Large Scale Plate Load Test on Gypsum-Rich Soils

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ABSTRACT
A large scale Plate Load Test was carried out at a proposed mine site in South America to investigate the potential settlements in the gypsum-rich soils beneath a lined process water pond. The plate load comprised a 2 m high stack of 25 mm thick steel plates 1.5 m by 1.5 m in size. The plates were founded at a depth of 2 m representing the proposed ground elevation after site stripping. Settlements under dry conditions were measured during stacking of the plates. The site was then irrigated to measure the additional settlements induced by a potential liner leak. The total volume of water added to the test site represented 33 years of leakage from a potential liner defect. This paper will present the methodology of the Plate Load Test and discuss the observed settlement performance.

RÉSUMÉ
Un program d'essais à la plaque large a été réalisé sur un site minier d'Amérique du Sud afin de déterminer les tassements potentiels dans un sol riche en Gypse sous un resevoir d'eau pourvu d'une membrane d'étanchéité. La masse de la plaque a été obtenue par un empilement de plusieurs plaques de 25 mm de 1.5 m par 1.5 m sur une épaisseur totale de 2 mètres. Les plaques ont été placées à une profondeur de 2 mètres correspondant à l'élévation finale du sol apres décapage. Les mesures de tassement ont été réalisées sur sols secs. Le sol a ensuite été progressivement irrigué afin de mesurer les tassements additionels induits par un apport d'eau excessif. Le volume total d'eau ajouté a simulé 33 années de fuites résultant d'une rupture accidentelle de la membrane d'étanchéité. Cette publication présente la méthodologie adoptée pour les essais à plaque large et discute des observations sur la performance des tassements obtenus.

1 INTRODUCTION

A large scale Plate Load Test was carried out to investigate the potential settlements in gypsum-rich soils under both “dry” and aggressive “wetting” conditions. The loading test was conducted between July 10, 2006 and March 31, 2007.

This paper presents the test methodology, settlements observed during the plate load test, and findings from exhumation investigations conducted during removal of the load plates and de-commissioning of the test site. The exhumation investigations included:

- Careful removal of the steel plates and measurement of soil rebound beneath the test site;
- Test holes with Standard Penetration Tests (SPT) and Large Penetration Tests (LPT) in the soils beneath the test site. Soils adjacent to the test site were also tested to allow comparisons to pre-test conditions; and
- An excavated test trench within and adjacent to the test site to evaluate the physical changes in the soils due to the plate loading and soil wetting.

2 LARGE PLATE LOAD TEST

2.1 General

The site is situated in a semi-arid desert environment in South America. Site investigations revealed gypsum in the presence of discrete lenses (Figure 5) as well as disseminated at concentrations of 0.5% to 4% by weight. A special program of plate loading tests on the gypsum-rich foundation soils was conducted to assess the compression of the soils under dry and wet loading states. Test procedures and results are summarized below.

2.1.1 Plate Load Tests

Conventional plate loading tests following the procedures in ASTM D1194-94 Bearing Capacity of Soil for Static Loading and Spread Footings. All tests were performed at 2 m depth representing the proposed ground elevation after excavation of the pond site. Tests were initially performed on the dry native soil and then repeated after wetting of the soils for 24 hours.

2.1.2 Large Plate Load Test

A Large Plate Test was carried out to investigate the potential local ground settlements under prolonged wetting. Such wetting could occur in the event of a defect in the composite HDPE/compacted clay liner beneath the process ponds.

The plate load comprised a 2 m high stack of 25 mm thick steel plates 1.5 m by 1.5 m in size. The plates were founded at a depth of 2 m, representing the proposed ground elevation after site stripping. Settlements under dry conditions were measured during stacking of the plates. The site was then irrigated to measure the additional settlements induced by aggressive wetting.

The bearing pressure applied by the plates to the ground was nominally 150 kPa. The bearing pressure was also representative of the bearing pressure beneath candidate footings or raft foundations in the nearby plant site. Taller stack heights to achieve higher bearing pressures were rejected due to safety concerns of possible tipping of the stack if large settlements occurred.

2.2 Selection of Test Site

The Large Plate Load Test was conducted at a "worst case" site for ground settlement based on the gypsum enrichment observed in nearby test pits.

2.3 Test Setup

Figures 1 and 2 show the layout of the test site and placement of the steel plates.

The test site was prepared by removing the loose, gypsum rich surficial soils to a depth of about 2.2 m and placing a 2.5 m x 2.5 m x 100 mm thick, well compacted gravel bed over the native soil. Beyond the gravel, the test site was lined with clay and a plastic membrane to minimize lateral spreading of seepage during wetting of the site.

2.4 Settlement Monitoring

Settlements of the plate load test site were recorded using a precise survey level instrument. Figure 1 shows the general arrangement of the survey points. The location for the level instrument (Point PF) was fixed by installing a 150 mm diameter pipe set with concrete in the ground and a threaded coupler at the top to attach the level. A reference benchmark (Point 4) set in concrete was installed in front of the instrument and a second benchmark was installed to the east of the level location.

Survey of settlement during the initial plate stacking was done following every 300 mm increase in stack height by measuring settlement with a survey rod resting on four fixed points welded to one of the lower plates near the base of the stack. On completion of the plate stacking, stack settlement surveys were carried out using welded rods at the four edges (labelled as N, E, S and W) of the upper plate. Survey tape with millimetre markings were permanently attached to the welded rods. With this system, settlement was reliably measured with an accuracy of 1 mm.

Settlement was also measured at monitoring hubs set in concrete at Points 1, 2 and 3 on Figure 1. These hubs were located at 5 m, 8 m and 11 m respectively from the centre of the plate load test to measure the distribution of settlement away from the load test.

2.5 Irrigation of Test Site

The test site was initially run in a dry state for two days to measure ground settlements under normal loading conditions. The site (pit) was then subjected to four cycles of wetting by flooding and irrigation as follows:

- Cycle 1 - July 12 to 26, 2006: The base of the test site was directly flooded with water provided by a 9000 L water truck. Water consumption during the first 8 days was less than 40,000 L/day, but quickly increased to up to 160,000 L/day, requiring up to 18 water truck (9,000 L each) trips to maintain the pit flooded.
- Cycle 2 - July 26 to August 10, 2006: Given the high infiltration rates, it was decided to irrigate the site in a more controlled manner using a perforated pipes around the edge of the steel plates. The irrigation water was delivered from an adjacent membraned lined pond in a pipe with a valve to regulate the flow rate. The setup of this irrigation system is shown in Figure 2. The rate of irrigation was maintained at 18,000 L/day to 27,000 L/day, requiring 2 to 3 truck loads per day.
- August 11 to August 30, 2006: Irrigation of the site was temporarily halted after 1 month of water addition to examine apparent direct correlation between settlement and wetting.
- Cycle 3 - September 1 to September 26, 2006: Irrigation recommenced for 1 additional month, ending the planned operating period of the plate load test.
- Cycle 4 - March 10 to March 29, 2007: Irrigation recommenced to re-wet the soils beneath the test site prior to starting the post-test site investigations.

The total volume of water applied to the soil over the total test period was 2100 m^3. This represents over 33 years of leakage from a potential defect in the proposed pond lining system.

2.6 Observed Settlement

Settlements records for the Large Plate Load Test are shown in Figure 2 and summarized in Table 1. The maximum settlement of the plate occurred on the west side (115 mm) and the minimum occurred on the east side (75 mm). Settlements on the south (95 mm) and north sides (96 mm) were approximately equal and mid-way in magnitude between the east and west sides. This pattern of settlement shows tilting of the plates towards the west.

Table 1. Large Plate Load Test Settlements

LOADING CONDITIONS	ELAPSED TIME	AVERAGE TOTAL SETTLEMENT (mm)	TOTAL WATER INFILTRATION (m^3)
Dry	1 day	6	
	3 days	10	
Wet	1 day	13	19
	1 week	15	182
	2 weeks	20	900
	3 weeks	30	1100
	4 weeks	55	1300
	11 weeks	80	1800
	39 weeks	95	2100

Settlements at Points 1, 2, and 3 (Figure 1) outside the test area were zero, indicating the infiltration and settlements were localized beneath the test site.

For each occurrence, settlements stopped within 1 to 3 days after cessation of water addition. This behaviour indicates that dissolution of gypsum in the soil is the primary mechanism for the observed settlement.

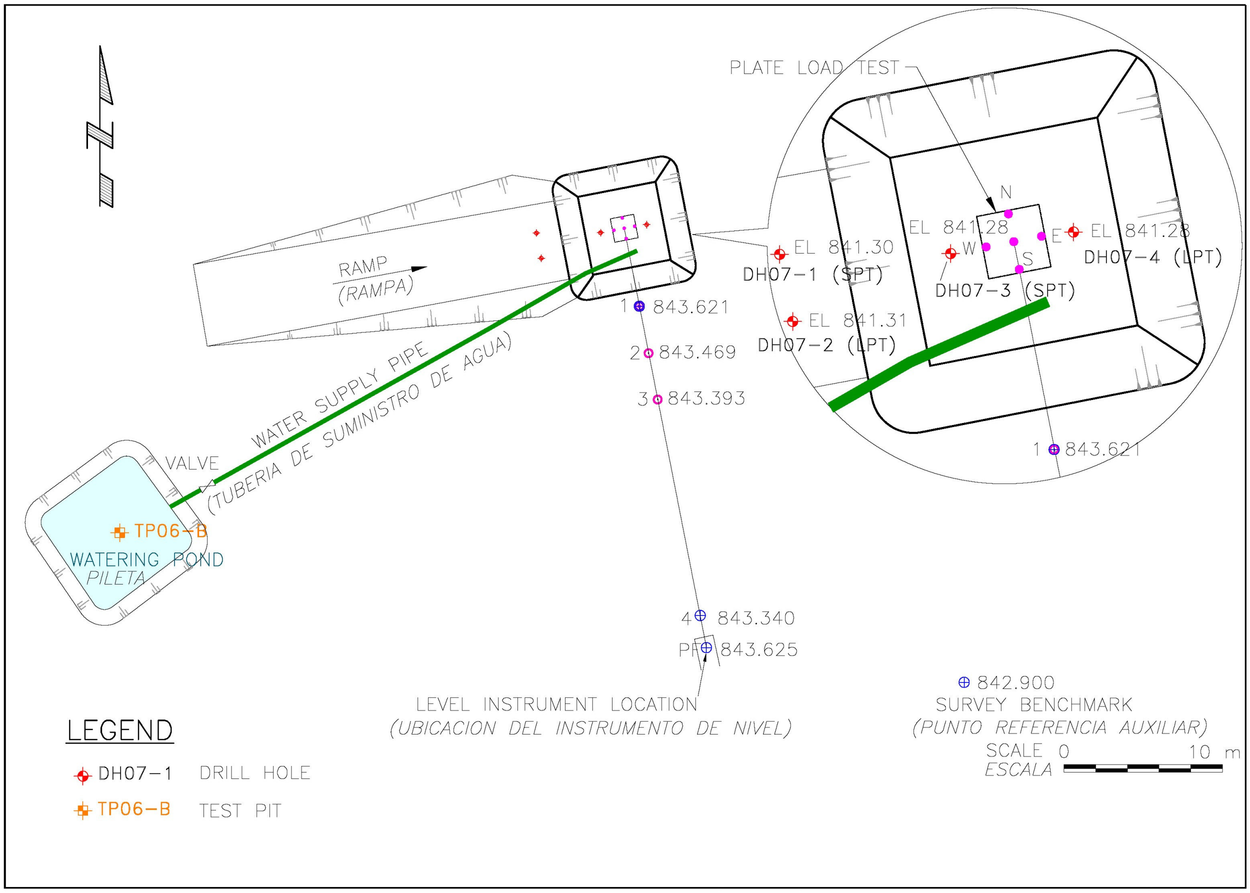

Figure 1. Large Plate Load Test Layout

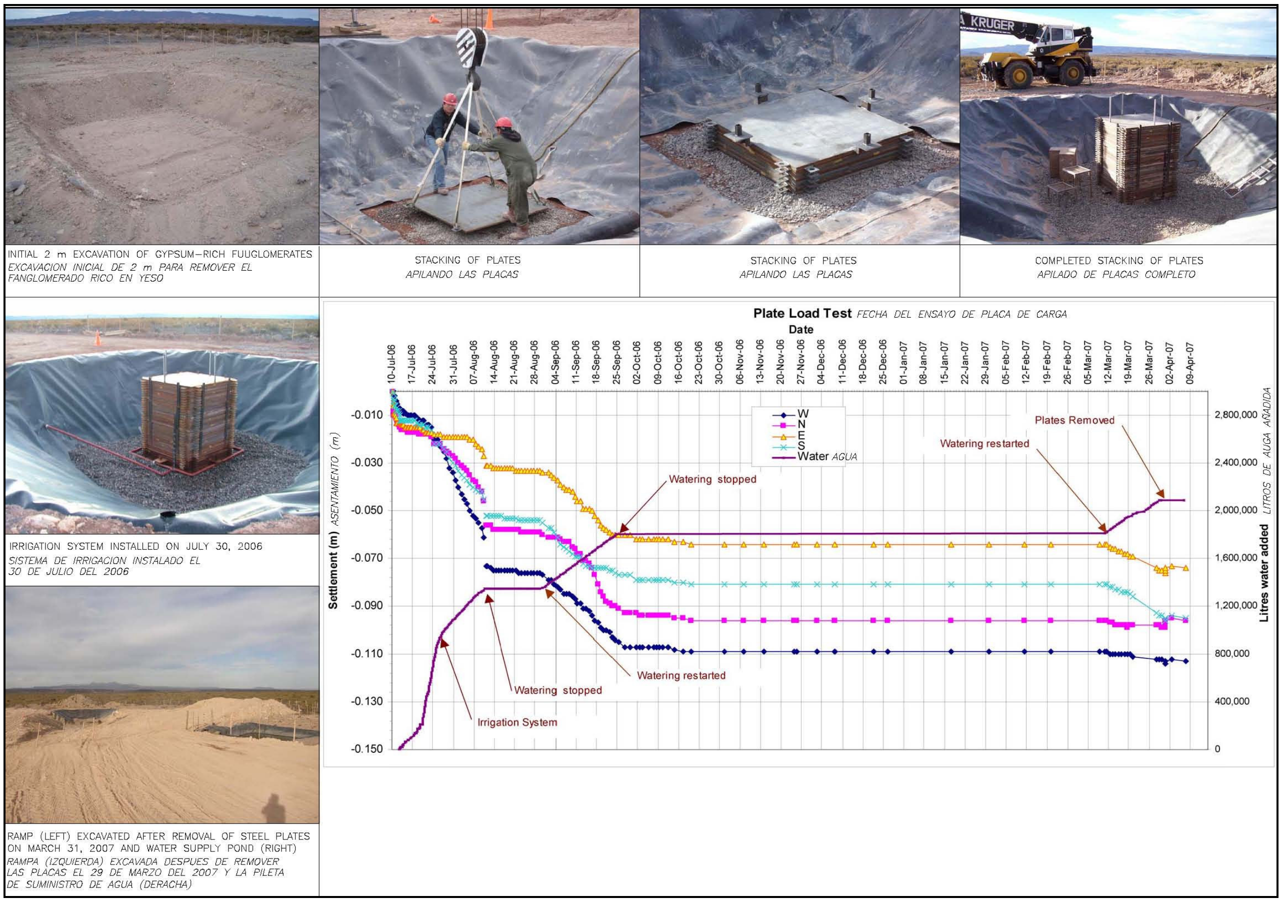

Figure 2. Large Plate Load Test Results

3 POST-TEST INVESTIGATIONS

3.1 Test Program

Post-test investigations were carried out to evaluate:

- Changes in the density of the soil that could affect the strength of the pond foundation; and
- Physical changes in the condition of the soils that could affect the performance of the proposed lining system.

3.1.1 Soil Rebound During Stack Removal

Rebound of the plate load test was measured after removal of each 300 mm of plates using survey rods set on top of the same four fixed points used to measure settlement during plate stacking. After all the plates were removed, a concrete monument was placed over the test location and ground rebound was measured at regular intervals for the first few hours and then measured regularly for the next seven days.

3.1.2 Test Holes

After the plates were removed, a ramp was excavated on the west side of the site to allow for access of a drill rig to drill two test holes under the plate load test site (DH07-3 and DH07-04) and two reference test holes (DH07-1 and DH07-2) away from the plate load test at a distance of 5.5 m to the west of the centre of the plate load test. The test hole locations are shown on Figure 1. Monitoring of Point 1 previously indicated zero settlement at 5 m from the centre of the loading plates.

Standard Penetration Tests (SPT) were conducted at 500 mm intervals for the full depth of DH07-1 and DH07-2. Large Penetration Tests (LPT) were conducted at 500 mm intervals for the full depth of DH07-2and DH07-4.

The SPT test comprised driving a 50.8 mm diameter split spoon sampler using a 623 N (63.5 kg) hammer dropped from a height of 0.76 m. The Large Penetration Test comprised a 76.2 mm outside diameter split spoon driven using a 1378 N (140.6 kg) hammer dropped from a height of 0.76 m. Both the SPT and the LPT were driven in 3 consecutive increments of 150 mm or until refusal defined as a penetration resistance of more than 50 blows per 150 mm.

3.1.3 Test Trench

Following the test hole drilling, a 10 m long trench was excavated to a depth of 2.2 m below the base of the plate load test. The north wall of the trench was excavated near vertical to observe the conditions below the plate load test and outside the plate load test. The trench excavation progressed in thin lifts and soil conditions were observed in detail, particularly looking for signs of dissolution channels, evidence of settlement and differences in the soil composition and structure.

3.2 Discussion of Findings

The principal findings from the post-test investigations are:

- The magnitude of soil rebound during the removal of the plate stack was negligible (<1 mm).
- The soils below the plate load test comprise interlayered sand, gravel, cobbles and boulders. The layers were typically less than 0.6 m thick. The sands and gravels were very weakly cemented to about 4 m below the plate. Soil layers were continuous across the site in the test holes and test trench.
- Figure 3 presents a comparison of the moisture contents taken from the SPT and LPT samples recovered from the test holes, and the water contents recorded in nearby test pit TP06-B. The moisture contents of all the test hole samples exceed the water contents previously recorded in TP06-B to a depth of about 5 m below the base of the test plate. The increase in water content ranges from 2% up to 14%. No obvious trend in moisture content difference is apparent between the test holes within and outside the test site. The few moisture points above 15% are the result of higher silt content in those samples.

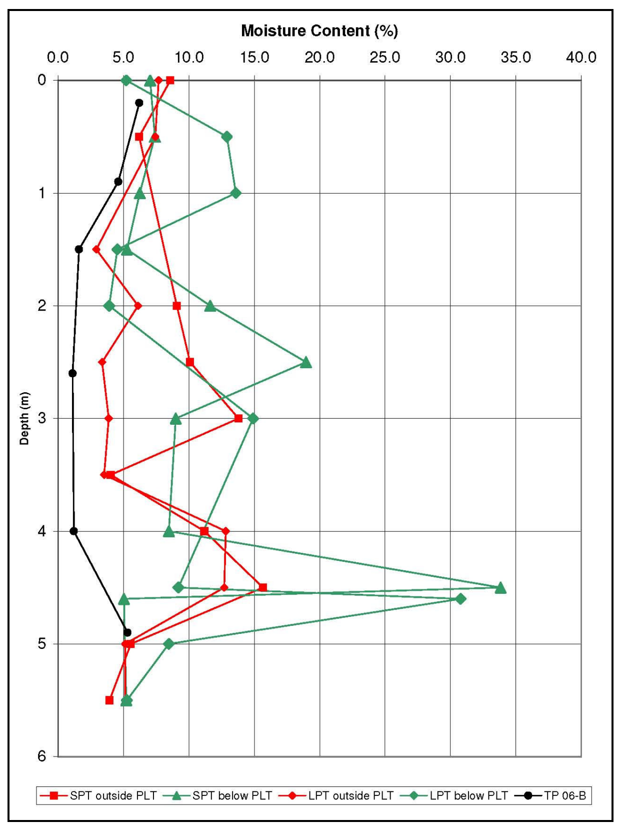

Figure 3. Water Content Profiles

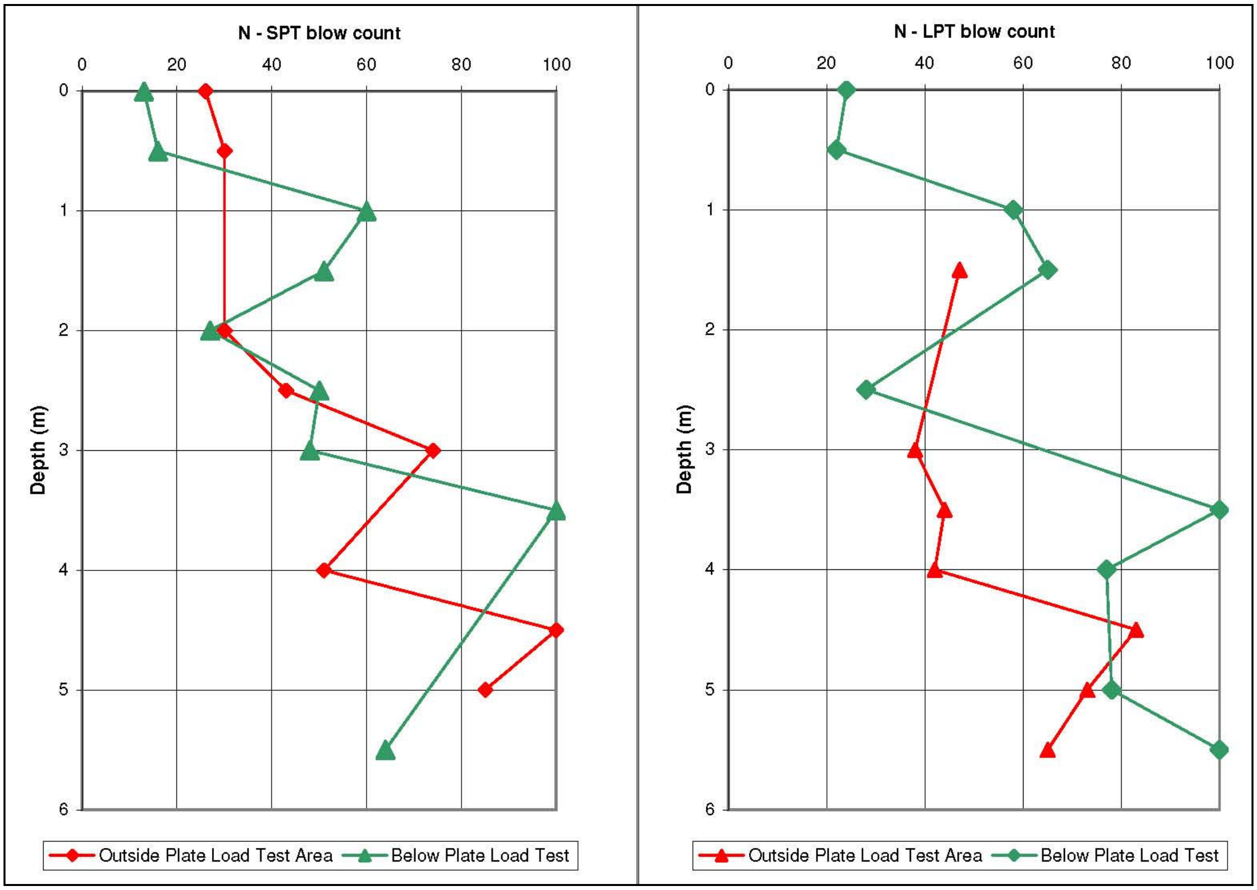

Figure 4. SPT and LPT Profiles

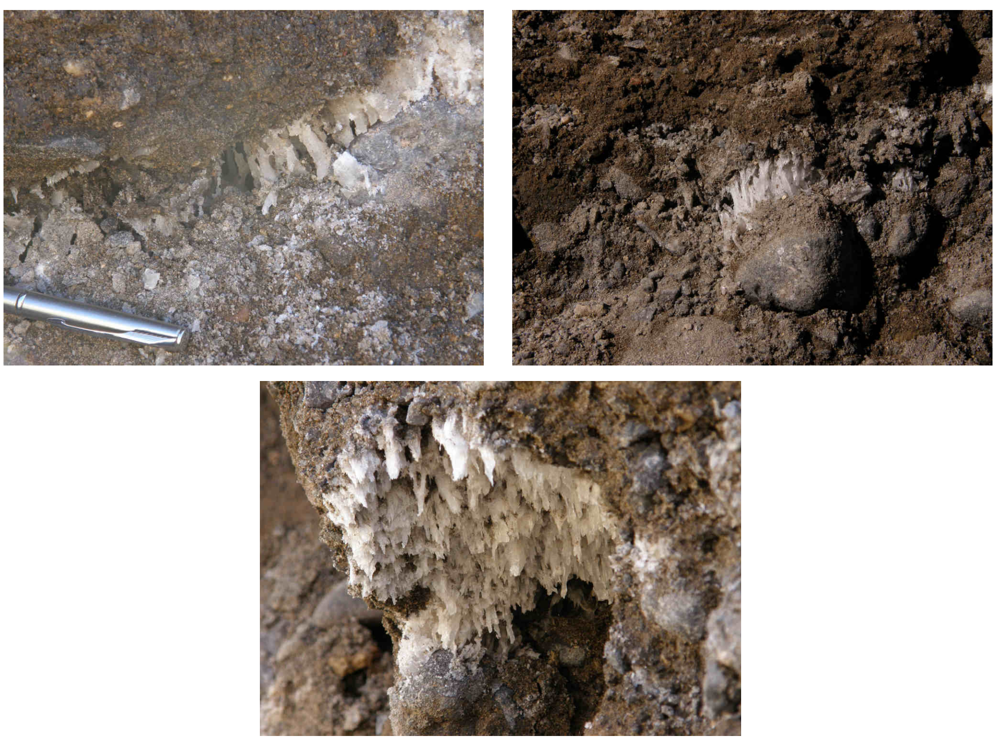

Figure 5. Examples of Gypsum Structure Outside Plate Load Test site

- Figure 4 presents the SPT and LPT blowcounts from the test holes. Tests done under the plate load test and outside the test area do not show any obvious difference in the pattern of the blowcounts. The SPT results in DH07-3 showed some decrease in blowcount in the upper 0.6 m of the soil. However, the blowcounts of 16 to 18 indicate the soils are still in a compact to dense state.
- Outside the test site, local pockets and layers of gypsum formations exist underneath cobbles and boulders. These layers are shown in Figure 5. These gypsum layers were also encountered under the plate load test area, but the open-work lattice structure was absent and likely closed by the softening of the gypsum and compression of the formations under the weight of the plate load test.
- No evidence of voids or pipes formed by dissolution of the gypsum were observed.

4 CONCLUSION

The principal findings from the large Scale Plate Load Test and the post-test investigations are:

- Compression of the soils in their native “dry” state was less than 10 mm under a 1.5 m by 1.5 m plate loaded to 150 kPa. Continuous wetting of the soils led to additional settlement as the gypsum softened and compressed under loading. Settlement was a direct result of dissolution and migration of gypsum by the watering. Settlement halted immediately after water addition is stopped.
- The magnitude of the settlement produced by 33 years of equivalent water addition from a defect in the composite liner system was 95 mm. Settlement was confined to a short radius around the leakage point.
- Settlements occurred due to soil compression, and no evidence of “dissolution” sinkholes or pipes were observed in the test trenches. Sudden ground collapse is not considered possible given the thinness and discontinuous nature of the gypsum in the soils.
- Both SPT and LPT blowcount data showed no significant loss of soil strength by the aggressive wetting of the test site.

REFERENCES

ASTM D1194-94. Standard Test Method for Bearing Capacity of Soil for Static Load and Spread Footings. ASTM International. West Conshohocken, PA.