0.15	0.19	0.17	0.18	0.1725
2				15	0.15	0.19	0.17	0.19	0.175
3	10	25		0	0.29	0.37	0.24	0.28	0.295
3				2.5	0.3	0.38	0.24	0.29	0.3025
3				5	0.31	0.4	0.25	0.3	0.315
3				7.5	0.31	0.4	0.25	0.3	0.315
3				10	0.32	0.4	0.25	0.3	0.3175
3				15	0.31	0.41	0.25	0.3	0.3175
4	10	35		0	0.44	0.56	0.41	0.46	0.4675
4				2.5	0.44	0.56	0.42	0.47	0.4725
4				5	0.45	0.57	0.42	0.47	0.4775
4				7.5	0.45	0.57	0.42	0.47	0.4775
4				10	0.45	0.57	0.42	0.47	0.4775
4				15	0.45	0.57	0.42	0.47	0.4775
5	10	45		0	0.61	0.73	0.57	0.62	0.6325
5				2.5	0.62	0.74	0.61	0.64	0.6525
5				5	0.62	0.75	0.61	0.64	0.655
5				7.5	0.62	0.75	0.61	0.64	0.655
5				10	0.62	0.75	0.72	0.75	0.71
5				15	0.62	0.75	0.72	0.75	0.71
6	10	55		0	0.79	0.95	0.85	0.88	0.8675
6				2.5	0.86	1.06	0.89	0.92	0.9325
6				5	0.89	1.1	0.94	0.96	0.9725
6				7.5	0.91	1.12	1.01	1.01	1.0125
6				10	0.91	1.12	1.03	1.03	1.0225
6				15	0.91	1.13	1.03	1.03	1.025
7	10	65		0	1.1	1.39	1.4	1.36	1.3125
7				2.5	1.26	1.59	1.6	1.51	1.49
7				5	1.26	1.6	1.6	1.51	1.4925
7				7.5	1.28	1.62	1.61	1.51	1.505
7				10	1.31	1.66	1.63	1.53	1.5325
7				15	1.36	1.71	1.66	1.56	1.5725

Surefoot Footing Under Static Axial Tension Load

Quick Load Test Method :D3689/D3689M (Modified) | **Supervisor:**
Date: | **Start Time:** | **Finish time:**
Footing System: SF 300 | **Embedment Depth (m):** 1.6
Anticipated Failure Load (AFL) (kN): 150 | **Weather:**
Hydraulic Jack: | **Remarks:**
Anticipated Duration of Test Time(min): 180

Test Stage	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
8	10	75		0	1.98	2.32	2.19	2.19	2.17
8				2.5	2.3	2.62	2.48	2.48	2.47
8				5	2.37	2.7	2.54	2.53	2.535
8				7.5	2.39	2.73	2.58	2.55	2.5625
8				10	2.4	2.73	2.59	2.56	2.57
8				15	2.41	2.73	2.61	2.58	2.5825
9	10	80		0	2.84	3.18	3.07	3.06	3.0375
9				2.5	4.76	5.33	4.12	3.97	4.545
9				5					
9				7.5					
9				10					
9				15					
10	10			0					
10				2.5					
10				5					
10				7.5					
10				10					
10				15					
11	10			0					
11				2.5					
11				5					
11				7.5					
11				10					
11				15					
12	10			0					
12				2.5					
12				5					
12				7.5					
12				10					
12				15					
13	10			0					
13				2.5					
13				5					
13				7.5					
13				10					
13				15					

Surefoot Footing Under Static Axial Tension Load

Quick Load Test Method :D3689/D3689M (Modified) | **Supervisor:**
Date: | **Start Time:** | **Finish time:**
Footing System: SF 300 | **Embedment Depth (m):** 1.6
Anticipated Failure Load (AFL) (kN): 150 | **Weather:**
Hydraulic Jack: | **Remarks:**
Anticipated Duration of Test Time(min): 180

Load Cycle	Load (%AFL)	Load Target (kN)	Gage Pressure (Mpa)	Hold Duration (min)	Settlement (mm)				Ave. Displacemnet (mm)
					Gage 1 Reading (mm)	Gage 2 Reading (mm)	Gage 3 Reading (mm)	Gage 4 Reading (mm)	
		76		0	6.3	6.14	4.65	5.13	5.555
				1	6.3	6.14	4.65	5.13	5.555
				3	6.41	6.21	4.69	5.2	5.6275
				5	6.48	6.26	4.71	5.26	5.6775
				6	6.51	6.28	4.74	5.3	5.7075
				10	6.6	6.33	4.79	5.41	5.7825
				15					
				20					
	25	50		0	6.47	6.11	4.59	5.21	5.595
				2.5	6.43	6.06	4.57	5.2	5.565
				5	6.42	6.06	4.57	5.2	5.5625
	25	25		0	5.95	5.57	4.08	4.65	5.0625
				2.5	5.88	5.49	4.01	4.57	4.9875
				5	5.88	5.49	4.01	4.58	4.99
	25	0		0	4.24	5.74	3.33	3.86	4.2925
				2.5	5.11	4.54	3.18	3.77	4.15
				5	5.11	4.53	3.17	3.79	4.15
				15	5.1	4.52	3.17	3.79	4.145

SUREFOOT FOOTINGS – THE RANGE

T150 (SF 50)

Residential

Bolting pattern:
147 mm x 3 x 16mm holes

Micro Piles:
3 x 32NB (Nominal Bore) 42.40D
Galvanised Pipe Light, Medium, Heavy

Load capacity:
Up to 25kN

Average installation time:
10 minutes approx

S250 (SF 150)

Residential

Bolting pattern:
140mm centres x 4 x 22mm holes

Micro Piles:
4 x 32NB (Nominal Bore) 42.40D
Galvanised Pipe Light, Medium, Heavy

Load capacity: Up to 100kN

Average installation time:
10 minutes approx

4-WAY

3-WAY

2-WAY

S400 (SF 300)

Commercial

Bolting pattern:
198-250 PCD x 4 x 22mm holes
300-350 PCD x 4 x 26mm holes

Micro Piles:
6 x 32NB (Nominal Bore) 42.40D
Galvanised Pipe Light, Medium, Heavy

Load capacity: Up to 160kN

Average installation time: 15 minutes

S500 (SF 500)

Commercial

Bolting pattern:
233-300 PCD x 4 x 22mm holes
350-400 PCD x 4 x 26mm holes

Micro Piles:
12 x 32NB (Nominal Bore) 42.40D
Galvanised Pipe Light, Medium, Heavy

Load capacity:
Up to 300kN

Average installation time: 25-30 minutes approx

S600 (SF 600)

Commercial

Bolting pattern:
350-400 PCD x 4 x 26mm holes
432-500 PCD x 4 x 32mm holes

Micro Piles:
16 x 32NB (Nominal Bore) 42.40D
Galvanised Pipe Light, Medium, Heavy

Load capacity: Up to 360kN

Average installation time: 60 minutes approx

Surefoot Load capacities are indicative and are dependent on soil type and pile embedment depth, for specification, please contact Surefoot directly.

SUREFOOT APPLICATIONS

RENEWABLE ENERGY

REMOTE AREAS

SNOW GROOMER WINCH POINT

COMBINATION FOOTINGS

S600 *Moment = 210kN.m*

S500 *UPLIFT = 470kN*

GRAVITY = 287kN

S500 *Moment = 150kN.m*

MODULAR HOMES
&
PORTABLE STRUCTURES


S400

INDUSTRIAL APPLICATIONS

S400
Crane Capacity =
380kN

HOUSING

BRIDGES & JETTIES


FRED BLAKE
CRANE HIRE
FOR HIRE


CUSTOM SUREFOOT
GRAVITY CAPACITY= 300kN

PLAYGROUNDS
&
SHADE SAILS

RETAINING WALLS

SHEDS