Reclamation Ground Settlement Monitoring by using GPS and other Positioning Technologies at Shenzhen Airport

Vincent Lui, Jacky Ng and Alan K. L. Kwong, Hong Kong SAR, China

Key words: GPS, surface settlement, sub-surface settlement, reclamation, remote access, ground improvement, vacuum preloading technique, field monitoring

SUMMARY

Hong Kong is a small territory of about 1070 km^2. There is an ever-increasing demand for land to cope with her increasing development. Typical geology in Hong Kong under the seabed comprises a layer of soft marine deposit of variable thickness of up to 20 m, overlying alluvium, residual soil, decomposed rock and bedrock. However, the marine deposit is too soft to support any structures. Conventional reclamation practice in Hong Kong is to dredge the marine deposit, build the seawalls and fill the enclosed space by sand. This conventional approach has many shortcomings. A research project was undertaken by The University of Hong Kong to develop a vacuum preloading technique that is environmentally safe to improve the engineering properties of the thick layer of soft marine deposits so that they can be kept in place during land reclamation. As a result, the environmental problems relating to dredging can be completely eliminated.

A vacuum preloading test near the Shenzhen Airport was carried out as part of a very large research program. Sub-surface field instrumentation comprised piezometers, inclinometers, extensometers and pressure cells to monitor the performance of the vacuum system and the physical changes of the marine deposit during vacuum preloading. Surface settlement was monitored using 3 units of high precision GPS equipment throughout the test for checking against the sub-surface monitored movement. It is necessary to use a fully automatic system like GPS for replacing conventional survey because the test was carried out over water, which was difficult to access and the test was carried out over a very long period of 4 months.

This paper reports the use of GPS for reclamation ground settlement monitoring and demonstrates cm-level positioning results through experimental trials. The results also agree very well with the sub-surface settlement readings.

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1. INTRODUCTION

Hong Kong is a small territory of about 1070 km^2. There is an ever-increasing demand for land to cope with her increasing development. Typical geology in Hong Kong under the seabed comprises a layer of soft marine deposit of variable thickness of up to 20 m, overlying alluvium, residual soil, decomposed rock and bedrock. However, the marine deposit is too soft to support any structures. Conventional reclamation practice in Hong Kong is to dredge the marine deposit, build the seawalls and fill the enclosed space by sand. This conventional approach has many shortcomings. A research project was undertaken by The University of Hong Kong to develop a vacuum preloading technique that is environmentally safe to improve the engineering properties of the thick layer of soft marine deposits so that they can be kept in place during land reclamation. As a result, the environmental problems relating to dredging can be completely eliminated.

A vacuum preloading test near the Shenzhen Airport was carried out as part of a very large research program. Sub-surface field instrumentation comprised piezometers, inclinometers, extensometers and pressure cells to monitor the performance of the vacuum system and the physical changes of the marine deposit during vacuum preloading. Surface settlement was monitored using 3 units of high precision GPS equipment throughout the test for checking against the sub-surface monitored movement. It is necessary to use a fully automatic system like GPS for replacing conventional survey because the test was carried out over water, which was difficult to access and the test was carried out over a very long period of 4 months.

2. SITE LOCATION

The test site was about 2 km south of the Shenzhen Airport, with geological condition very similar to that in Hong Kong. See Figure 1 for location. It was located approximately 50 m directly below the landing path of the aircraft.

The thickness of the soft marine clay is about 7.5 m and covered with water. Construction of the wick drains and installation of monitoring instruments commenced around October 2006 and finished around November 2006. Figure 2 shows the installation of the wick drains and Figure 3 shows the installation of the sub-surface settlement monitoring devices (extensometers).

Plan view of the sub-surface instruments is presented on Figure 4 with cross sectional profile shown on Figure 5.

3. CONSTRUCTION

The test site was prepared by dewatering the pond and covered with a layer of cushioned sand so that drilling and sampling equipment could move around the site. Wick drains of 7 m long were inserted below the surface at a spacing of 1.5 m by 1.5 m. Sub-surface instruments including piezometers, vacuum transducers, earth pressure cells, extensometers, inclinometers were installed. Suction pipes and vacuum pumps were connected and the site was flooded with 2 m deep of water. 2 layers of geomembrane were then placed under water and their edges were secured with sand bags to maintain an airtight seal so that vacuum pressure could develop in the soft marine clay.

3 units of high-precision GPS equipment and 2 surface settlement plates were installed to monitor the surface settlement and to compare with the sub-surface settlement against time when the vacuum pressure was applied to the underlying soft marine clay.

Figure 6 shows the GPS in operation when the entire geomembrane was covered with water and under vacuum pressure testing. It was necessary to use a fully automatic system like GPS for replacing conventional survey because the test was carried out over water, which was difficult to access and the test was carried out over a very long period of 4 months.

4. GPS OPERATION

3 units of dual-frequency high-precision GPS equipment (Leica GX1230 receiver and AX1202 antenna) were used in this project. 1 set of equipment was setup as a base station on a tripod fixing on a stable ground control point. Another 2 sets were setup on poles fixing on top of geomembrane. All 3 receivers collected GPS L1 + L2 code & carrier phase satellites observation data every 1 second interval simultaneously into their internal memory card. Then, the raw data was processed by Leica LGO software to compute GPS baselines from the base station to those two monitoring points in order to achieve individual epoch 3D coordinates changes of the monitoring positions.

The whole GPS measurement process started from mid-November 2006 to late January 2007. However, GPS data could not be collected in the period from late November to December 2006 due to power supply failure and we replaced a new power generator in mid-December 2006 to continue data collection.

The whole process of field observation is fully automatic. If there is a cable or wireless communication device such as radio link, GSM, GPRS, etc connecting between the receivers at base stations and monitoring points, real-time kinematic (RTK) positioning method can be used to detect 3D position movement in real-time even up to 20Hz update rate. It would be an advantage especially for detecting highly dynamic movement applications and disaster prevention such as seismic monitoring and movement detection of bridges and building structure.

5. SETTLEMENT OBSERVATION

Settlement of the soft marine clays started in the early November 2006 and after 2 months of continuous vacuum loading, conventional surveying recorded a settlement of 600 mm, which was very close to that obtained by the GPS which showed a settlement of 550 mm (Figure 7). The small discrepancy was mainly due to the pond water being fluctuated against the tide and that some maintenance work on the geomembrane was carried out during the pumping, causing disturbance and movement to the GPS. Another factor that would probably affect the GPS reading was that the site was about 50 m directly below the landing path of the aircraft. Since the middle of January 2007 where no more maintenance was required on the geomembrane, the GPS showed a very consistent trend of 5 mm/day settlement with local fluctuation of ±20 mm between each reading interval. The surface settlement showed very good agreement with the extensometers, which also showed an exponential decreases in sub-surface settlement with increases in depth; an observation agreed very well with that measured from the piezometers.

6. SUMMARY AND CONCLUSIONS

This paper reported the use of GPS for reclamation ground settlement monitoring and demonstrated cm-level positioning results through experimental trials. The results also agreed very well with the sub-surface settlement readings and the piezometer readings.

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Fig. 1 Site Location - 2 km south of Shenzhen Airport

Fig. 2 Installation of Wick Drains

Fig. 3 Installation of Sub-Surface Extensometers

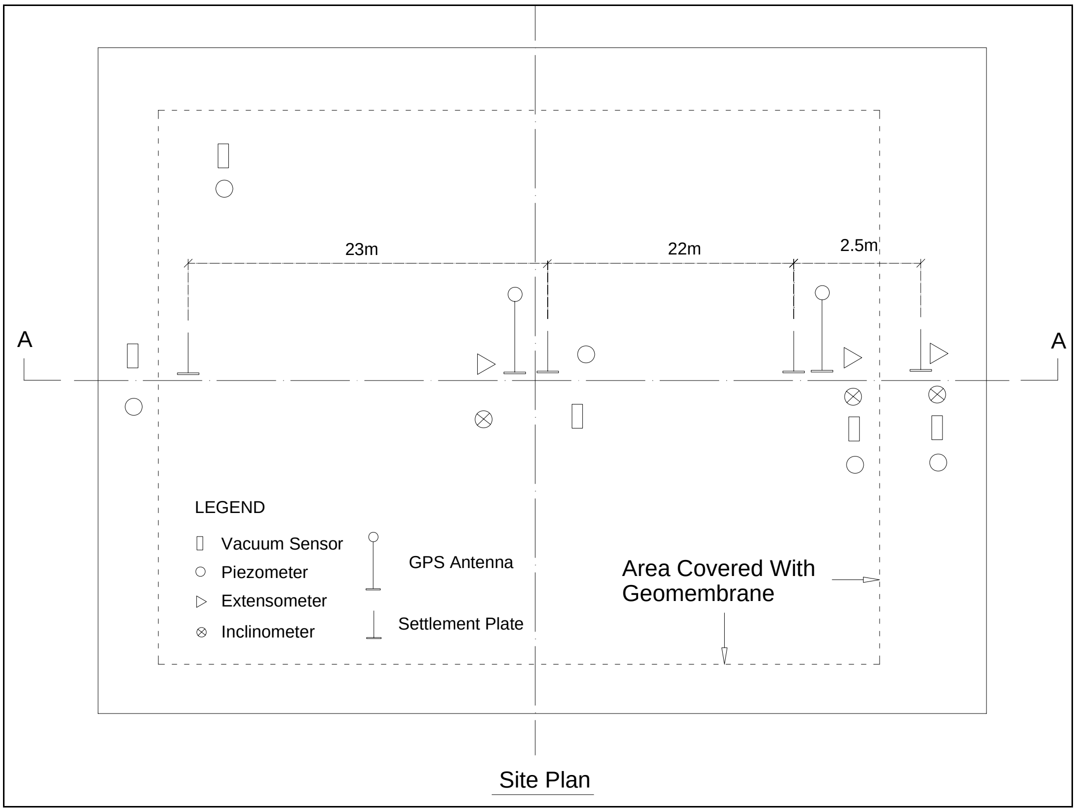

Fig. 4 Plan View of Sub-Surface Instruments

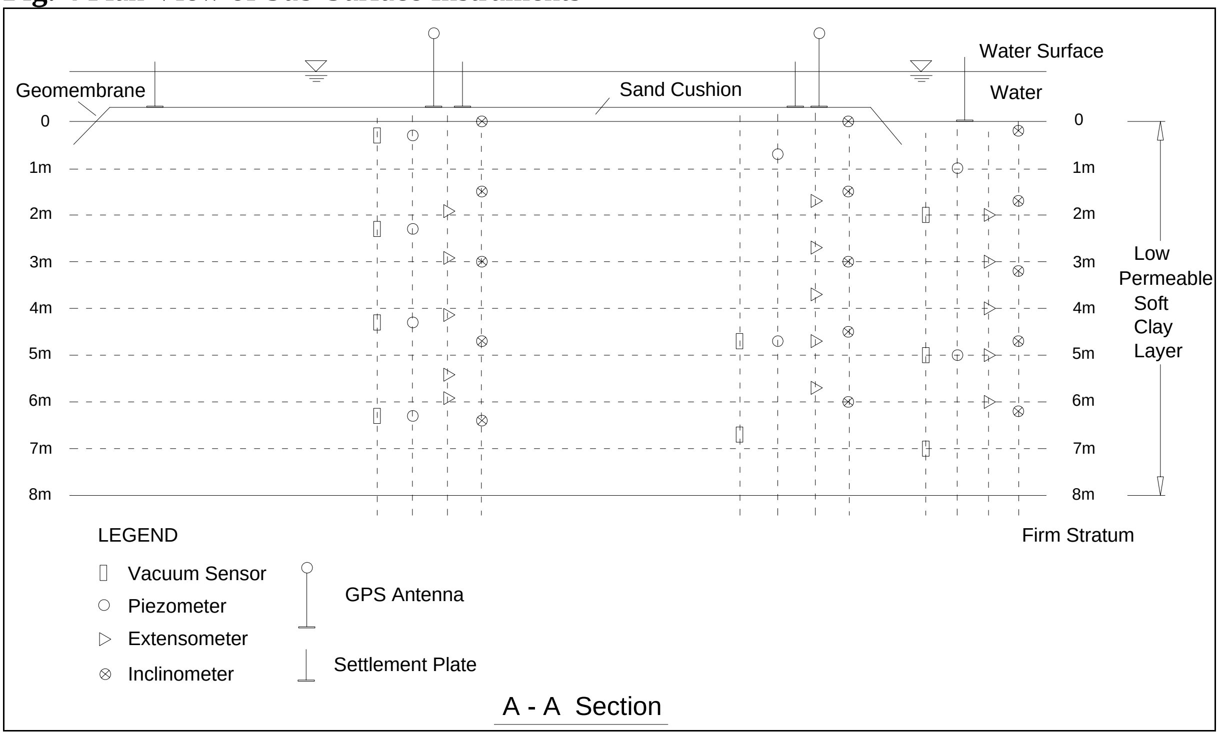

Fig. 5 Cross Sectional Profile of Sub-Surface Instruments

Fig. 6 3 GPS on top of Geomembrane

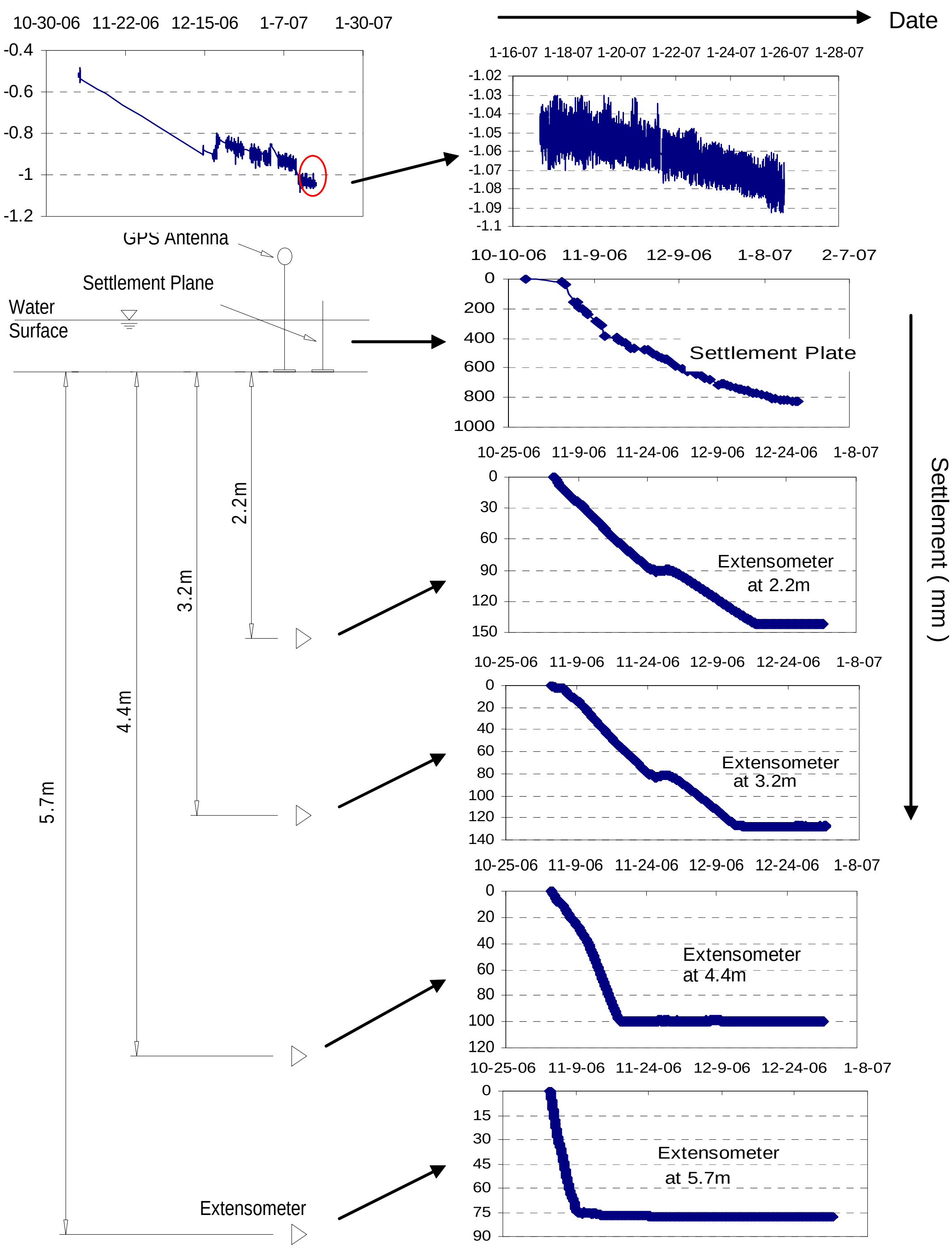

Fig. 7 Comparisons of Settlement from GPS, Conventional Survey and Extensometers

BIOGRAPHICAL NOTES

Dr. **Alan Kwong** is a full time Senior Teaching Consultant at the University of Hong Kong, teaching MSc. Courses in the area of Foundation Engineering, Tunneling, and Rock Mechanics. Alan is conducting research in the area of vacuum preloading, soil nailing, photogrammetric and 3D scanning of rock joints, and blasting.

Before joining The University of Hong Kong, Alan was the Principal Geotechnical Engineer of Montgomery Watson Harza (1999-2002) and Associate Director of Golder Associates Hong Kong Ltd. (1995-1999).

Alan has over 20 years of experience in the field of slope engineering, foundations and tunneling in Hong Kong and Canada.

Mr. **Vincent Lui** is a Sales Manager and Technical Specialist at Leica Geosystems Hong Kong office, in charge of GNSS products, GPS network system and structural monitoring solution for Hong Kong, Macau and Taiwan. Vincent is currently developing a GPS network infrastructure and a number of positioning services and systems in Hong Kong that serve for many applications including deformation monitoring in the area of subsidence, landslide, bridge, water dam and high-rise building.

Vincent has over 11 years of experience in the field of GNSS, navigation, reference station infrastructure and tunnel & subsidence monitoring in Hong Kong and China.

Mr. **Jacky Ng** is a Technical Engineer at Leica Geosystems Hong Kong office, working in areas of GPS, tunnel & rail monitoring and 3D Laser applications. He is specialized in system implementation and software processing. Jacky has over 10 years of experience in the field of engineering surveying in Hong Kong.

CONTACTS

Alan K. L. Kwong
The University of Hong Kong
Room 624 Haking Wong Building
Department of Civil Engineering
Hong Kong SAR
China
Tel. +852-2859-2673
Fax +852-2559-5337
Email: kwongakl@hkucc.hku.hk

Vincent Lui
Leica Geosystems Ltd
Unit 1701-3, DCH Commercial Centre,
25, Westlands Road, Quarry Bay,
Hong Kong SAR
China
Tel. +852-2161-3882
Fax +852-2564-4199
Email: vincent.lui@leica.com.hk

Jacky Ng
Leica Geosystems Ltd
Unit 1701-3, DCH Commercial Centre,
25, Westlands Road, Quarry Bay,
Hong Kong SAR
China
Tel. +852-2564-2299
Fax +852-2564-4199
Email: jacky.ng@leica.com.hk