Ground improvement case history of shallow foundations on dynamically compacted deep fill

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Joseph Yonan, P.Eng., Tony Ruban, P.Eng.
EBA Engineering Consultants Ltd., Calgary, Alberta, Canada
EBA Engineering Consultants Ltd., Edmonton, Alberta, Canada

ABSTRACT
A new, fully automated precast concrete pipe plant was constructed in the northwest area of Calgary, Alberta. The initial site investigation identified a deep fill up to 32 m thick. Traditional approaches of deep foundations or replacing the existing uncontrolled fill were initially evaluated as options to address the issue of the deep fill. A more innovative approach using ground improvement and shallow footings was proposed to reduce the cost of foundation construction. This paper provides case history information of the use of dynamic compaction as a successful technique of ground improvement in the Calgary area.

RÉSUMÉ
La construction d'une nouvelle usine de tuyaux de ciment pré-moulés, entièrement automatisée, a été prévue dans la zone nord-ouest de Calgary, Alberta. L'investigation préliminaire du site a permis de localiser un remblai d'une épaisseur de 32 mètres. Deux solutions ont été envisagées pour aborder ce problème: l'approche traditionnelle de construction de fondations profondes ou le remplacement du remblai. Une approche plus innovante, utilisant des techniques d'amélioration du sol associées à la construction de semelles superficielles, a été proposée pour réduire le coût de la construction des fondations. Cet article présente une étude de cas pour lequel l'utilisation de la compaction dynamique a été utilisée comme une technique efficace pour l'amélioration du sol dans la région de Calgary.

1 INTRODUCTION

This paper presents a case history of the use of dynamic compaction technique of ground improvement for the design and construction of a new, fully automated precast concrete pipe plant in the northwest area of Calgary, Alberta, as shown in Figure 1. The pipe plant will incorporate support equipment, machines, overhead cranes, a kiln for casting and curing pipes, and a number of concrete pits. The remaining portion of the pipe plant will have slab-on-grade floors.

The project site was originally a gravel quarry. The gravel was excavated to a maximum depth of approximately 32 m below the existing ground surface. The quarry was later backfilled with overburden soils consisting of clay, silt, and sand that were removed from other parts of the quarry. A part-time spot check of compaction testing was conducted during the backfilling operation.

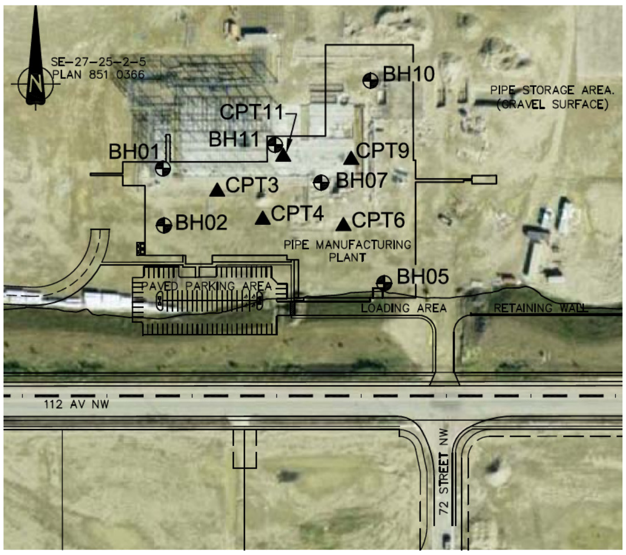
Historically, an approach of excavation and fill replacement or piles is common practice in the Calgary area. However, due the extensive depth of fill, it was unlikely that the conventional approaches were economically viable. One of the options considered was to implement a ground improvement technique to densify the existing fill using dynamic compaction. A dynamic cone testing program was conducted to monitor the compaction improvement of the existing fill and provide an indication of soil density improvement.

Figure 1. Site location plan.

2 GEOTECHNICAL INVESTIGATION

A total of 11 testholes were advanced, consisting of 6 augured boreholes drilled to depths ranging between

18.6 m and 34.8 m below existing ground surface. In addition, five Cone Penetration Testing (CPT) soundings were advanced to depths ranging between 13.5 m and 30.3 m. The depth of CPT penetration was limited due to effective refusal encountered in the gravelly clay fill and clay till encountered during testing. The approximate testhole locations are shown on Figure 2. Hand slotted, 25 mm PVC standpipes were installed in all the drilled (augured) boreholes to permit monitoring of depth to groundwater level.



APPROXIMATE AUGER BOREHOLE LOCATION

APPROXIMATE CPT LOCATION

Figure 2. Approximate borehole and CPT locations.

3 SUBSURFACE CONDITIONS

Fill consisting of clay, silt, or sand was encountered in all the testholes at the surface and extended to depths ranging between 15.2 m and 32.3 m. Clay fill was encountered below sand fill or silt fill in all the boreholes at the surface. The thickness of the clay fill varied in the range of 3.4 m to 26.5 m. The clay fill was generally silty, contained some sand, and varied in gravel content (from a trace of gravel to some gravel). The clay fill also contained some organics. The clay fill was low to medium plastic, moist, and light brown to medium brown or grey in colour. Silt fill was encountered in some boreholes at depths ranging between 15.2 m and 28.1 m. The thickness of silt fill varied from 3.0 m to 4.6 m. The silt fill contained some sand, some gravel, and a trace of clay. Occasional cobbles were also encountered in the clay and silt fill. The silt fill was low plastic, moist, and medium brown to dark brown in colour. Sand fill was encountered in one borehole at a depth of 15.2 m below the existing ground surface. The sand fill was 1.2 m thick. The sand fill contained some silt and some gravel. The sand fill was moist and medium brown in colour.

Clay till was encountered in the northwest portion of the building footprint underlying the clay fill at a depth of 32.3 m. The clay till was 1.8 m thick and was described as silty, some sand, and varied in gravel content (from trace to some gravel). The clay till was very stiff in consistency and was medium plastic, moist, and medium brown in colour.

Native clay and gravel was encountered in the southeast portion of the building's footprint at a depth of 15.2 m below the existing ground surface. The clay and gravel was silty and sandy. The clay portion was medium plastic. The clay and gravel was moist and grey in colour. The borehole in this area was terminated in clay and gravel at a depth of 18.6 m below the existing ground surface due to effective auger refusal.

Sand and gravel were encountered at depths ranging between 26.5 m and 34.1 m below the existing ground surface. The sand and gravel were silty and were compact to dense, damp, and medium brown or grey in colour.

Upon completion of drilling, all the boreholes were dry. The depth to groundwater in each of the standpipes was measured after two weeks at depths ranging between 14.70 m and 15.32 m below the existing ground surface in half of the boreholes. The remaining standpipes were dry.

4 FOUNDATION CONSIDERATIONS

As mentioned above, fill soils extending up to 32.3 m below the existing ground surface were encountered during the drilling program. Part-time compaction monitoring (spot checks) were conducted on the fill placed above the native soils. The field drilling and CPT testing indicated a well-compacted fill in the lower 15 m of the fill.

Due to the variability of the deep fill soils below the building footprint, a shallow foundation system consisting of strip and spread footings bearing on the existing fill soils is expected to experience a significant amount of deformation over the life of the structure. However, due to the variability of the fill quality and presence of organic pockets within the upper fill, a range of long-term differential settlement over 100 mm was anticipated. This level of settlement was not tolerable for the performance of the structure.

To minimize the total and differential settlement for shallow foundations, several possible options were considered to develop the site keeping the existing fill:

- Ground improvement of the existing upper fill. This would entail performing some form of subsurface densification, such as rapid impact or dynamic compaction, resulting in reducing the differential settlement to a value of approximately 50 mm.
- Partial or complete replacement of the fill. Based on the site investigation, the lower 15 m appeared to be fairly consistent and reasonably competent. Therefore, the need to replace the lower 15 m of fill would be less critical than the upper 15 m. To further reduce the potential of long-term differential

settlement, the existing fill soils should be excavated to a depth of at least 15 m below the final floor elevation of the building structure and replaced with structural fill.

- Alternatively, if any differential settlement could not be tolerated, a deep foundation system consisting of driven steel piles founded on native sand and gravel (encountered at depths ranging between 26.5 m and 34.1 m below the existing ground surface) could be considered to support the structural loads of the proposed development.

The ground improvement dynamic compaction option was selected by the designers and the owner as the preferred alternative for site development based on the premise that some differential settlement was considered to be tolerable. Discussions with the designers indicated that re-levelling of most footing foundations was feasible in the event that differential settlement began to affect the performance of individual foundations.

4.1 Ground Improvement

The approach for ground improvement site preparation depended largely on the selected option of ground improvement and the level of potential settlement. It was understood that the building structure could be designed to tolerate an estimated maximum 100 mm of total settlement and 50 mm of differential settlement if a ground improvement approach of the existing fill was adopted. Based on discussions with the ground improvement contractor (GeoPac West Ltd.), it was agreed that the recommended approach would comprise the use of dynamic compaction technique with a series of passes across the site utilizing up to a 22.5 ton drop weight and an approximate drop height of 28 m.

4.2 Shallow Foundation

A shallow foundation system consisting of spread and strip footings was considered for the proposed building structure with the risk of potential differential settlement.

The allowable static bearing pressure for the design of strip and spread footings and raft foundation system was 200 kPa on dynamically compacted soils.

4.3 Dynamic Compaction

4.3.1 General

Dynamic compaction of the project site was conducted by a specialized contractor (GeoPac West Ltd.) in November 2007. The dynamic compaction undertaken targeted to improve the penetration resistance and density variation of the fill soils present at the project site up to a depth of approximately 10 m to 15 m below the original ground surface.

4.3.2 Dynamic Compaction Program

Prior to undertaking the dynamic compaction program, the site was prepared in the following sequence. The existing grade was subcut from the existing elevation to a level approximately 3 m below the final floor subgrade elevation in the proposed building footprint area plus an additional 10 m beyond the limits of the footprint. A 2.5 m thick layer of structural fill was placed over the excavated area. At some locations of the site, mainly in the west and northwest where the existing grade was 3 m below the final floor subgrade elevation, structural fill was placed to raise the site to 0.5 m below the final floor subgrade. The structural fill was well-graded 75 mm pit-run gravel with less than 5% fines (passing the 80 um sieve). This granular fill was compacted to 95% of Standard Proctor maximum dry density (SPD) in maximum 300 mm lifts.

The dynamic compaction was conducted in a series of three high-energy phases (Phases 1, 2, and 3) across the project site using a drop weight of 22.5 tons and a drop height of 28 m. The third phase was followed by a low-energy “ironing” phase using a drop weight (tamper) of 19.5 tons and a drop height of 15 m. The ironing phase was primarily conducted to level the site after Phase 3 of dynamic compaction.

An initial grid spacing of 10 m for impact points were used in the first phase of dynamic compaction. A total of 173 compaction points with 18 drops per point was undertaken for the first phase. The impact points in the second phase of compaction were located midway between the first set of impact points in a grid spacing of 10 m. A total of 177 compaction points with 11 drops per point were conducted for the second phase.

The third phase of compaction utilized a grid spacing of approximately 7 m at impact points located midway between the first and second set of impact points. A total of 350 compaction points were undertaken for Phase 3. The total ironing energy applied after Phase 3 compaction was 862,000 ton-metres.

Based on the total energy used for all phases, including the ironing phase and the total treatment area, an average of 303 ton-metres of energy per square metre was applied to dynamically compact the overall area.

During the dynamic compaction process, a crater was formed at the impact point that was up to 2 m deep (Figure 3).

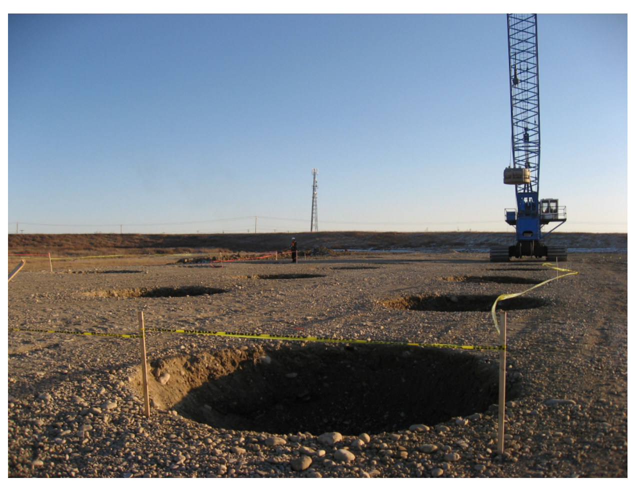


Figure 3. Impact craters from drop hammer.

These craters were backfilled by infilling with a dozer using the surficial granular pit-run on site. After completing the three sets of dynamic compaction, a final seating pass was completed by the ground improvement contractor to tighten the surface of the gravel. After completing the dynamic compaction, the entire site had been lowered by approximately 0.5 m, leaving the site approximately 1 m below final subgrade level. The final 1.0 m of fill was backfilled with 19 mm well-graded crushed gravel compacted to 100% SPD in 150 mm lifts.

4.4 Dynamic Cone Penetration Test Program

Due to the presence of gravel in the clay fill and native clay till, the use of CPT was proven to be limited as refusal was encountered during testing at different depths. It was decided that Dynamic Cone Penetration Tests (DCPT) would be used to assess the soil density improvement, albeit with some limitations. The DCPT program was conducted prior to dynamic compaction (first phase) and after the first, second, and third phases of dynamic compaction. The DCPT program prior to dynamic compaction (first phase of dynamic compaction) was conducted using an auger drill rig. A total of 56 testhole locations using DCPT were advanced to a maximum depth of 12.0 m below the existing ground surface. The DCPT program was conducted in a grid spacing of 20 m except in the southeast corner of the site, where the testing was conducted in a grid spacing of 10 m to obtain more soil data.

The DCPT program comprised driving a dynamic cone (50 mm in diameter) using a Standard Penetration Test (SPT) hammer and auguring the testhole after every 3 m of dynamic cone penetration. DCPT testhole ocations were surveyed prior to testing.

Blow counts to drive the dynamic cone every 300 mm were noted during the DCPT program.

The DCPT program was conducted upon completion of dynamic compaction (after Phases 1, 2, and 3) using a similar technique as described above except that casing was used in the upper 2.5 m to 3.0 m due to the presence of the gravel that was placed above the fill before and after the dynamic compaction. A total of 14 testhole locations (comprising five locations after Phase 1, five locations after Phase 2, and four locations after Phase 3) were advanced after different phases of dynamic compaction. The DCPT testhole locations are shown on Figure 4. The DCPT testhole locations conducted after each dynamic compaction phase (Locations 1, 2, and 3 on Figure 4) were selected based on the anticipated lower strength soil obtained prior to conducting dynamic compaction.

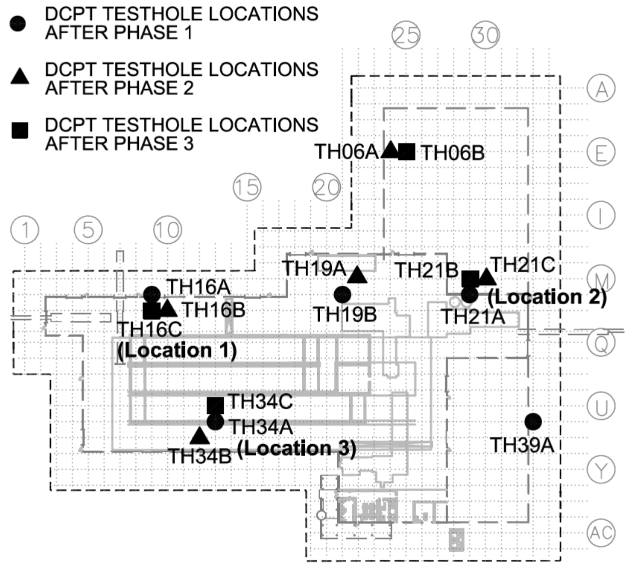


Figure 4. DCPT testhole location plan (upon completely dynamic compaction Phases 1, 2, and 3).

5 SETTLEMENT MONITORING PROGRAM

A settlement survey program was proposed to monitor the performance of the building foundation. Seventeen settlement monument points were placed at selected locations throughout the building structure. The selection of the settlement monuments was based on the type of structure within the building, such as columns, floor slabs, and other settlement-sensitive areas.

The settlement survey program commenced after the substantial completion of the building structure in April 2009. The settlement monument points were monitored after one month, three months, seven months, and one year. The results of the settlement monitoring are presented on Figure 5.

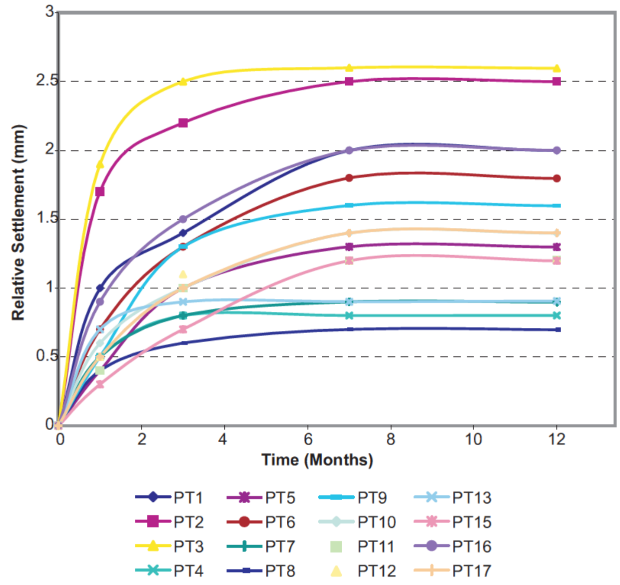


Figure 5. Relative settlement in months.

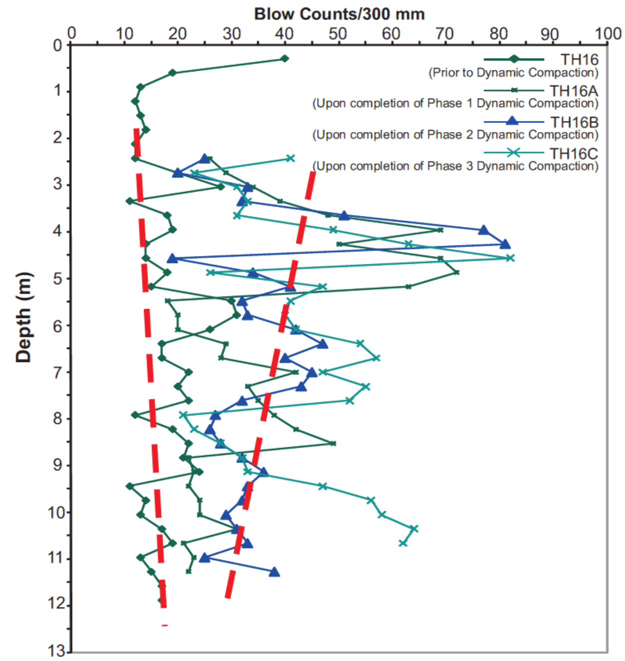


Figure 6. The results of three phases of dynamic compaction at location 1 (TH16).

6 DISCUSSION AND CONCLUSIONS

Based on the in situ testing using DCPT conducted in the testholes within dynamically compacted areas, the DCPT results for different phases of dynamic compaction indicate a consistent increase in stiffness or density of the fill soil as indicated by the increase in resistance in the DCPT. The plots of depth against blow counts are presented on Figures 6, 7, and 8.

It should be noted that a variation and inconsistency in the DCPT as indicated by a slight drop of the blow counts at the beginning of each dynamic cone test cycle (3 m depth) are due to difficulty in maintaining an exact auger drilling depth of each cycle. However, an overall trend can be drawn from the test results showing an increase from an approximate average of 10 blows to an approximate average of 50 blows at the upper depths with a decreasing trend to an approximate average of 40 blows at lower depths. It appears that the dynamic compaction method applied to the proposed site has shown a significant improvement in the ground condition for the proposed development.

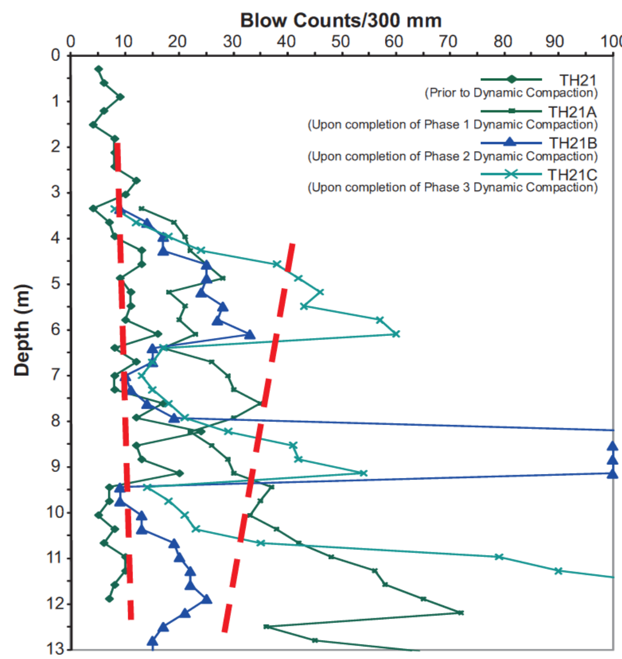


Figure 7. The results of three phases of dynamic compaction at location 2 (TH21).

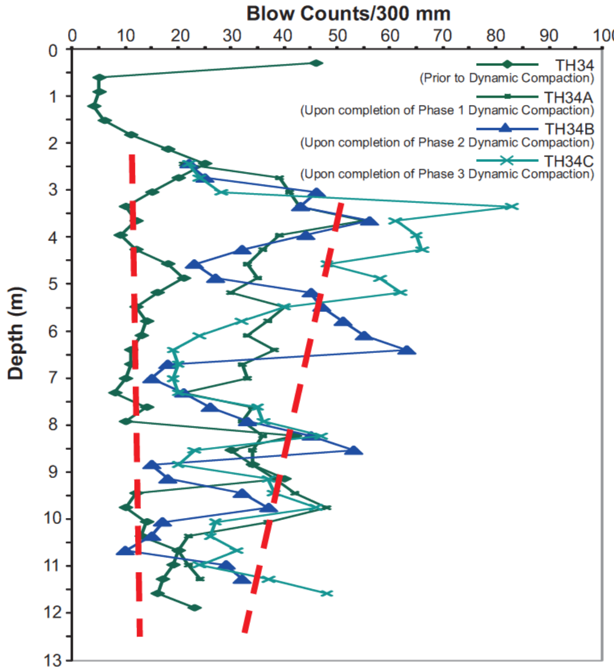


Figure 8. The results of three phases of dynamic compaction at location 3 (TH34).

Following construction completion, settlement survey monitoring for a period of approximately one year (and still ongoing) has indicated negligible movement of the foundation.

Ground improvement using dynamic compaction saved the remediation of the site by allowing the use of unacceptable placed fill. The advantages of not removing the existing fill were:

- Reduced project cost by using this approach compared to deep foundations (piles) or removal and replacement of the upper 15 m of fill;
- Saved time by managing to complete the project to meet the requested production schedule; and
- Environmentally friendly – saved on fuel costs and emissions from using heavy construction equipment if deep foundation or removal and replacement of existing till was used.

The use of dynamic compaction has proven to provide an economical solution for the development of this site. Although not utilized commonly in southern Alberta, this demonstrates the potential benefits of adopting this form of ground improvement.

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