REPORT ON INVESTIGATION OF BENDING AND SHEAR BEHAVIORS OF HELIX CIRCULAR PILES

Never Stand Still

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For:

Helix Steel Australasia Pty Ltd

20 August 2014

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(CIES/CVEN/UNSW, 20 August 2014)

INTRODUCTION

In this project, CIES (Centre for Infrastructure Engineering and Safety) at School of Civil and Environmental Engineering (CVEN) of the University of New South Wales (UNSW) has collaborated with Helix Steel Australasia Pty Ltd on an investigation of the bending and shear behaviors of circular concrete piles reinforced with Helix TSMR (Twisted Steel Micro Rebar) plus a N16 or N20 bar at the pile center. CIES has undertaken following experimental preparations, tests and analyses:

- Prepare formworks for casting 6 pile specimens (1.7m long and 200mm in diameter): 4 pile specimens each with one N16 rebar at the center and, the other 2 pile specimens each with one N20 rebar at the center.
- Design and make special loading supports for testing circular specimens under 4-point loads;
- Cast 6 pile specimens with a 50MPa grade self-compacting concrete in two batches: one batch contained 30 kg/m^3 of Helix TSMR for casting 4 pile specimens with N16 bars and, the other batch contained 25 kg/m^3 of Helix TSMR for casting 2 pile specimens with N20 bars; eight cylinder samples (of 100mm diameter) were cast from each concrete batch for testing compressive strength and elastic modulus;
- During each casting process, use 3 cylinder moulds (100mm diameter) for fibre counting
- Cure the specimens and samples under wet hessian for 14 days, then expose them in the Lab environment until commencement of testing at least 28 days from casting;
- At concrete age of 7, 28 days and during the period of testing the pile specimens, test cylinder samples for Compressive strength (As1012.9);
- During the period of testing the pile specimens, test cylinder samples for Modulus of Elasticity (AS1012.17);
- Prepare test apparatus and instrumentations for testing of 6 piles;
- Test each of 6 piles to failure with two supports at the test span of L = 1.5m and two point loads: 3 Bending tests with the shear span a = 0.5m and, 3 Shear tests with a = 0.2m; (Note: shear span “a” is the distance between the centers of a point load and its nearest support)
- During testing of each of 6 piles, record the data of the load versus the displacement at the mid-span bottom of the pile specimen;
- Present and plot curves of the recorded test data and provide necessary descriptions and comments of the test results.

This report presents a summary of the experimental preparations and the test results of 6 Helix pile specimens and concrete samples. A copy of the electronic “Excel” data file of the test results will be included together with this report.

SPECIMENS, CONCRETE PROPERTY AND HELIX TSMR COUNTING RESULTS

Fig 1 shows the 6 pile specimens cast in the vertical positions in the Heavy Structural Laboratory of the School of Civil Engineering of the UNSW.

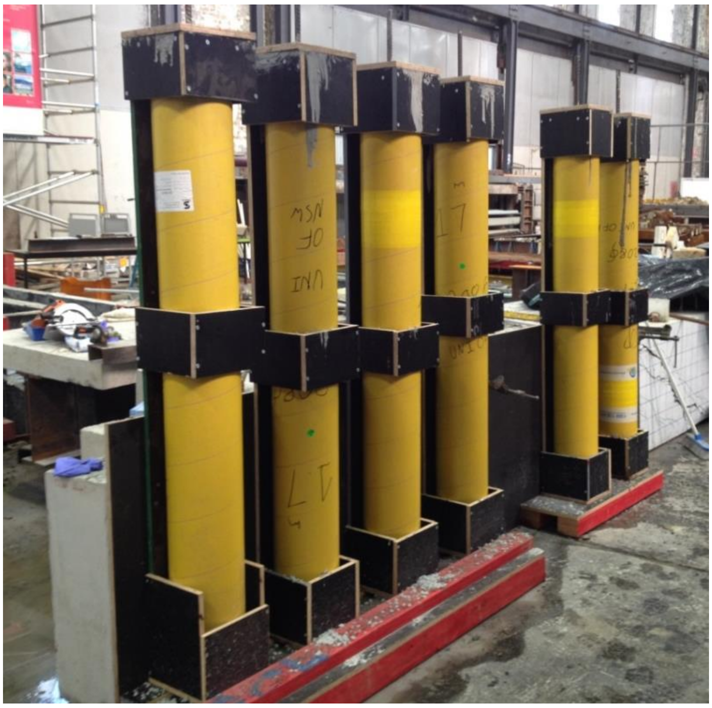

Fig 1. Six pile specimens cast in vertical positions in the Lab

A commercial self-compacting concrete of 50 MPa Grade was adopted in this investigation. Two concrete batches (each 3 m^3 in volume) were used for casting the pile specimens:

- Batch-1 containing 30kg/m^3 of Helix TSMR was used for casting 4 pile specimens each with one N16 rebar at the center, and;
- Batch-2 containing 25kg/m^3 of Helix TSMR was used for casting 2 pile specimens each with one N20 rebar at the center.

During casting of the pile specimens, concrete cylinder samples were also cast for testing concrete properties; fibre counting tests were performed with three 100 mm diameter cylinders to evaluate the Helix TSMR content and, the average fibre counting results are:

- Batch-1 concrete: 49.8g at start of casting and 47.6g at end of casting; these were translated into the fibre content of 31.7 and 30.3 kg/m^3 in the cylinder samples;
- Batch-2 concrete: 40.0g at start of casting and 41.0g at end of casting; these were translated into the fibre content of 25.5 and 26.1 kg/m^3 in the cylinder samples.

The fibre counting results indicated a fairly good distribution of Helix TSMR in both concrete batches as the specified 30 kg/m^3 and 25 kg/m^3 respectively. The specimens and samples were cured under wet hessians for 14 days before stored in the lab environment. Tests were carried out with concrete cylinder samples for the concrete compressive strength *f'*c at 7, 14, 28 and 43 days and, for the modulus of elasticity at 43 days. The test results are shown in Table 1.

Table 1: Concrete Property Test Results

Batch No.	7-Day compressive f'c (MPa)	14-Day compressive f'c (MPa)	28-Day compressive f'c (MPa)	43-Day compressive f'c (MPa)	43-Day Modulus Ec (GPa)
Batch-1	38.0	49.0	65	72	38.4
Batch-2	36.0	43.0	60	64	35.1

TEST SETUP AND MEASUREMENTS FOR PILE SPECIMENS

Fig 2 shows the test setup for a typical pile specimen. All the pile specimens were tested as horizontal beams with the same effective span of L_0 = 1.5m and subjected to two symmetric point loads, which are at a distance "a" of either 0.5m or 0.2m to their nearest supports. The loading test of each pile specimen was conducted with a 500 kN servo-controlled INSTRON testing facility.

Fig 2. Test setup for a pile specimen with L_0 = 1.5m and a = 0.5m

A load cell was used for recording the total load value of the two point loads; a displacement sensor was mounted under the pile specimen at its center to measure the vertical displacement. An electronic data logger was engaged to record and plot the load vs the displacement curve during the testing period. During the tests, the crack width of the major crack was manually measured with a crack gauge at different loading levels.

MAIN TEST RESULTS

Table 2 presents the test arrangement for the six pile specimens and the main test results.

Table 2: Test Arrangement and Main Test Results

Pile No.	Shear span "a" (m)	Maximum Load "P_{max}" (kN)	Bending Moment at "P_{max}" (kN-m)	Shear Force at "P_{max}" (kN)	Load at crack=1mm, "$P_{cr=1}$" (kN)	Failure Mode
P-N16-1	**0.5**	47.8	12.0	23.9	47.5	Bending
P-N16-2	**0.2**	125.8	12.6	62.9	80.5	Bending
P-N16-3	**0.5**	48.5	12.1	24.3	41.5	Bending
P-N16-4	**0.2**	130.5	13.0	65.2	92.0	Bending
P-N20-1	**0.5**	63.3	15.8	31.6	52.0	Bending
P-N20-2	**0.2**	167.0	16.7	83.5	134.0	Shear

Fig 3 and Fig 4 compare the load vs central displacement curves of the two groups of pile specimens containing either N16 or N20 steel rebar respectively. Fig 5 compares all the 6 pile specimens on their load vs central displacement curves.

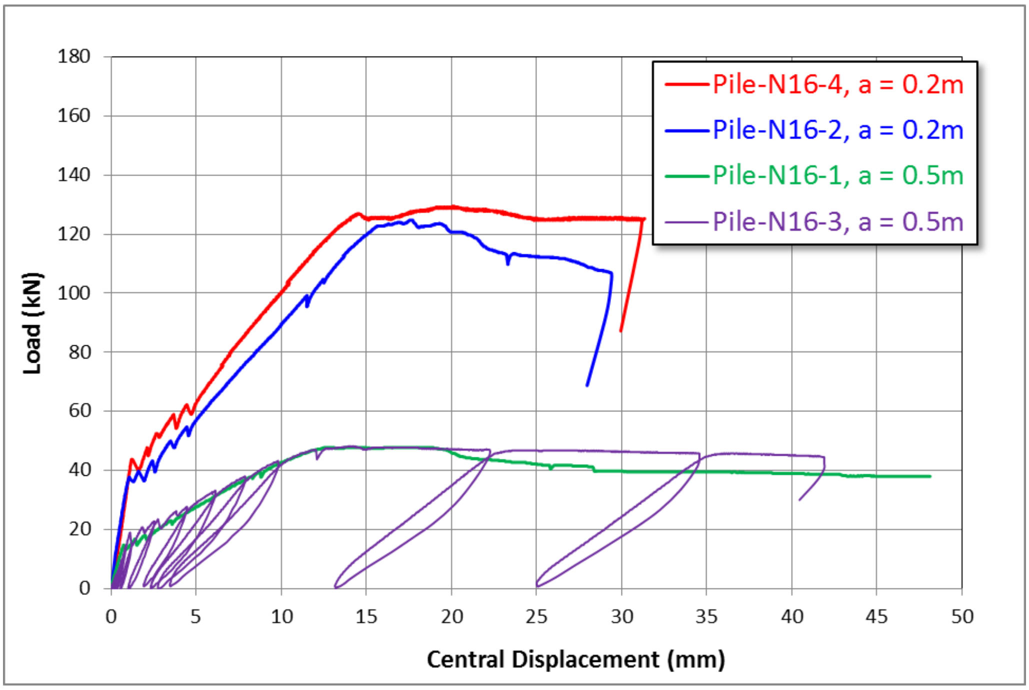

Fig 3. Load vs central-displacement curves of 4 piles containing N16 rebar

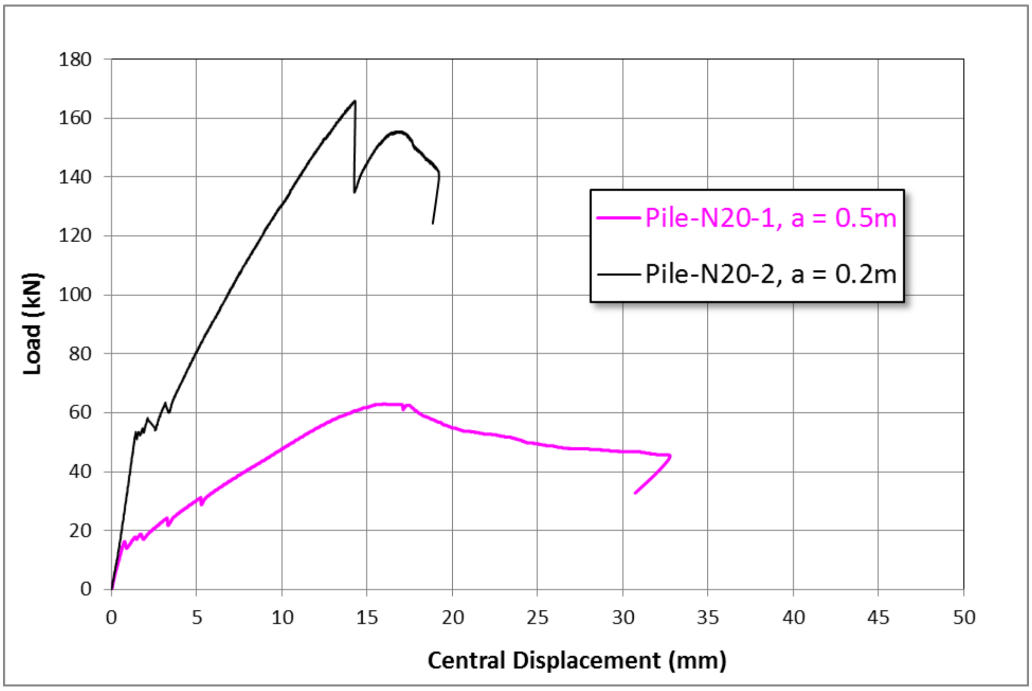

Fig 4. Load vs central-displacement curves of 2 piles containing N20 rebar

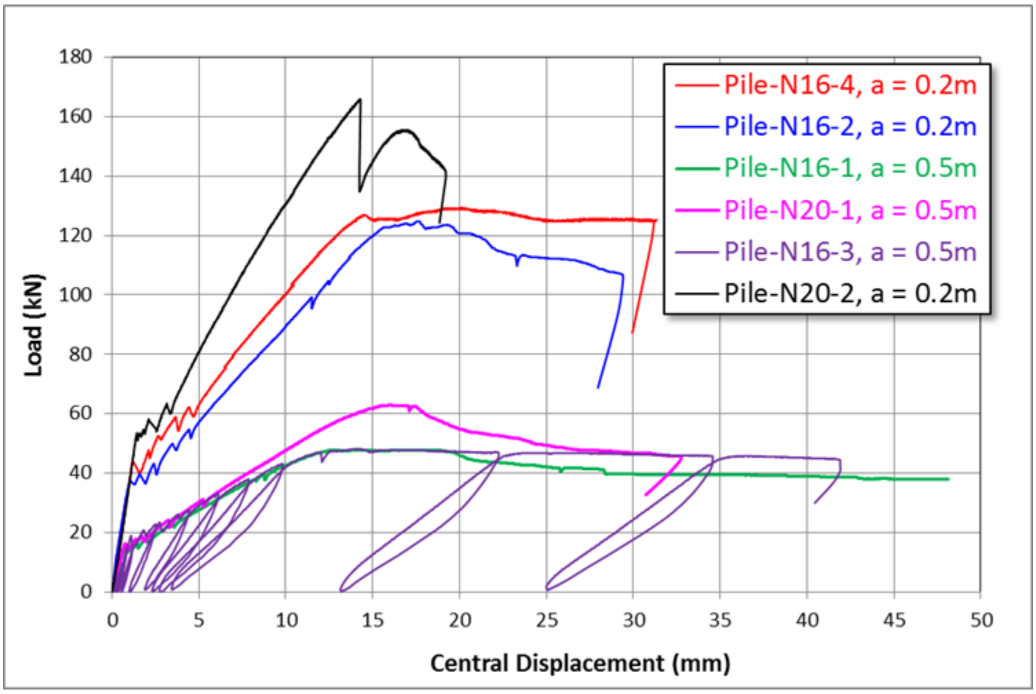

Fig 5. Load vs central-displacement curves of all 6 piles specimens

FAILURE MODES AND BEHAVIOURS OF SIX PILE SPECIMENS

Fig 6 and Fig 7 present the failure modes of the two pile specimen P-N16-1 and P-N16-3 respectively. Both piles were tested with the two point loads at the shear span a = 0.5m; while P-N16-1 was subjected to loading controlled by a displacement rate, P-N16-3 was subjected to a cyclic loading pattern following the loading path of P-N16-1 (see their curves in Fig 3).

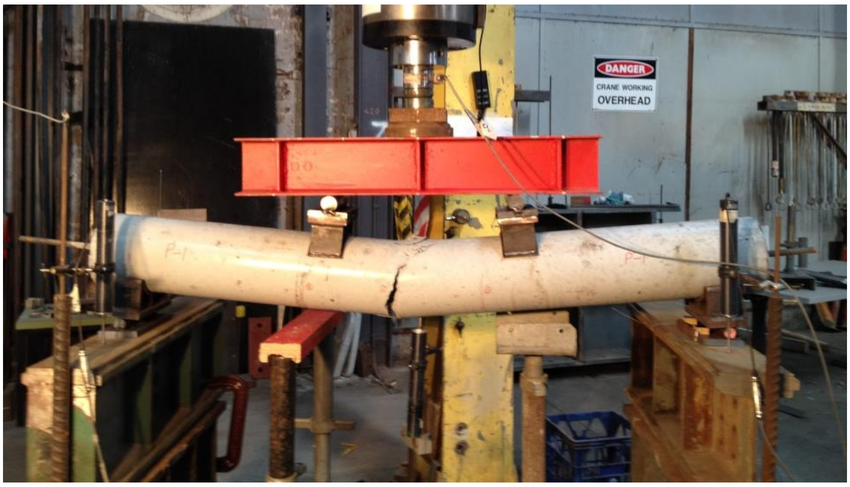

Fig 6. Pile specimen P-N16-1 at failure (L_0 = 1.5m, a = 0.5m)

Fig 7. Pile specimen P-N16-3 at failure (L_0 = 1.5m, a = 0.5m)

The failure modes of the two piles in Fig 6 and Fig 7 were typical bending failure with a major vertical bending crack and crush of concrete in the above compressive zone. Their load-central displacement curves in Fig 3 clearly show the typical bending failure behaviours characterized with a great ductility to maintain the load bearing capacity over a large displacement range and accompanied with significant opening of the main crack.

For P-N16-3 being loaded with cycles following the loading path of P-N16-1, the upper envelop of its load-displacement curves was almost the same as that of P-N16-1, indicating its loading capacity and ductile behaviour were not negatively affected by the cyclic loading scheme.

Fig 8 and Fig 9 show the failure modes of two piles P-N16-2 and P-N16-4 which were tested under two point loads at a very short shear span a = 0.2m. While in this loading case, the concrete shear force in the short shear span region becomes much more significant than that at a = 0.5m, these two piles were still found to fail in bending with a major vertical bending crack and crush of concrete in the above compressive zone. In Fig 3 the load-displacement curve of P-N16-4 demonstrated a typical ductile bending behaviour although the load bearing capacity of P-N16-2 dropped a bit more after the load peak.

Fig 8. Pile specimen P-N16-2 at failure (L_0 = 1.5m, a = 0.2m)

Fig 9. Pile specimen P-N16-4 at failure (L_0 = 1.5m, a = 0.2m)

Fig 10 shows pile specimen P-N20-1 at failure; it was tested with the shear span a = 0.5m. Its failure also falls into a bending failure mode with a major bending crack and crush of concrete in the compressive zone. However, unlike P-N16-1 and P-N16-3 which have great ductility to maintain the load bearing capacity over a large displacement range, the load-displacement curve of P-N20-1 in Fig 4 dropped shortly after the load peak. This might be because in P-N20-1, the occurrences of yielding of the N20 bar and distress/crush of concrete in its compression zone were close to each other; unlike that in the two piles P-N16-1 and P-N16-3 the yielding of N16 bar occurred much earlier therefore enabling the piles to maintain their bending capacity over a large displacement range until crush of concrete due to increasing compressive stresses.

Fig 10. Pile specimen P-N20-1 at failure (L_0 = 1.5m, a = 0.5m)

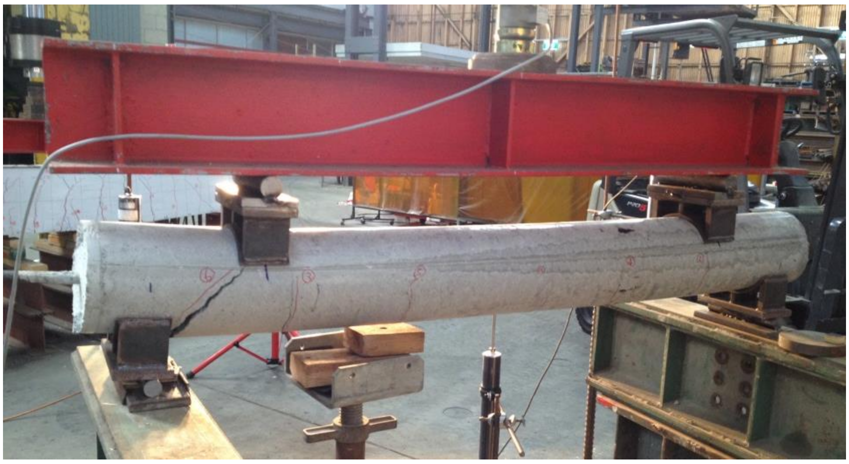

Fig 11. Pile specimen P-N20-2 at failure (L_0 = 1.5m, a = 0.2m)

Fig 11 shows the failure mode of the pile specimen P-N20-2 tested with the shear span a = 0.2m. It was found to fail in a typical shear failure mode with a featured inclined shear crack within the shear span between a point load and its nearest support. During the loading process, there were initially 5 bending cracks developed within the pure bending zone between the two point loads;

however, shortly after the inclined 6th crack being developed in the shear span a sudden drop of the peak load occurred accompanying with a dramatic opening of the inclined shear crack. The sudden load drop is clearly seen in Fig 4 with the recorded load vs displacement curve. Afterwards, the load picked up again but only reached a secondary peak before it dropped significantly together with opening of the inclined crack up to 15mm wide.

Of all the six pile specimens tested in this investigation, only the pile specimen P-N20-2 tested at a = 0.2m failed in the typical shear failure mode and, it recorded the highest shear force of 83 kN (see Table 2) in the shear span. The results indicated, under the test condition of a = 0.2m for the piles with a N16 rebar or a =0.5m for the piles with either N16 or N20 rebar, the piles all had higher shear capacities than their relevant bending moment capacities; therefore they all failed in a more ductile bending mode rather than in a brittle shear failure mode.

CRACK WIDTH DEVELOPMENT IN SIX PILE SPECIMENS

During the test process, the crack width of the major crack in each pile was manually measured with a crack gauge at different loading levels; the measurement results were approximate but should be reasonably close to the true values.

Fig 12 presents the load vs crack width development in the major crack in six pile specimens. A benchmark of the load at the crack width of 1mm for each pile specimen is presented in Table 2. During the process of testing the piles with the shear span a = 0.5m, 3 to 5 cracks were developed in a pile, while testing the piles with a = 0.2m, 5 to 7 cracks were developed. It was observed the crack widths increased gradually rather than dramatically with the load increases; the crack opening process was restricted to some extend by the fibres in the piles. For the two concrete batches with 30kg/m^3 and 25 kg/m^3 of Helix TSMR, no obvious differences were identified during the tests.

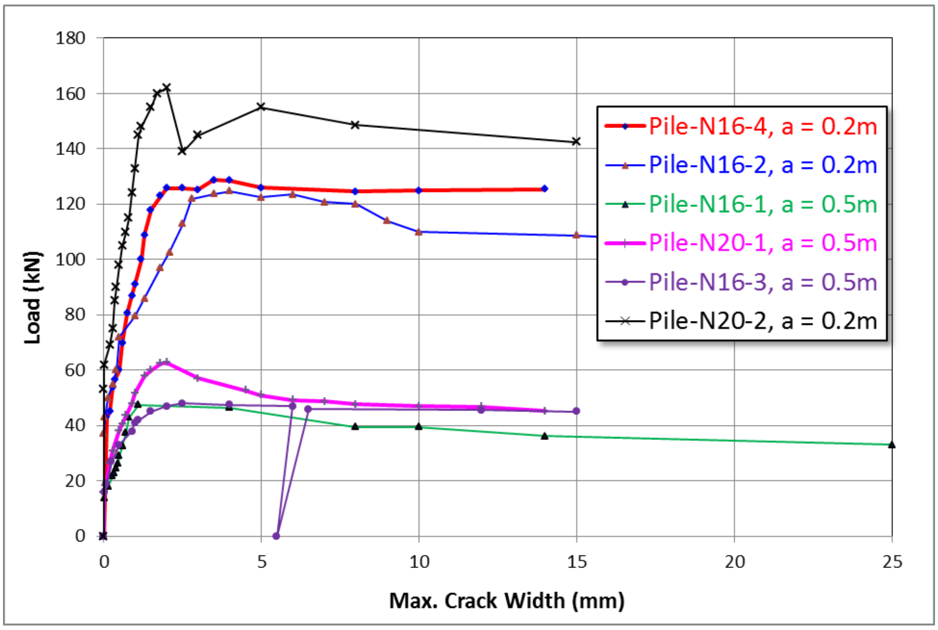

Fig 12. Load vs crack width in 6 piles specimens

COMPARISONS WITH THEORETIOCAL RESULTS

Helix Steel carried out theoretical analyses of the design capacities of 200mm diameter concrete piles reinforced with Helix TSMR plus 1-N16 bar or 1-N20 bar; the analyses used the Class C Hybrid design approach in the Helix method UER #0279 (see Appendix 1).

Appendix 2 and Appendix 3 presented respectively the main results of the design capacities of 200mm diameter piles reinforced with 30kg/m^3 of Helix TSMR plus 1-N16 bar or with 25kg/m^3 of Helix TSMR plus 1-N20 bar. The design bending-moment capacities of these two piles are 11.5kN-m and 14.1kN-m, which are in line with the experimental test results of 12 to 13kN-m and 15.8kN-m respectively. In Appendix 3, the design shear strength of the pile with 25kg/m^3 of Helix TSMR plus 1-N20 bar is 83kN based on ACI 318-05 Eq 11-3 and the UER #0279; this compares to the experimental test result of 83.5kN of the pile P-N20-2 which failed in a typical shear failure mode.

SUMMARY

Six pile specimens and a number of cylinder samples were cast with a self-compacting concrete containing Helix TSMR (Twisted Steel Micro Rebar) and experimentally tested in this investigation. The piles were 200mm in diameter and 1.7m in length. Four piles with 1-N16 bar at the pile center were cast with a concrete batch containing 30kg/m^3 of Helix TSMR and, the other two piles with 1-N20 bar at the pile center were cast with a concrete batch containing 25kg/m^3 of Helix TSMR. The 28 day compressive strengths of the two concrete batches were 65 MPa and 60 MPa respectively. All the pile specimens were tested as horizontal beams with an effective span of L_0 = 1.5m and subjected to two symmetric point loads, which are at a distance “a” (named the shear span) of either 0.5m or 0.2m to their nearest support center. Two piles with a N16 rebar and one pile with a N20 rebar were tested with a = 0.5m while the other three piles were tested with a = 0.2m.

It was found with the experimental tests that five of the six piles failed in bending failure mode with the characteristic of a fair to great ductility to maintain their load-bearing capacity around the peak load; a pile tested with a cyclic loading pattern showed no negative influences on its loading capacity and ductile behaviour. One pile specimen with 1-N20 bar was tested at a = 0.2m and it failed in the typical shear failure mode with a sudden drop of the load and formation of an inclined crack in the shear span. It was observed during the tests that the crack widths increased gradually rather than dramatically with the increase of loading, which indicated the Helix TSMR in the pile specimens helped to improve ductility and restrict the crack opening process. As recognised in literature, addition of fibres in concrete could also increase the shear capacity of beams to some extent. The design moment and shear capacities based on the approach of the Helix method UER #0279 appear to be in line with the experimental results of this investigation.

Overall, this investigation provided encouraging test results of the Helix centrally reinforced piles on their performance in the failure mode and crack development. The experimental test results would provide a benchmark and useful information for engineers to evaluate and design such special types of reinforced concrete piles. However, the findings are limited by the scope and test conditions of this investigation. Further studies may need to be undertaken for performance information in other specific conditions or applications.

Appendix 1

Helix Method UER #0279

UNIFORM EVALUATION REPORT

EVALUATION SUBJECT:
Helix 5-25 Micro-Rebar Concrete Reinforcement System

Report No.	**0279**
Originally Issued:	05/2013
Revised	6/5/2014
Valid Through:	05/2015

REPORT HOLDER:
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Section: 03 20 00 CONCRETE REINFORCEMENT

1.0 SCOPE OF EVALUATION

1.1 Compliance To The Following Codes & Regulations:

- 2012 and 2009 International Building Code® (IBC)
- 2012 and 2009 International Residential Code® (IRC)

1.2 Evaluated in Accordance With:

- IAPMO UES EC015-2013, adopted December 2013
- ICC-ES AC208, approved October 2005, editorially revised November 2012

1.3 Properties Evaluated:

- Shrinkage and temperature crack control in concrete
- Structural tension and shear resistance in concrete
- Fire Resistance

2.0 USES

Helix 5-25 Micro-Rebar functions as tensile reinforcement for concrete.

2.1 Helix Micro-Rebar may be used to reduce shrinkage and temperature cracking of concrete. Helix Micro-Rebar may be used as an alternative to the shrinkage and temperature reinforcement specified in Section 7.12 and Chapter 22 of ACI 318 (as referenced in Section 1901.2 of the IBC and Sections R404.1.2 and R611.1 of the IRC).

2.2 Helix Micro-Rebar may be used as tension and shear reinforcement in other structural concrete as detailed in this report which satisfies the requirements of ACI 318 Section 1.4 and Section 104.11 of the IBC and IRC.

2.3 Use in Seismic Design Categories C, D, E, and F is subject to the restrictions listed in Section 5.2 of this report.

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3.0 DESCRIPTION

Helix 5-25 Micro-Rebar reinforced concrete consists of two materials, as described in Sections 3.1 and 3.2 of this report.

3.1 Product Information: Helix 5-25 Micro-Rebar is made from cold-drawn, deformed wire complying with ASTM A 820, Type I. The steel wire has a tensile strength of 275 ksi +/- 15 ksi (1850 MPa +/-150 MPa) and a minimum of 3 g/m^2 zinc coating. The length (l) is 1.0 inch +/- 0.1 inch (25 mm +/- 0.004 mm), equivalent diameter is 0.020 inch +/-0.007 inch (0.5 mm +/- 0.02 mm), and cross sectional area is 0.003 square inches (0.196 mm^2). Each Helix Micro-Rebar has a minimum of one 360-degree twist. Helix Micro-Rebars are packaged in 22.5 pound (10 kg) boxes, 45-pound (22.5 kg) boxes or 2450-pound (1100 kg) bags.

3.2 Normal Weight Concrete with a minimum 28 day compressive strength of 3,000 psi (20.66 MPa).

4.0 DESIGN AND INSTALLATION

4.1 Design Class Selection: The Helix design class shall be selected based on the application and consequence of failure. The registered design professional shall select the design class based on the criteria in Sections 4.2 through 4.5 of this report. Figure 1 of this report provides guidance in making the design class selection.

4.2 Class A – Shrinkage and temperature Reinforcement

4.2.1 Helix 5-25 Micro-Rebar replaces deformed reinforcement bars (rebar) or welded wire reinforcement for shrinkage and temperature reinforcement specified in Section 7.12 of ACI 318 in members complying with the requirements of Section 22.2.1 (a or b) of ACI 318. This application includes structural plain concrete structures designed in accordance with Chapter 22 of ACI 318 (as referenced in Section 1901.2 of the IBC and Sections 404.1.2 and R611.1 of the IRC).

4.2.2 Helix 5-25 Micro-Rebar replaces shrinkage and temperature reinforcement in non-composite stay in place form steel deck applications.

4.2.3 Helix 5-25 Micro Rebar may be used in any concrete structure where reinforcement is not required by the IBC or IRC or addition to reinforcement required by the IBC or IRC to reduce shrinkage and temperature cracking of the concrete.

4.3 Class B – Minimum Structural Reinforcement

4.3.1 Helix 5-25 Micro-Rebar replaces structural reinforcement in soil-supported structures including footings, and foundations.

4.3.2 Helix 5-25 Micro-Rebar replaces structural reinforcement in arch structures members in which arch action provides compression in the cross-section.

4.3.3 Helix 5-25 Micro-Rebar replaces structural reinforcement in structural concrete slabs supported directly on the ground designed in accordance with ACI 318.

4.3.4 Helix 5-25 Micro-Rebar used replaces structural reinforcement in pile-supported slabs on ground designed in accordance with ACI 318, with un-occupied space below not to exceed the slab thickness (so failure will not result in structural collapse endangering occupants).

4.3.5 Helix 5-25 Micro-Rebar replaces reinforcement in structural walls designed in accordance with ACI 318 Chapter 14 and conforming to the following criteria:

- Thickness of bearing walls shall be not less than 1/24 the unsupported height or length, whichever is shorter nor less than 5½ inches (140 mm). Non-bearing walls support no more than 200 pounds per linear foot (2919 N/m) of vertical load in addition to its own weight.
- Thickness of bearing walls designed in accordance with the IRC shall not be less than 4 inches (100 mm).
- Bearing walls support more than 200 pounds per linear foot (2919 N/m) of vertical load in addition to its own weight
- Walls shall be braced against lateral translation (walls shall be laterally supported in such a manner as to prohibit relative lateral displacement at top and bottom or on both sides of individual wall elements such as occurs with free-standing walls or walls in large structures where significant roof diaphragm deflections).
- At least one No. 5 (16 mm) bar shall be provided around all window, door, and similar sized openings except that for structures regulated under the IRC, at least one No. 4 (13 mm) bar may be provided. The bars shall be anchored to develop f_y in tension at the corners of openings.

4.3.6 Helix 5-25 Micro-Rebar is used to reinforce slabs-on-ground designed using non-linear load analysis provided maximum tensile strains are limited to levels provided in Section 5.7 of this report.

4.4 Class C – Structural Concrete
Helix 5-25 Micro-Rebar replaces structural reinforcement for all other structural concrete including in unsupported horizontal spans.

4.5 Class Cs – Non-Linear Slab Design
Helix 5-25 Micro-Rebar used as reinforcement in slabs on ground designed in accordance with ACI 360-10 Chapter 11.3.3 Methods 2 and 4, Yield Line Analysis and Nonlinear finite element analysis (when tensile strain limits given in 5.7 are exceeded; when not exceeded the design shall comply with Section 4.3.6 of this report).

4.6 Design
Helix 5-25 Micro-Rebar dosage quantity shall be determined by procedures in this section and Tables 1, 2, and 3 of this report. Figure 2 of this report, the Helix Force Equilibrium and Strain Compatibility Diagram, shall be observed in the structural design.

4.6.1 Required Area of Steel

- Class A: The required area of steel, A_s, for shrinkage and temperature reinforcement shall be determined by the design procedures in Section 7.12 of ACI 318 or other applicable code sections.
- Class B & and C: The required area of steel reinforcement shall be determined at the centroid of the tension zone (Helix 5-25 Micro-Rebar acts as a rectangular tensile block as shown in Figure 2 of this report) in accordance with standard design procedures in ACI 318 using load and resistance factor design.
- An appropriate strength reduction factor has been applied to the Helix design strength in Tables 1 to 3 of this report.

4.6.2 Required Helix Micro-Rebar Quantity
Table 1 of this report provides the total number of Helix Micro-Rebar required to provide the same tensile resistance as the area of steel computed in Section 4.6.1 of this report. This number shall be divided by the cross-sectional area of the concrete in tension to obtain the number of Helix 5-25 Micro-Rebar required per unit area. This concrete area may result from either direct tension, flexural tension, or shear. Table 1 includes a factor to account for variation on Helix 5-25 Micro-Rebar resistance.

4.6.3 Helix 5-25 Micro-Rebar Dosage
The minimum Helix 5-25 Micro-Rebar dosage required to ensure the number of Helix 5-25 Micro-Rebar per unit area (as determined in Section 4.6.1 of this report) are provided in the tensile region of the concrete shall be selected from Table 2 of this report. This table includes factors to account for variation in orientation and distribution of Helix 5-25 Micro-Rebar.

4.6.4 Helix 5-25 Micro-rebar Tensile Force
Using the required number of Helix 5-25 Micro-rebar per unit area computed from Section 0 of this report, the provided Helix 5-25 Micro-Rebar unit tensile stress shall be selected from Table 3 of this report. This value may be multiplied by the cross-sectional area in tension to compute the total tensile resistance force.

4.6.5 Strain in the Helix 5-25 Micro-Rebar Concrete
Using the provided Helix unit tensile stress computed from Section 4.6.1 of this report, the average strain shall be calculated by (Eq.-1):

$$\varepsilon \cong \frac{\text{Helix tensile stress}}{E_{ct}} \qquad \textbf{(Eq.-1)}$$

Where:

E_{ct} = the tensile modulus of elasticity of Helix 5-25 Micro-Rebar concrete, computed from Section 8.5 of ACI 318,psi (MPa).

ε = average concrete tensile strain

4.6.6 Pre- or post- tensioned concrete
With pre- or post- tensioned concrete, the initial compressive strain may be subtracted from the average strain calculated in Eq.-1.

4.6.7 Restrained shrinkage
In cases of restrained shrinkage, the shrinkage strain shall be added to the average strain computed in Eq.-1.

4.6.8 Shear
The same method as provided in Sections 4.6.1 to 4.67 shall be used for determining shear and torsion reinforcement. The contribution of plain concrete shall be neglected in shear applications (do not add V_c to the shear resistance computed for Helix Micro-Rebar). The area in tension should be taken as no more than the 1.41 x the section width x height minus twice the neutral axis depth. When replacing both bending and shear reinforcement the higher of the two dosages shall govern the design.

4.7 Hybrid Design
Hybrid design includes a combination of deformed reinforcement (rebar) and Helix 5-25 Micro-Rebar. For Hybrid Design, the area of steel computed in accordance with Section 4.6.1 of this report may be reduced by the cross-sectional area of the rebar that will remain prior to determining the required minimum number of Helix Micro-Rebar in Section 4.6.2 of this report.

4.7.1 Hybrid design for Class A or B structures have no minimum bar reinforcing requirement provided the application requirements in Sections 4.2 and 4.3 are met and strain limits conform to Section 5.7 of this report.

4.7.2 Structures complying with the Class A or B application restrictions in Sections 4.2 and 4.3 of this report but exceeding the strain limits in Section 5.7 may be designed as Class B Hybrid. This process will reduce the strain computed in Section 5.7 of this report. The strain limit shall be maintained even if the minimum amount bar reinforcement as prescribed in ACI 318 section 10.5 is provided. Alternatively, the registered design professional may elect to use Class C without the need for bar reinforcement.

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4.7.3 Structures not complying with Class A and B application limitations listed in section 4.2 and 4.3 of this report may be designed as Class C hybrid with a minimum amount of bar reinforcement as prescribed in ACI 318 Section 10.5 except as provided in Section 5.12 of this report.

4.7.4 Subject to approval of the code official, the requirement for bar reinforcement in Sections 4.7.2 and 4.7.3 of this report may be waived if registered design professional shows through supplemental testing and/or analysis adequate strength for the factored loads and serviceability requirements.

4.7.5 Strength provided by concrete in non-composite stay in-place forms in applications not complying with the Class A and B application limitations may be used to satisfy the minimum reinforcement requirement provided the registered design professional shows the Helix-reinforced concrete provides resistance equal to or greater than the resistance provided by the required bar reinforcement. The Helix-reinforced design strength, however, shall be adequate to carry the entire load (the contribution of the stay in place forms shall not be added to the capacity).

4.8 Yield Line Methods (ACI 360-10).
The section moment capacity ϕMn shall be calculated using the values in Table 3 of this report. The quantity $\frac{M_n}{S_m \times fr}$ shall replace $\frac{\mathrm{R}e,3}{100}$ in ACI 360-10 equations. All other calculations remain the same.

4.9 Fire-Resistance Ratings

4.9.1 For flat walls complying with IBC 722.2.1.1, Helix 5-25 Micro-Rebar are permitted as an alternative to the specified reinforcement according to IBC 722.2.1.1 The maximum dosage is 66 lb/yd3 (38 kg/m3).

4.9.2 For Slabs on metal deck, Helix 5-25 Micro-Rebar are permitted as an alternative or in addition to the welded wire fabric used in concrete members under Underwriters Laboratories Design Nos. G256 dated January 6, 2014 and G514 dated October 11, 2013. The maximum dosage is 66 lb/yd3 (38 kg/m3).

5.0 CONDITIONS OF USE

The Helix 5-25 Micro-Rebar described in this report comply with, and/or are suitable alternatives to what is specified in those codes listed in Section 1.0 of this report, subject to the following conditions:

5.1 The concrete with Helix 5-25 Micro-Rebar shall comply with the ASTM C1116, Type I requirements. Substitution of any other steel fiber for Helix 5-25 is not allowed.

5.2 Structures complying with the requirements of Class A, B and Cs (Section 4.1) are allowed in all seismic design categories permitted by the IBC for these applications. Class C structures in Seismic Design Categories C, D, E, and F are outside of the scope of this report.

5.3 Helix Micro-Rebar shall be blended into the concrete mix in accordance with Section 4.0 of this report, IBC Section 1905.8, and the manufacturers published installation instructions. If there is a conflict between the evaluation report and the manufacturer's published installation instructions, the more restrictive governs.

5.4 Concrete used in classes A, B and Cs shall be normal weight and have a minimum compressive strength of 3,000 psi (20 MPa) and a maximum compressive strength of 8,000 psi (56 MPa).

5.5 The Helix Micro-Rebar shall not be used to replace any joints specified in IBC Section 1909.3.

5.6 Concrete used in Class C structures shall be normal-weight and have a minimum compressive strength of 4,000 psi (28 Mpa) and a maximum compressive strength of 8,000 psi (56 MPa) and the mix shall have minimum fine to total aggregate ratio of 0.50 to assure adequate bond with the Helix Micro-Rebar.

5.7 Class A and B Strain Limits: The average tensile strain in the concrete shall not exceed the following

Number of Helix per area	Tensile Strain, ε
Less than 3 Helix/in^2 (4,650 Helix/m^2)	0.000076
3 to 7 Helix/in^2 (4,650 to 10,850 Helix/m^2)	0.000105
Greater than 7 Helix/in^2 (10,850 Helix/m^2)	0.000110

5.8 Hybrid design in accordance with Section 4.7 of this report is allowed for Class A and B structures complying with Section 4.2 of this report, with no minimum reinforcing bar requirement, provided strain limits comply with Section 0 of this report.

5.9 Helix 5-25 Micro-Rebar shall be limited to the following dosages:

5.9.1 Class A:
Minimum 9 lb/yd^3 (5.4 kg/m^3)
Maximum 70 lb/yd^3 (42 kg/m^3)
Except for slab on ground applications designed as unreinforced concrete in accordance with ACI 360-10 Chapter 7, the minimum dosage does not apply.

5.9.2 Class B:
Minimum 9 lb/yd^3 (5.4 kg/m^3)
Maximum 70 lb/yd^3 (42 kg/m^3)

5.9.3 Class C:
Minimum 15 lb/yd3 (9 kg/m^3)
Maximum 70 lb/yd3 (42 kg/m^3)

5.9.4 Class Cs:
Minimum 20 lb/yd3 (12 kg/m^3)
Maximum 70 lb/yd3 (42 kg/m^3)

5.10 For flexure, standard balanced and tension controlled Limits as prescribed in ACI 318 Section 10.3 apply.

5.11 A registered design professional shall approve use of Helix 5-25 Micro-Rebar.

5.12 Unsupported horizontal spans (free-spanning beams or slabs with occupied space above or beneath) shall have the minimum amount of bar reinforcement required to carry nominal service loads.

5.13 Helix 5-25 Micro Rebar shall not be used to replace supplemental rebar placed around openings and tied to lifting points in either cast-in-place or precast concrete.

5.14 Helix 5-25 Micro-Rebar shall be added to the concrete either at the ready-mix plant or at the jobsite. The manufacturer's published installation instructions and this report shall be strictly adhered to, and a copy of the manufacturer's published installation instructions shall be available at all times on the jobsite or the batch plant during installation. Installation instructions are available at www.helixsteel.com.

5.15 When Helix 5-25 Micro-Rebar is added at the ready-mix plant, a batch ticket signed by a ready-mix representative shall be available to the code official upon request. The delivery ticket shall include, in addition to the items noted in ASTM C 94, the type and amount of Helix Micro-Rebar added to the concrete mix.

5.16 Field verification of Helix 5-25 Micro-Rebar dosage not required for Class A, B and Cs or in applications designed with the minimum quantity of structural reinforcing bars in accordance with ACI 318. When verification is required, such as for Class C structures and as otherwise specified, the procedures in Appendix A shall be observed.

5.17 Helix Micro-Rebar is manufactured under a worldwide exclusive license by Polytorx, LLC d.b.a Helix Steel.

6.0 EVIDENCE SUBMITTED

- Data in accordance with the ICC-ES Acceptance Criteria for Steel Fibers in Concrete (AC208), dated October 2005, editorially revised November 2012.
- Data in accordance with IAPMO UES Acceptance Criteria for Twisted Steel Micro-Rebar (EC015), dated December 2013.

7.0 FIGURES, TABLES AND EXAMPLES

Figures (Attached)
- Figure 1: Helix Design Class Selection Flow Chart
- Figure 2: Helix Force Equilibrium and Strain Compatibility Diagram

Tables (Attached)
- Table 1: Helix micro rebar replacement
- Table 2: Helix micro rebar dosage rate
- Table 3: Helix micro rebar tensile force

Examples Calculations (Attached)
- Example 1: Class A Slab on Grade Design - Original Rebar Design Given
- Example 2: Class B Slab on Metal Deck – Original Mesh Given
- Example 3: Class B Wall Design –Minimum Reinforcement Ratio Given
- Example 4: Class B Grade Beam Shear Design Only – Original Shear Rebar Given
- Example 5: Class B Wall Design – Hybrid

8.0 APPENDICIES

A. Optional Field Dosage Verification Method
B. Minimum Helix Dosage Quick Reference

THE FULL EVALUATION REPORT MAY BE DOWNLOADED AT: www.uniform-es.org

UNIFORM EVALUATION REPORT UER-0279

9.0 IDENTIFICATION

Labels on the boxes or bags bear the name Helix 5-25 and the number of the IAPMO UES evaluation report number (ER-0279), which identifies the product listed in this report. Either Mark of Conformity may be used as shown below:

IAPMO ES ® or UES ™

IAPMO UER #0279

Brian Gerber, PE, SE **Technical Director** **Uniform Evaluation Service**	**Richard Beck, PE, CBO, MCP** **Director** **Uniform Evaluation Service**	**GP Russ Chaney** **CEO** **The IAPMO Group**

For additional information about this evaluation report please visit www.uniform-es.org or email at info@uniform-es.org

Appendix 2

Helix Design of 200mm Diameter Pile with 30kg/m^3 of Helix TSMR and 1-N16 Bar at Center

CONCRETE DURABILITY WITH A TWIST

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Design of 200 Pile in accordance with AS3600

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Proposed Helix design: 200 mm Diameter Pile with Helix Class C Hybrid 30 kg/m3 of Helix 5-25 plus 1 bar on center of N16

Prepared for: -
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HELIX™ Micro-Rebar CONCRETE DURABILITY WITH A TWIST

PROJECT:	-	DATE:	11-Aug-14
CLIENT:	-	DSN. BY:	Samhar Hoz
CASE:	1803200	REV. BY:	Luke Pinkerton, PE

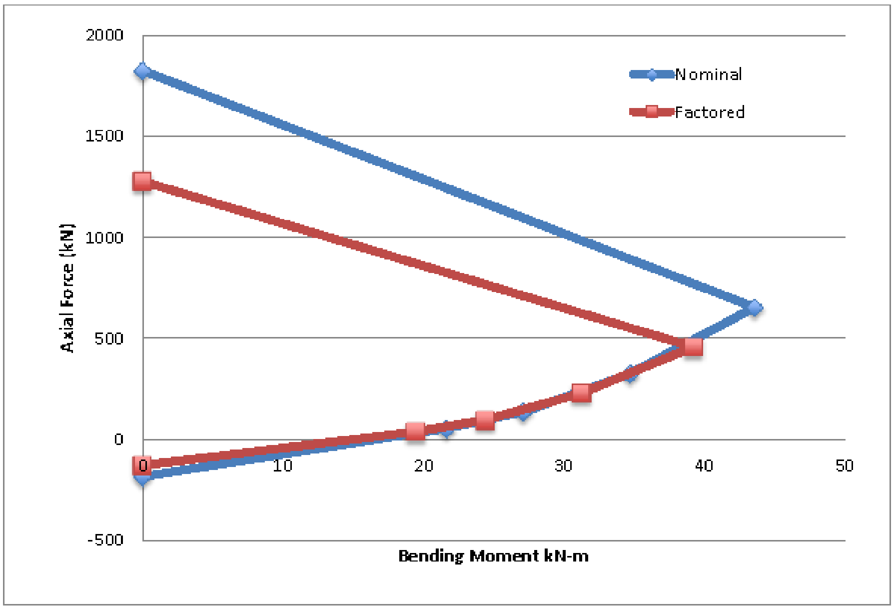
Design of 200 Pile in accordance with AS3600 — *reference or commentary*

Side by side summary

		English		SI	
Diameter	h	8	*in*	200.0	mm
Concrete Strength	f'_c	8,773	*psi*	61	Mpa
Helix Tensile Stress		222	*psi*	1.53	Mpa
Helixresistance factor		0.9		0.90	
Area of bar reinforcing	A_s	0.310	*in^2*	200.000	mm^2
Bar Depth	s	4	*in*	100	mm
Number of bar layers		1		1	
Steel yield strength	f_y	72,500	*psi*	500	Mpa
Resistance Factor Bending	ϕ_f	0.80		0.80	
Shear resistance factor	ϕ_v	0.70		0.70	
Helix dosage rate	H_d	50.00	lb/yd	**30.0**	kg/m3

Key Performance Metrics

	Helix Design		Helix Design	
Bending Moment Capacity	102	kip-in	11.5	kN-m



Helix Steel 300 N. 5th Ave, Suite 130 Ann Arbor, Michigan 48104-1447
phone: 734-322-2114 fax: 734-786-1633 www.helixsteel.com

FINAL-Copy of 1803200-N16+30Kg-Vibropile test UNSW-072314 release 1k

Appendix 3

Helix Design of 200mm Diameter Pile with 25kg/m^3
of Helix TSMR and 1-N20 Bar at Center

HELIX™
Micro-Rebar
CONCRETE DURABILITY WITH A TWIST

-

-, -

Design of 200 Pile in accordance with AS3600

-

Proposed Helix design: 200 mm Diameter Pile with Helix Class C Hybrid design 25 kg/m3 of Helix 5-25 plus 1 bar on center of N20

Prepared for:
-
-
-
-, -
-
-

Prepared by:
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page 2 of 2

HELIX™ Micro-Rebar CONCRETE DURABILITY WITH A TWIST

PROJECT: -
CLIENT: -
CASE: 1803200

DATE: 11-Aug-14
DSN. BY: Samhar Hoz
REV. BY: Luke Pinkerton, PE

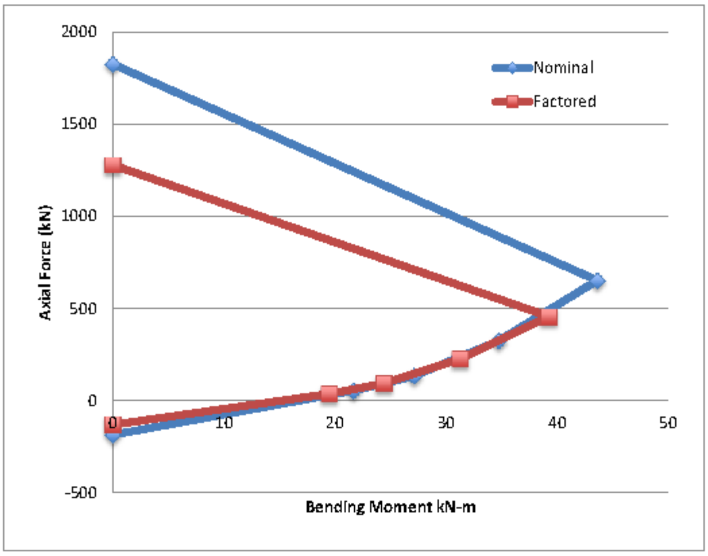
Design of 200 Pile in accordance with AS3600 — *reference or commentary*

Side by side summary

		English		SI	
Diameter	h	8	*in*	200.0	mm
Concrete Strength	f'_c	7,714	*psi*	53	Mpa
Helix Tensile Stress		183	*psi*	1.26	Mpa
Helix Resistance Factor		0.9		0.90	
Area of bar reinforcing	A_s	0.481	*in^2*	310.000	mm^2
Bar Depth	s	4	*in*	100	mm
Number of bar layers		1		1	
Steel yield strength	f_y	72,500	*psi*	500	Mpa
Resistance Factor Bending	ϕ_f	0.80		0.80	
Shear resistance factor	ϕ_v	0.70		0.70	
Helix dosage rate	H_d	41.67	lb/yd	**25.0**	kg/m3

Key Performance Metrics

	Helix Design		Helix Design		
Bending Moment Capacity	131	kip-in	14.1	kN-m/m	
Shear Strength (Helix only)	12.6	kip	56.0	kN	Helix: UER-0279
Shear Strength (Helix +Concrete)	19	kip	83	kN	ACI 318-05 Eq 11-3 Helix: UER-0279



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Final Copy of 1803200-N20+25Kg-Vibropile test UNSW- 072314.pdf — release 1k