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Pile driving triggers subsidence Le battage de pieux peut causer l'effondrement du sol

K.R. PEAKER, Ph.D., P.Eng., Vice President, Trow Geotechnical Ltd, Canada

S.A. AHMAD, M.A.Sc., P.Eng., Manager, Geotechnical Division, Trow Geotechnical Ltd, Canada

SYNOPSIS: The Civic Regional Building in the downtown core of Sudbury, Ontario, Canada is a five-storey concrete frame building supported on long driven concrete piles. During driving part of the site settled 0.9 m over 48 hours.

The subsoil stratigraphy beneath the Sudbury Civil Regional Building comprises 6 m of loose recent alluvial material with a groundwater table 1 to 2 m beneath the ground surface, followed by 12 m of soft to firm silty clay. Beneath this clay layer and continuing to a depth of 46 m is a stratum of 27 m of loose to dense fine becoming coarse silt. Bedrock is at a depth of 65 m with 15 m of dense till over bedrock.

Soon after pile driving began water was noted rising adjacent to the piles. During the operation when a damaged pile was removed, water gushed freely from the hole. Up to 0.9 m of subsidence was recorded with the centre of the settlement occurring near the pile driving operation. The zone of influence for this subsidence extended well beyond the property lines into adjacent roadways; fortunately no buildings were immediately adjacent to this site. The lateral movement of piles close to the centre of the zone was measured up to 150 mm toward the centre of the zone of influence.

INTRODUCTION

The Ontario concept of Regional Government in the mid 1970's gave rise to the Sudbury Civic Square project. This project included a civic Region Building and a Provincial Building. The project in the downtown core consisted of a 5-storey single parking basement level structure with adjacent West Tower Building and a proposed future 12-storey Provincial Building. These proposed structures were to wrap around the existing Bell Canada Tower a 5-storey single basement office complex.

The site had been used as a parking lot for several years after demolition of smaller commercial type stores and residential housing. This area had, during earlier times, been the site of Junction Creek that meandered through the development. The flood plain occupied most of the area prior to infilling and redirecting the creek through a concrete culvert. The Bell Building immediately north of the proposed buildings and forming part of the complex was founded on a raft below a single basement level (see Figure 1).

This paper deals with the pile driving and the resulting subsidence that occurred at the Civic Region Building.

SUBSOIL DATA

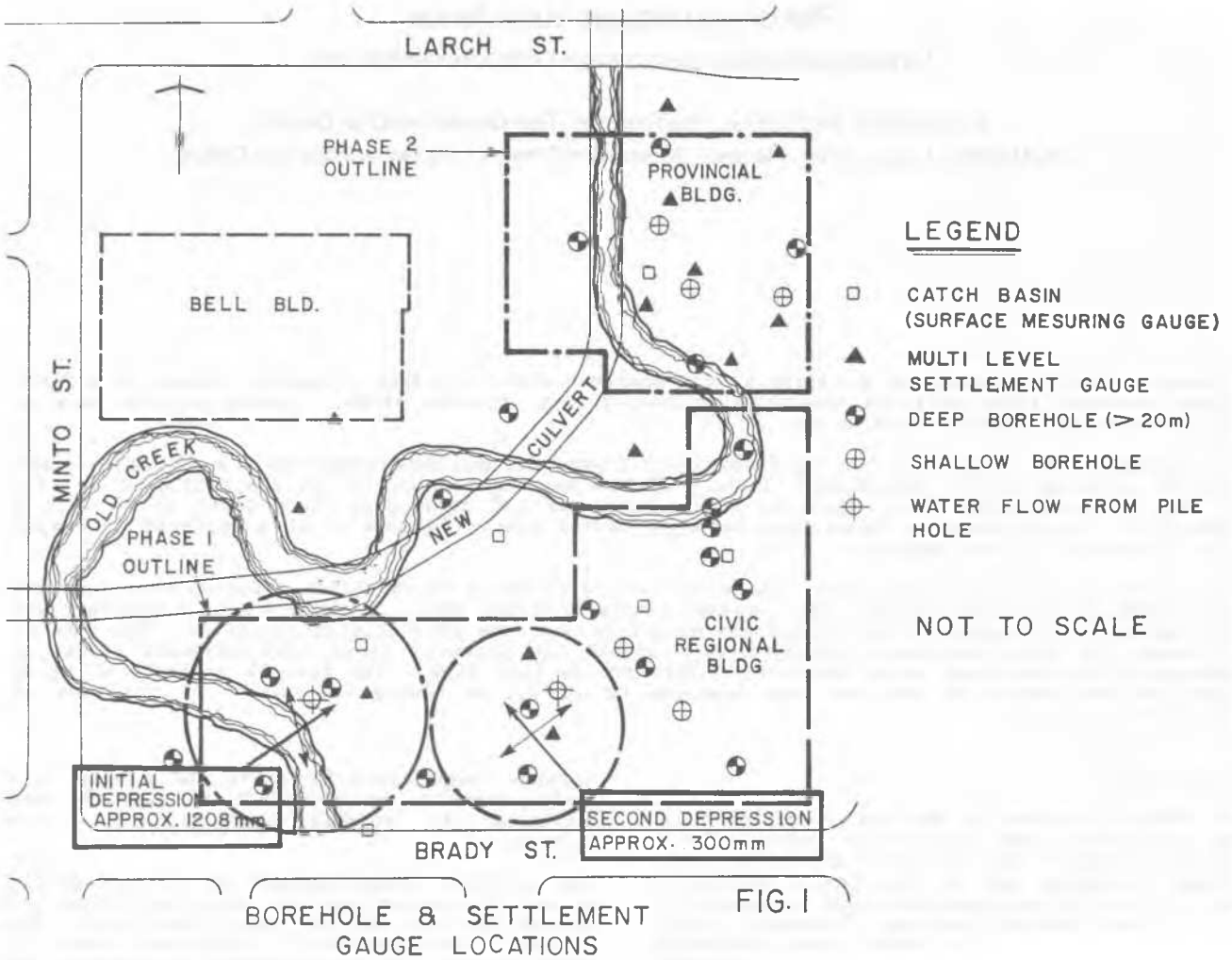
The geology of the Sudbury area⁽¹⁾ is noted for its extreme variations in bedrock elevation and soft clays. The geology is

further complicated by silts and clayey silt whose capacity is difficult to predict when subjected to dynamic loading, i.e., pile driving.

The original design concept was to incorporate a raft foundation for the major buildings and spread footings for the connecting links. The initial investigation⁽²⁾ indicated that it would probably be more economic to support the building on piles. Further investigations to select pile founding levels were subsequently undertaken.

The subsoil was found to be reasonably uniform over the entire site, with the exception of the depth of fill and alluvium overlying the firm silty clay. This alluvium was found to vary from 2 to 6 metres in depth with the deeper depths reflecting old creek channels or flood plains that had traversed the site in a random fashion. Figure 2 shows a typical subsoil profile consisting of 6 metres of fill and recent alluvial material over a firm silty clay to a depth of 18 metres; below 18 metres the clay grades to a stratified silt gradually becoming more sandy and at 30 metres changes to a silty sand. To the 40 metres depth the silt and sandy silt exist in a compact to dense state. Below 40 metres and to 46 metres, a layer of loose silty sand was encountered overlying dense sand, gravel and cobble till. Below 46 metres, bedrock was not proven, but is anticipated at 65 metres depth.

The geotechnical properties of each layer are included in abbreviated form on Figure 2.



BOREHOLE & SETTLEMENT GAUGE LOCATIONS

Figure 3 indicates typical gradings for representative depths. The groundwater level in the upper fill and alluvium was near old creek level some 2 metres below existing surrounding ground surface. The sand gravel and cobble till at a depth of 46 metres showed a peizometric head at least 1 metre above the existing ground surface, i.e., Elevation 257 metres.

FOUNDATION CONSIDERATIONS

Prior to construction the designers decided to eliminate the raft and utilized driven piles. Experience in this area showed low displacement H piles would penetrate 3 to 4.5 metres beyond the depth of displacement piles. Because of the potential cost saving displacement piles were considered most practical. Based on this requirement it was estimated that piles carrying nominal loads, i.e., 445 kN on a 250 mm and 710 kN on a 300 mm displacement pile would meet refusal at an average depth of 35 metres or Elevation 221 metres. This depth was determined by the

Elevation (m)	Depth (m)	Description	Comments
-256	0	FILL - sand, organics, loose	N < 4
-252.4	3.0	SILTY CLAY ALLUVIUM (organic) loose	N < 3
-250	6.0	SILTY CLAY, FIRM	C = 40 kPa σ = 18.4 kN/m ³ W = 35% 40 LL = 33% PL = 19%
-237.8	18.2	SILT - STRATIFIED with clay seams compact to dense	N > 20 < 40 σ = 20.1 kN/m ³ W = 20%
-225.6	30.4	MORE SAND	
-216.4	39.6	SILT SANDY compact to dense	N > 20 < 70 σ = 20.1 kN/m ³ W = 18-20%
-209.7	45.7	SANDY SILTY loose, compact	N < 12 W = 22%
-57.8	57.8	SAND GRAVEL & COBBLES (TILL) very dense	N > 100

FIGURE 2 SUBSOIL STRATIGRAPHY

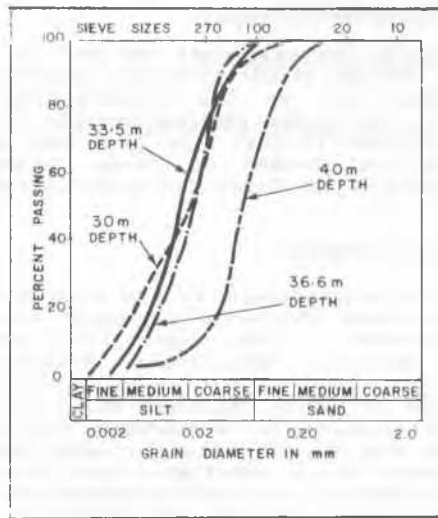


FIGURE 3 TYPICAL GRAIN SIZE DISTRIBUTION OVER ENTIRE DEPTH

standard penetration test results in the boreholes and to a larger extent by the dynamic cones driven at the base of the boreholes. Local experience had shown that typical pile 'refusal', i.e., 15 blows/25 mm would be achieved for displacement piles 4.5 to 6 metres below the refusal to driving of the dynamic cone i.e., more than 100 blows/300 mm.

The actual load carrying capacity of the piles was to be determined by load tests, however, the most economic pile for the deep depths was one that was driven to a capacity equal to the structural capacity of the pile. The piles selected were precast concrete piles with quick attach patented full moment splices. The nominal 200 mm pile was to carry 620 kN while the 300 mm size should be driven to carry maximum loads of 1020 kN. These capacities were to require sets of 20 blows/25 mm with the maximum safe capacity to be confirmed by the load test.

PILE LOAD TEST RESULTS

Three piles were selected for testing. The result of these tests is presented as Figure 4. It can be seen that the 300 mm piles were capable of carrying a 1020 kN design load and the 200 mm pile obtained the necessary safe capacity of 620 kN.

PILE DRIVING - CIVIC REGION BUILDING

Pile driving began with the driving of the test piles January 13 and 31, 1975. Production driving commenced late January of 1975. During the early days on site, significant problems associated with pile breakage occurred and the driving schedule was very much behind by mid February when it was

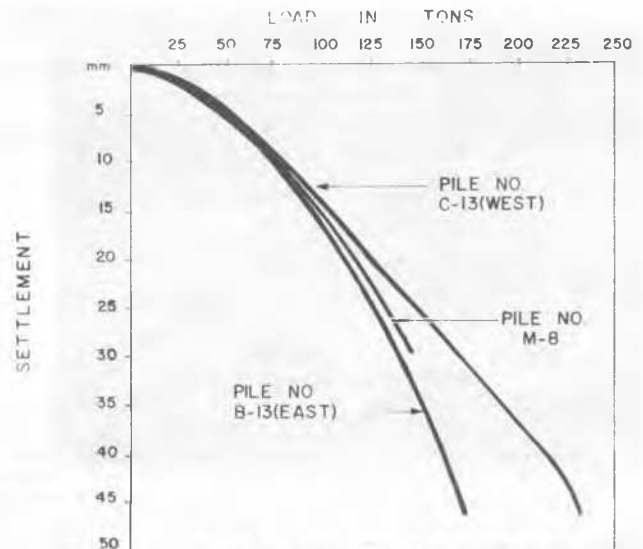


FIGURE 4 PILE LOAD TEST RESULTS

decided to bring a second pile driver on site. From January to mid February only 20 of the 437 piles for the civic region complex had been driven. The initial hammer, a Linkbelt 520 rated at 35 kJ was supplemented with a Linkbelt 440 (24 kJ). Both hammers when checked with the Pile Driving Analyser were delivering up to the designated 24 kJ of energy to the pile.

By March 5, both units working side by side were driving up to 6 piles per day. On one pile a maximum of 2000 blows was required to penetrate the upper 0.3 to 0.6 metres of frozen ground, however, this was exceptional as most piles penetrated the frost zone with less than 150 blows.

During the first week of March, a local depression around the pile drivers, approximately 36 metres in diameter and 1.2 metres in depth with a volume of 1200 cubic metres was recorded. This depression occurred rapidly, i.e., within 2 days. Elevations taken on catch basins in the depression indicated a settlement of 1 metre below original level. The extent of this subsidence is shown on Figure 1. As this depression was forming driving continued. Silt laden water was noted to be flowing up around some of the piles. An analysis of the silt showed that it corresponded to the grain sizes of the material from the deeper silt strata below 21.5 metres.

Piles within the depression moved more than 150 mm laterally towards the centre of the zone of influence and there was concern for their integrity. A retapping program carried out on the piles that were obviously affected showed that their original resistance to driving remained unchanged. Figure 5 indicates some of the magnitude of the settlement.



FIGURE 5
SUBSIDENCE VISABLE AFTER PILE CUT-OFF

Speculation as to what was the source of the settlement and the consequences for continuing work were of immediate concern. To determine if the settlement was deep-seated or occurred as a result of consolidation of the upper loose fill and alluvial material, settlement points were installed at ground surface, within the fill/alluvium and into the silty clay. During installation of the settlement gauges a pile suspect of being damaged was withdrawn from the position shown on Figure 1 and water gushed from the 18 metre hole for a 38 to 48 hour period and settlement of 1 foot over large (30 metre cone) area resulted.

It was obvious that the pile driving was causing the problem regardless of from where the problem originated. To reduce this effect, the pile drivers were separated to opposite ends of the site and pile driving was restricted to 1 or 2 piles a day per pile group. Piling continued until the 437 piles were in place and little, i.e., less than 25 mm of movement was detected over the remainder of this site. No pattern of movement at depth could be obtained from the settlement points.

VIBRATION MONITORING - OFF SITE DAMAGE

Throughout the entire driving program a vibration consultant was retained to assess the vibrations and potential damage resulting from pile driving. The results of this monitoring showed that at no time did maximum vibration amplitudes reach 50 mm per second at a distance of 5 metres from the pile. Apart from significant cracking to adjacent roads no off site damage was recorded for this project.

LONG TERM PERFORMANCE

Monitoring of the site over the past 10 years shows no adverse effect from the subsidence to the project or to the neighbouring Bell Building. It is interesting to note that no other buildings in this area have been or are likely to be founded on piles, since the construction of the Civic Centre Buildings.

ENGINEERING COMMENTS

It would be significant if the site data and experience could delineate the exact source of the settlement. The upper fill and the alluvial material were loose initially and could have been a potential source of subsidence. Tests carried out in these materials after the subsidence showed an increased density and decreased water content. This could have resulted from vibration induced consolidation and densification or it could also have resulted by driving a large number of displacement piles. The silt encountered at a depth of 40 metres is described as loose and possibly the driving could have resulted in vibrations that densified this material -water was noted emerging from extracted pile holes and this could have originated at this level. The measuring points that did show relevant movement indicated deep seated subsidence.

It is possible that for the major depression of 1.2 metres of subsidence that this movement occurred in both the upper and lower layers.

CONCLUSIONS

1. The choice of pile type should be carefully related to all site conditions and economics should not be the prime consideration.
2. The potential for densification of loose layers of cohesionless material can be of greater significance than is often considered for most sites.
3. Ground control measurements must be well thought out and be in place prior to construction if they are to provide the control and information to warrant their cost.
4. The long-term effect of the subsidence in this case was negligible for the constructed building and for adjacent property.

REFERENCES

- (1) Jas. E. Thomson 1956 "Geology of the Sudbury Basin", Ontario Department of Mines, Johnston.
- (2) Trow 1973 "Foundation Investigation Proposed Civic Regional Building Sudbury, Ontario, Report prepared for the Regional Municipality of Sudbury, 52047.