DESIGN AND PERFORMANCE OF MICROPILES IN OILSAND AT THE SYNCRUDE UPGRADER EXPANSION (UE-1) PROJECT FORT MCMURRAY, ALBERTA

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ABSTRACT
Over 500 micropiles were installed at the Syncrude Canada Ltd. Mildred Lake plant site north of Fort McMurray, Alberta as part of the Upgrader Expansion (UE-1) project in 2002-04. Micropiles were used to augment either the vertical compression or uplift capacity of existing bored concrete pile groups due to the installation of new equipment in areas where conventional auger piling rigs could not access. The micropiles had a nominal diameter of 178 mm, a minimum pile length of 9 m and were typically installed 4.5 to 6 m into competent insitu oilsand. Design pile capacities were typically 240 kN for compression piles and 265 kN for tension piles. Load tests were carried out on three prototype piles and extended creep tests were conducted on a number of piles prior to production. In addition proof tests were performed on over 300 production piles to confirm load capacity. The micropile load tests and proof tests generally met the specifications. This paper describes the design and installation of the micropiles and presents a summary of the results collected during the extensive micropile load test program.

RÉSUMÉ
Plus de 500 micro pieux furnet installés lors de l'agrandissement de UE-1 en 2002-2004 au site de l'usine de Mildred Lake de Syncrude Canada située au nord de Fort McMurray en Alberta. Les micro pieux furent utilisés pour accroître ou bien la compression verticale ou la capacité de support de groupes de pieux en ciment qui existaient déjà. L'installation de ces micro pieux fut nécessaire du fait de l'installation de nouveaux équipements dans des endroits où il n'y avait pas d'accès possible pour les foreuses de pieux en ciment. Les micro pieux, d'un diamètre de 178 mm et d'une longueur minimum de 9 mètres, furent installés de façon typique 4.5 à 6 mètres dans du sable bitumineux compétent. La capacité des pieux était typiquement de 240 kN pour des pieux de compression et de 265 kN pour des pieux de tension. On conduisit des essais de surcharge sur trois proptotypes de pieux et des essais de fluage de longue durée furent conduits sur un certain nombre de pieux avant la construction. De plus des essais de résistance furent conduits sur plus de 300 pieux pour confirmer leur capacité de support. Les essais de support et de résistance des pieux furent en général conformes aux spécifications. Cet article décrit la conception et l'installation des micro pieux et présente un sommaire des résultats obtenus pendant le programme étendu d' essais de surcharge.

1. INTRODUCTION

Over 500 micropiles were installed at the Syncrude Canada Ltd. Mildred Lake plant site north of Fort McMurray, Alberta as part of the Upgrader Expansion (UE-1) project in 2002-03.

The micropiles were used to augment either the vertical compression or uplift capacity of existing conventional pile groups due to the installation of new equipment in areas where conventional auger piling rigs could not access.

Some of the typical installations included a group of 3 to 4 micro piles supporting a pile cap for pipe racks and equipment structures. Micropiles were also used as part of the foundation modification below existing vessels where they were installed adjacent to existing cast-in-place concrete end bearing piles to provide additional uplift resistance to the existing pile foundations. The piles were used in locations where conventional boring rigs were not able to access.

The micropiles had a nominal diameter of 178 mm, a minimum pile length of 9 m and were typically drilled 4.5 to 6 m into competent insitu oilsand. The micropiles were constructed by drilling a cased hole, placing a 45 mm diameter Dywidag bar reinforcement and grouting the hole. The micropiles were pressure grouted and post grouted.

The allowable load of the micropiles was designed using the estimated static design parameters for the oilsand and overlying soils, based on results of the geotechnical investigation. Design loads were typically 240 kN for compression piles and 265 kN for tension piles.

Vertical micropiles have limited lateral loading capacity due to the micropile's relatively small diameter. Where the vertical micropiles were required to resist horizontal load, the upper 3 m of the micropiles were provided with steel casing to provide additional lateral capacity and/or the micropiles were battered.

Load tests were performed on three prototype piles and extended creep tests were conducted on a number of piles prior to production. In addition proof tests were performed on over 300 production piles to confirm acceptable performance. The micropile load tests and proof tests generally met the specifications.

This paper describes the design and installation of the micropiles and presents a summary of the results collected during the extensive micropile load test program.

2. SITE CONDITIONS

The Syncrude Canada Ltd. Upgrader Expansion (UE-1) Project is located north of Fort McMurray, Alberta. The plant site has been investigated and the soils conditions characterized during extensive geotechnical investigations (Thurber 1985 and 2001).

The plant site is typically underlain by a sequence of sand and/or gravel fill overlying native sand, clay till, and oilsand containing occasional clay shale and cemented siltstone stringers. The depth to oilsand typically ranges from about 4 to 6 m below ground level, where the micropiles were installed. The bitumen content of oilsand varied from 1.5 to 10.8% at depths ranging from 4.6 to 13.4 m.

The native sand and gravel are typically compact to dense; the clay till is stiff to very stiff, and the oilsand is very dense in soils terminology.

Triaxial tests on high quality undisturbed cores of oilsand (Thurber, 1985) yielded a peak friction angle of 50 degrees. The bitumen content of these core samples was between 2.7 and 4.3% at a depth of 11.9 and 12.8 m at the Syncrude Plant site. Standard Penetration Test N values are typically greater than 100 blows per 300 mm.

High capacities are achieved on cast in place concrete end bearing belled piles founded in oilsand (Sharma et al. 1986). Recent pile load tests on straight shaft concrete piles installed in the McMurray oilsands but at a different site also indicate that these piles are capable of developing very high shaft friction in the oilsand.

3. MICROPILE DESIGN AND INSTALLATION

Federal Highway Administration (FHWA) “Micropile Design and Construction Guidelines” characterizes micropiles into two general types: displacement piles and replacement piles.

Displacement piles are driven or vibrated into the ground, thereby displacing the surrounding soil laterally during installation. Replacement piles are placed or constructed within a previously drilled hole, thus replacing the excavated ground. The micropiles for this project were of the replacement pile type combined with pressured grouting to increase the pile surface area by displacing the surrounding soil.

The micropiles had a nominal diameter of 178 mm and were constructed by drilling a cased hole to the specified depth, placing a 45 mm diameter Dywidag bar reinforcement and grouting the hole. Typical details of compression and tension piles are shown in Figure 1.

Pressure grouting was specified to achieve the required pile capacities and involved primary grouting during the initial installation and post pressure grouting after the primary grout had setup. Post grouting involved injecting additional grout under pressures in the range of 3 MPa through a grout pipe and valves installed with the anchor. A minimum of 24 hours was allowed for setting up time between successive pressure grouting stages.

The allowable capacity of the micropiles was designed based on allowable skin friction along the grouted pile length. Typical skin friction values of 50 kPa were used for the grouted length in the overburden sand and clay and 100 kPa in the oilsand. These values were derived based on effective strength parameters obtained from the Syncrude site and also supported by typical values reported in the literature (FHWA).

The design static micropile capacities were 240 kN for compression piles (MP1 in Figure 1) and 265 kN for tension piles (MP5 in Figure 1). The tension pile (MP5) included a minimum of 6 m of free stress length as specified by the structural designers. The design pile load was estimated based on the pile length installed in oilsand assuming that the upper 3 to 4 m of micropiles installed in the overburden could be disturbed or temporary removed due to future construction activities. A vertical pile deflection of 6 mm was estimated at design load for compression piles.

All piles were inspected during installation and proof (uplift) tests were conducted on the majority of micropile installations to confirm the load capacity. The tension piles were pre-tensioned to about 30% of the design load after the proof test to remove possible slack in the micropiles.

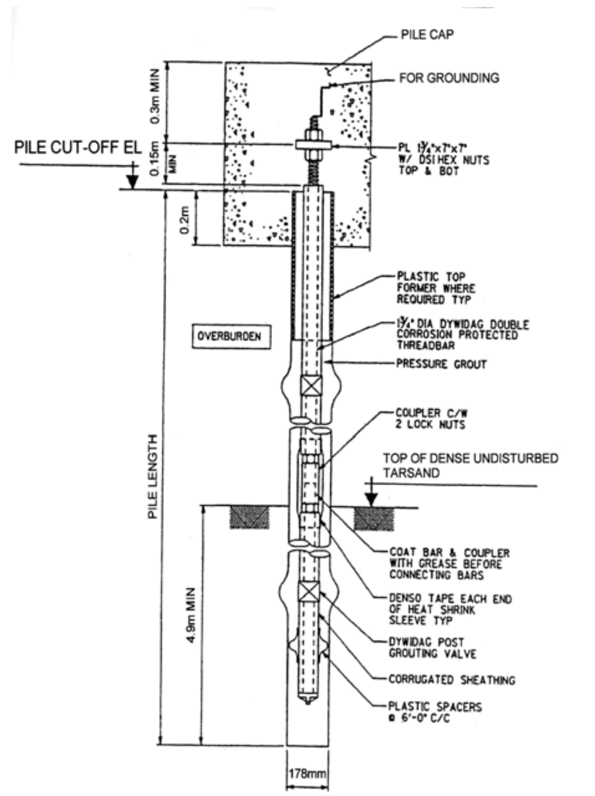
4. DESIGN LOAD TESTS

4.1 Verification Test

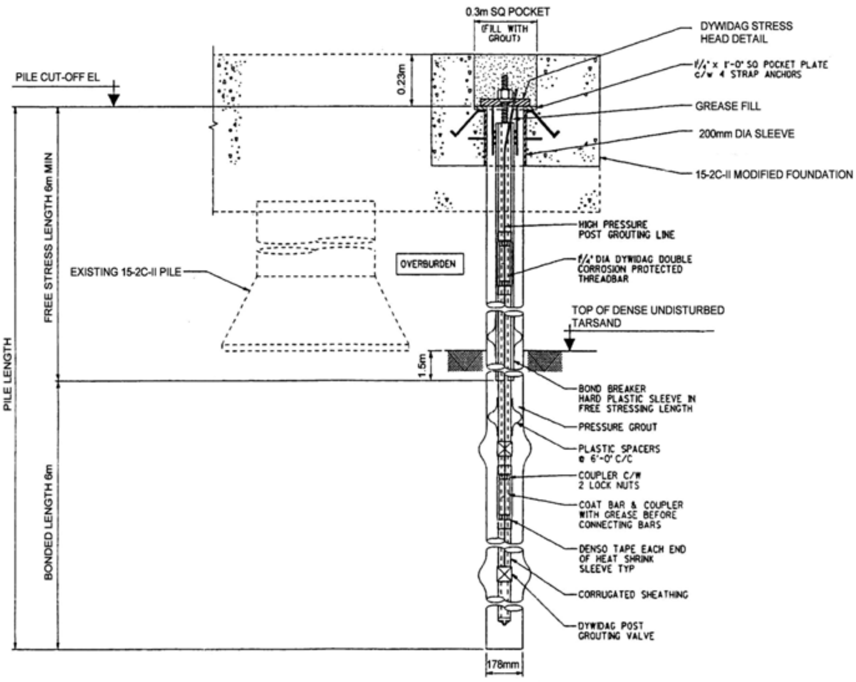
Full scale pile load tests were performed on two post grouted micropiles (TP1 and TP3) and one non-post grouted compression pile (TP2) to confirm the design vertical pile capacity before the installation of the production piles.

The test piles TP1 and TP2 were originally loaded to 2.5 times design load without failure and measured relatively little vertical pile deflections. The tests were subsequently repeated to 1.67 times design load and the results of the retests are presented herein.

Test pile TP1 was subjected to axial compression and had a pile length of 11.5 m and penetrated 5 m into the competent oilsand. A schematic of the test pile arrangement is shown in Figure 2. TP1 was loaded to 400 kN, equivalent to 1.67 times the design load of



COMPRESSION PILE TYPE MP1



TENSION PILE TYPE MP5

Figure 1 Micropiles General Details

240 kN. The load test was conducted in six equal increments and each increment was held between 30 and 60 minutes The measured deflection at design load was 4.7 mm and the measured deflection at 1.67 times design load was 7.8 mm. The load deflection curve of the test pile (TP1) is shown in Figure 3.

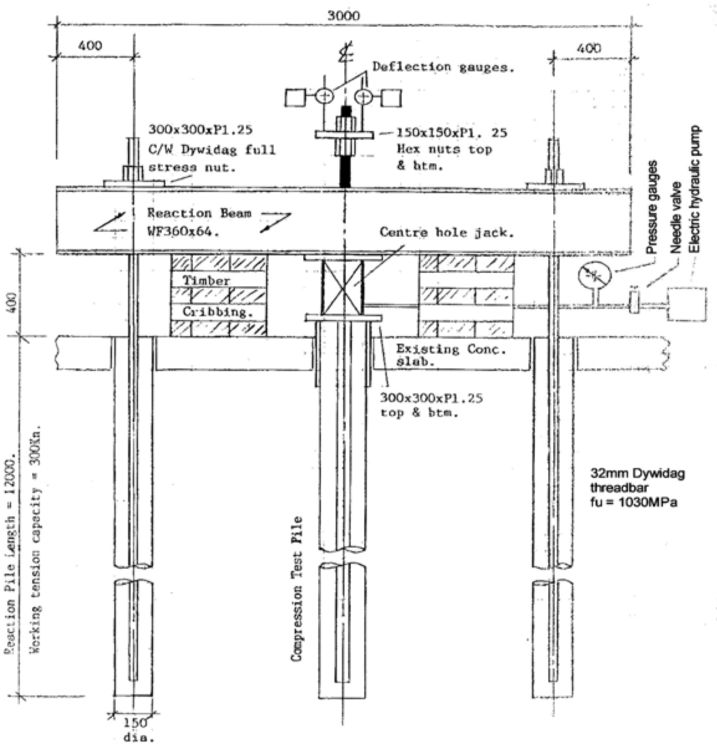


Figure 2 Schematic of Micropile Load Test Arrangement – Compression Pile

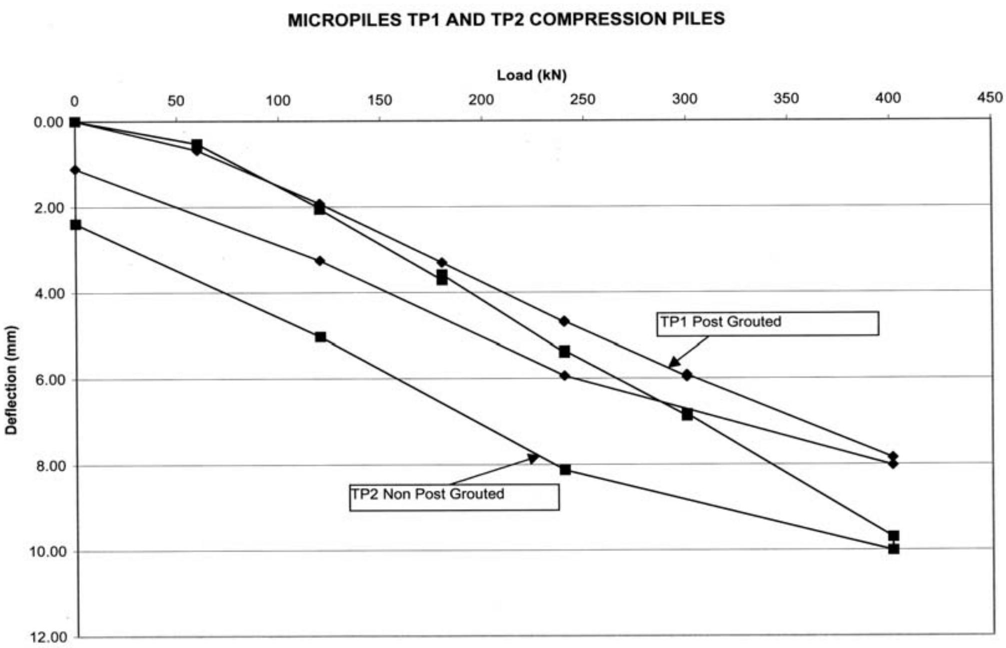


Figure 3 Load Test Data from Compression Piles

TP2 was carried out on a non-post grouted compression pile. TP2 had a pile length of 11.5 m and penetrated 5.5 m into the oilsand. TP2 was also loaded to 400 kN using the same procedure as TP1. At design load the measured deflection was 5.4 mm and at 1.67 times design load the measured deflection was 9.4 mm as shown in Figure 3. The load settlement curve showed a very small rebound instead of creep during the load holding stage of the test indicating that the load was likely not kept constant.

Test pile (TP3) was subjected to axial tension and had a pile length of 14.6 m and penetrated 6.7 m into oilsand. TP3 was loaded in eight load increments to a maximum test load of 663 kN in tension, which was equivalent to about 2.5 times the design load of 265 kN without reaching failure as shown in Figure 4. The measured deflection was 24.7 mm at 2.5 times design load and 9.7 mm at the design load of 265 kN.

4.2 Creep Test

Creep tests were conducted on the three test piles after the completion of the verification testing. The post grouted compression pile TP1 was held constant at 1.67 times design load for a period of 300 minutes and recorded a total movement of 8.0 mm as shown in Figure 3. The non-post grouted compression pile TP2 recorded a total movement of 10.0 mm. The tension pile TP3 was held constant at 2.5 times design load for 300 minutes and recorded a total movement of 26.1 mm.

There was some fluctuation on the measured vertical deflection at the top of pile over the monitoring period between 20 and 50 minutes where the applied load was not held constant caused likely due to jack-bleed etc as illustrated in Figure 5. However, the overall measured creep rate was less than 1 mm per log cycle.

4.3 Results

The verification test results indicated that both compression and tension piles were capable of supporting the design loads of 240 kN and 265 kN respectively, with factors of safety in excess of 2.5 on ultimate capacity.

The creep test results also indicated creep rates were less than 1 mm per log cycle where the verification test piles were loaded to 1.67 and 2.5 times of design load. Standard criteria for allowable creep displacement is typically in the order of 1 to 2 mm per log cycle of time for acceptance criteria for soil anchor testing.

Results of TP2 carried out on a non post grouted compression pile indicated an approximately 20% higher pile deflection compared to the post grouted compression pile TP1. Post grouting was specified for all production piles for the project.

5. ACCEPTANCE CRITERIA FOR PROOF TESTING ON PRODUCTION PILES

Based on the results of the load tests and following the recommended guidelines from the FHWA's Micropile Design and Construction Guidelines, the acceptance criteria for the proof tests on production piles were defined as follows:

- The proof test pile shall support an applied test load of at least 1.67 times design load without failure.
- While holding the applied test load of 1.67 times design load, the creep shall not exceed 1 mm during the period of 1 to 10 minutes (one log cycle).
- If the 1 mm value is exceeded, the total creep movement within the period of 6 to 60 minutes (equal to one log cycle of time) shall not exceed 2 mm.

In addition, the maximum vertical pile top deflection was limited to 6 mm at the design load for axial compression piles based on the design assumption.

6. PROOF TESTS AND CREEP TEST RESULTS

Proof tests were carried out on 330 production piles (304 compression piles and 26 tension piles) representing approximately 66% of the micropiles installed between June 2002 and December 2003. This number of proof tests exceeds the typically recommended 5% proof testing on production piles.
For ease of testing, the proof test was carried out in tension as shown on Figure 6. The load was applied in equal increment to the maximum load of 1.67 times design load and each load step was held for 10 minutes. The proof test results were reviewed based on the acceptance criteria and were accepted where the results met the criteria. A summary of the test results is presented in Table 1.

TABLE 1 SUMMARY OF PROOF TEST RESULTS

	Measured Pile Top Vertical Deflection (mm)		**Measured Creep at 1.67 Times Design Load (mm/log cycle)**
	At Design Load	**At 1.67 Times Design Load**	
Compression Piles			
Min	1.0	0.5	0.3
Max	6.6	16.4	1.0
Average	3.3	6.4	0.3
Standard Deviation	1.2	2.2	0.2
Tension Piles			
Min	7.4	13.4	0.0
Max	14.5	25.8	0.3
Average	11.5	21.2	0.1
Standard Deviation	1.7	2.7	0.1

Approximately 10 proof tests were repeated where the initial results did not meet the creep criteria. Another five proof test results were reviewed by the structural designer, where the vertical pile top deflection exceeded the 6 mm at design load.

Nine extended creep tests were carried out on selected micropiles where the 1.67 times design load was applied for 300 minutes. The measured creep rates were less than 1 mm per log cycle.

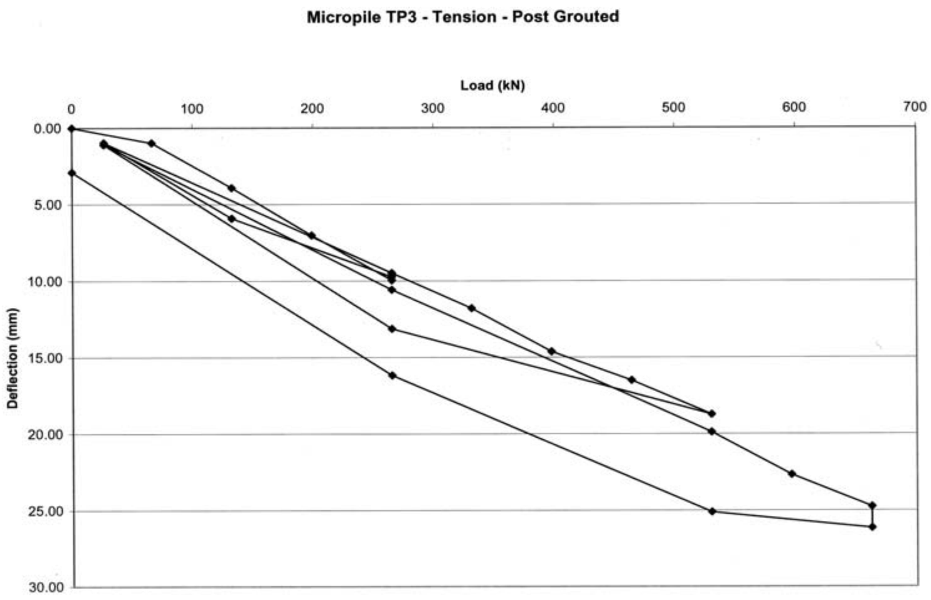


Figure 4 Load Test from Tension Pile

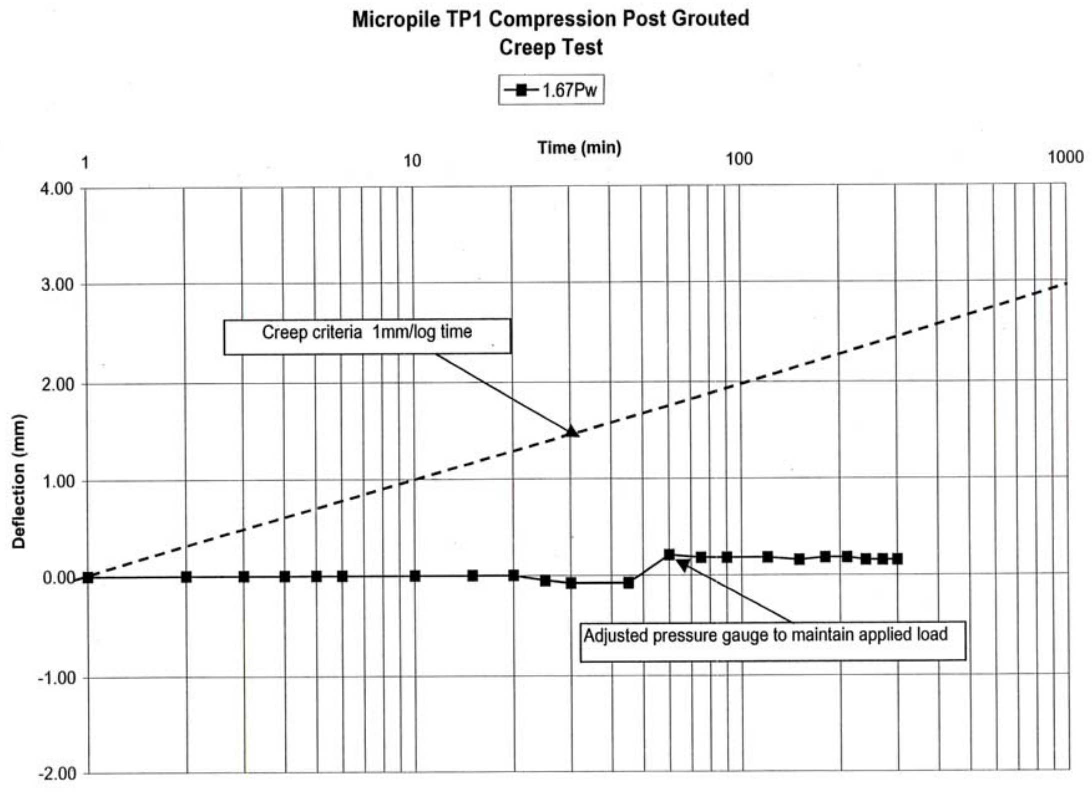


Figure 5 Creep Test Data from Compression Pile (TP1)

7. CONCLUSIONS

The verification test results confirmed allowable design loads of 240 kN on compression piles and 265 kN for tension piles with acceptable micropile deflections.

Pressure grouting was required to develop the bond capacity.

The proof test results confirmed that the micropiles met the specified acceptable criteria.

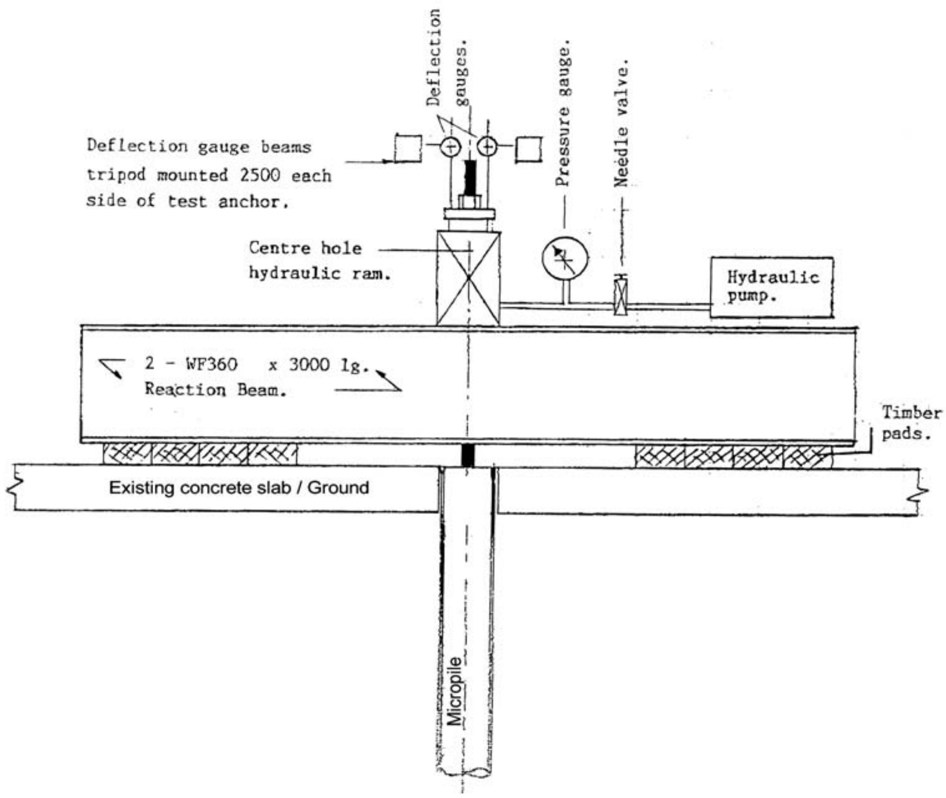


Figure 6 Schematic of Micropile Proof Test Arrangement

The extended creep test results indicated acceptable pile creep at design loads.

The micropile capacities reported in this paper were from testing performed at the Syncrude Mildred Lake Plant site north of Fort McMurray. It is recommended that micropiles should not be used in other sites without geotechnical investigation and verification tests.

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