Monitoring Slope Failure at Kadoorie Agricultural Research Centre with a 3D Laser Scanner

Andrew Wong, Alan K. L. Kwong and Jacky Ng, Hong Kong SAR, China

Key words: Fill slope, soil nail, instrumentation, slope failure, movement monitoring, 3D laser scanner

SUMMARY

A loosely compacted fill slope with an angle of 33° was constructed at the Kadoorie Agricultural Research Centre of The University of Hong Kong. The height and width were 4.75 m and 9 m respectively. It was constructed by end-tipping method and resulted in a loose state with an initial dry density of 70% of the maximum dry density. Two rows of grouted nails were installed at a grid of 1.5 m x 1.5 m at an inclination of 20° from the horizontal. The slope was brought to failure by subjecting it to surcharge at the slope crest in combination with induced rise in groundwater table and precipitation. Heavy instrumentation comprised in-place inclinometer, vibrating wire piezometers, vibrating wire extensometer, earth pressure cell, tensiometer and strain gauges along soil nails and they had been monitored throughout the test. Surface movement was monitored using a GPS system and a 3D laser scanner.

This paper focuses on the use of 3D laser scanner in capturing the formation of cracks and surface movement during the failure. It is found that by overlapping the point clouds generated from the scanner at different time intervals, the surface movement of the slope can be accurately recorded without the need of physically accessing the slope surface.

When the slope reaches failure, the use of laser scanning can safely and quickly record the movement and dimension of washout and cracks, providing advantages over conventional survey method. This study shows that the movement obtained from the scanner agrees very well with that from conventional inclinometer reading at the surface. The travel distance of the surcharge block can be easily measured and point cloud can be easily modeled into geometrical shape for further rendering.

Monitoring Slope Failure at Kadoorie Agricultural Research Centre with a 3D Laser Scanner

Andrew Wong, Alan K. L. Kwong and Jacky Ng, Hong Kong SAR, China

1. INTRODUCTION

Many loose fill slopes exist in Hong Kong and they pose risk to life and economic consequences due to their liquefaction potential in static condition as a result of rain infiltration. The use of soil nails in in-situ material such as completely decomposed granite or completely decomposed volcanic is very popular and large amount of experience and field data have been gathered in the past, which demonstrated that soil nailing is effective in upgrading and stabilizing slopes in Hong Kong.

However, experiences in installation and field monitoring data are not available for soil nails in loosely compacted fill slope. The concerns are that soil nails may not work in loosely compacted fill slope because 1) the soil may develop high pore water pressure and flow around the soil nails and 2) the soil on either sides of the failure zone may be too weak to provide a secure anchorage for the soil nails (HKIE, 1998). Therefore, a comprehensive field study program was launched at The University of Hong Kong (HKUST and HKU, 2000) to study the failure mechanism and behavior of the soil nails in loosely compacted fill slope subject to surcharge and induced rise in groundwater table.

A loosely compacted fill slope with an angle of 33° was constructed at the Kadoorie Agricultural Research Centre of The University of Hong Kong. The height and width were 4.75 m and 9 m respectively. It was constructed by end-tipping method and resulted in a loose state with an initial dry density of 70% of the maximum dry density. It is considered that the stress state of this slope would represent reasonably well to that of most of the existing fill slopes in Hong Kong.

Two rows of grouted nails were installed at a grid of 1.5 m x 1.5 m at an inclination of 20° from the horizontal. Holes of 100 mm diameter with two different lengths (8 m and 6 m) were drilled. A 25 mm diameter steel ribbed bar was inserted into each hole and the hole was filled with grout from the bottom up using a plastic hose. Figure 1 shows the plan and cross sectional view of the installed soil nails in the slope.

A 75 mm blinding layer with A252 steel mesh was placed at the fill slope base to isolate the fill slope from the natural ground. A layer of asphalt was also applied at the surface of the blinding as an additional watertight measure. A layer of 150 mm thick no-fines concrete was placed above the blinding layer as an internal drainage layer. Permeable geotextile was applied between the no-fines concrete and the end-tipping fill to prevent the migration of fine particles from the fill into the drainage layer.

Recharge system comprised crest recharge trench, buried piping system and surface sprinkler and they were installed separately so that rise in groundwater table in combination with rainfall could be stimulated in the field. The recharge trench was directly connected to the drainage layer and the piping system consisted of 10 sets of perforated bronze pipes laid 300 mm beneath the crest and the flow rate of each set of pipe could be individually adjusted through a valve. Sprinklers were installed on the slope surface to simulate artificial rainfall on the slope.

1 m x 1 m x 0.6 m concrete blocks were stacked up to 3 m high at the central area of the slope crest, representing a surcharge loading of 72 kPa.

Instrumentation comprised of 2 nos. of in-place inclinometer strings (a total of 6 measuring elements), 7 nos. of vibrating wire piezometers, 24 nos. of soil moisture probes and 6 nos. of tensiometers, 6 nos. of vibrating wire earth pressure cells, 2 nos. of load cells, 46 nos. of vibrating wire strain gauges, 12 nos. of flow meters and 2 nos. of automatic data loggers. Figure 2 shows the plan and cross sectional view of the instrumentations.

2. 3D LASER SCANNER

As part of the monitoring program, a 3D laser scanner was employed to record the surface movement at different stages of loading (surcharge and induced rise in groundwater table). A portable 3D laser scanner (Cyrax 2500) is capable of recording positions of hundreds of thousands of points in 5 to 15 minutes with 4 mm accuracy in a 50m-target range. The vertical and horizontal point-to-point measurement spacing is 2 mm at 50m-target range. Each scanning column and row can accommodate 1000 points and the field of view is 40° max in vertical and horizontal direction. Inside the scanner, two mirrors rapidly and systematically sweep narrow, pulsing laser beam over the chosen target (or scene). A time-of-flight method is used to measure how long it takes for each laser pulse to hit a surface and return to the scanner without the need of a reflector. Range measurements are generated for every laser pulse while integrated optical encoders record mirror angles. The resulting positions commonly known as "point cloud" are displayed graphically, as they accumulate in real-time, on the system's laptop. The "point cloud" looks like a detailed, colored rendering of a scene. It is 3D and therefore can be viewed from any perspective. Since every point has an accurate 3D position, it can be used directly for point-to-point measurements or converted into 3D models, 2D drawings, contours or profiles etc.

3. MOVEMENT MONITORING

The general view of the slope surface is presented on Figure 3. In this figure, the location of GPS, concrete tie beam, settlement reference points, scanner tie points and reference cross sections are shown. Figure 4 shows the point cloud (3D scene) taken at 0930hr, 23 November 2002, before the groundwater table was raised and toppling of the surcharge blocks. Details of the surcharging and program of inducing rise in groundwater table and subsequent failure of the blocks can be found in Li (2003). In order to capture the surface movement with time during the induced rise in groundwater table, the slope surface was scanned at half an hour interval and each scan was referenced to the same tie points as those shown on Figures 3 and 4. Since the tie points were stationary and each scan was referenced to the same local coordinate system, therefore it was possible to record the change in point cloud positions with time. In this paper, only cross sectional profile A-A (with a close-up view of the point cloud on Figure 5) is presented to demonstrate that movement of 28 mm had occurred at the slope surface between 0930hr and 1910hr. The regression analysis shows that the positions of the tie points between each scan was less than 2 mm, thus indicating that high accuracy was achieved for the point cloud at each scan and that the recorded movement of 28 mm at this point was real movement of the slope surface between this time interval.

4. CAPTURING WASHOUT SHAPE AND DIMENSIONS

When the groundwater table was further increased and the sprinkler system was continuously stimulating rainfall infiltration to the slope, a large washout was observed and the scanner had safely captured the shape and dimension of this washout. Figure 6 shows the close-up view of the point cloud at 1910hr (23 November 2002) and the dimensions of the washout (maximum width=0.402 m, maximum length=2.412 m, maximum depth=0.338 m). The front row of the concrete surcharge blocks had started to move very slowly, showing signs of tilting at this time. The concrete blocks could have tumbled down the slope at any moment and manual measurement of the washout would have been too risky. This demonstrates that the use of remote scanning technique in capturing movement, position and depth of scouring/washout in an inaccessible and distressing slope has definite advantages over manual measurement.

5. MODELLING OF POINT CLOUD

Groundwater table continued to rise and the concrete blocks finally tumbled down the slope at 1930 hr (23 November 2002). Significant movement had now occurred on the slope and the GPS had displaced laterally due to the movement of the slope and the falling of the blocks. Figure 7 shows the locations of the blocks and the point cloud provides a clear identification of the positions of various blocks after failure. The vertical and horizontal travel distances of each individual blocks can be easily calculated by comparing the positions of the block corners before and after failure of the slope.

It is noted that the GPS position had moved significantly due to the falling of the blocks. Since the GPS pole has a cylindrical shape, therefore the point cloud of the GPS can be easily modeled into a cylinder, providing the best-fit geometry intersecting and representing all the points. This is illustrated on Figure 8, which compares the point clouds and the cylindrical models of the GPS at 1910hr (before blocks tumble) and 1930hr (after blocks tumble). It is clearly seen that the GPS had moved 0.219 m at the top and 0.082 m at the bottom between this time intervals. The advantage of the modeling is that the centerline of the GPS is used as the reference line for comparing the movement occurred.

6. COMPARISONS WITH INCLINOMETER READINGS

As stated in the Introduction, a number of inclinometers were installed to monitor the sub-surface movement during the field test. The inclinometer located at the crest of the slope had indicated the surface movement to be 85 mm between 1000hr and 1929hr, whereas the scanner had registered a movement of 81 mm between 0930hr and 1910hr. It is noted that although the time intervals for taking the inclinometer readings were not exactly the same as that of the scanning intervals, it is considered very satisfactory because the results are very close to each other, thus verifying that the measurements from the scanner are correct.

7. SUMMARY AND CONCLUSIONS

This paper presented a slope movement-monitoring project using the latest 3D laser scanning technology. It is found that by overlapping the point cloud generated from the scanner at different time intervals, the surface movement of the slope can be accurately recorded without the need of physically accessing the slope surface.

When the slope approaches limit equilibrium, the use of laser scanning can safely and quickly record the movement and dimension of washout and cracks, providing advantages over conventional survey method. This study shows that the movement obtained from the scanner agrees very well with that from conventional inclinometer reading at the surface. The travel distance of the surcharge block can be easily measured and point cloud can be easily modeled into geometrical shape for further rendering.

ACKNOWLEDGEMENT

The financial support by the Research Grant No. HKU7117/03E provided by the Research Grants Council of the Hong Kong Special Administrative Region, China is greatly appreciated.

REFERENCES

Hong Kong Institution of Engineers (HKIE), 1998. Soil Nails in Loose Fill – a Preliminary Study.

HKUST and HKU, 2000. Behavior of loose fill slopes and its stabilization with soil nails-application for allocation from the Central Allocation Grant for Research 1999-2000, Hong Kong University of Science and Technology and The University of Hong Kong.

Li, J., 2003. Field Study of a soil nailed loose fill slope. Ph. D. thesis, The University of Hong Kong, 218p.

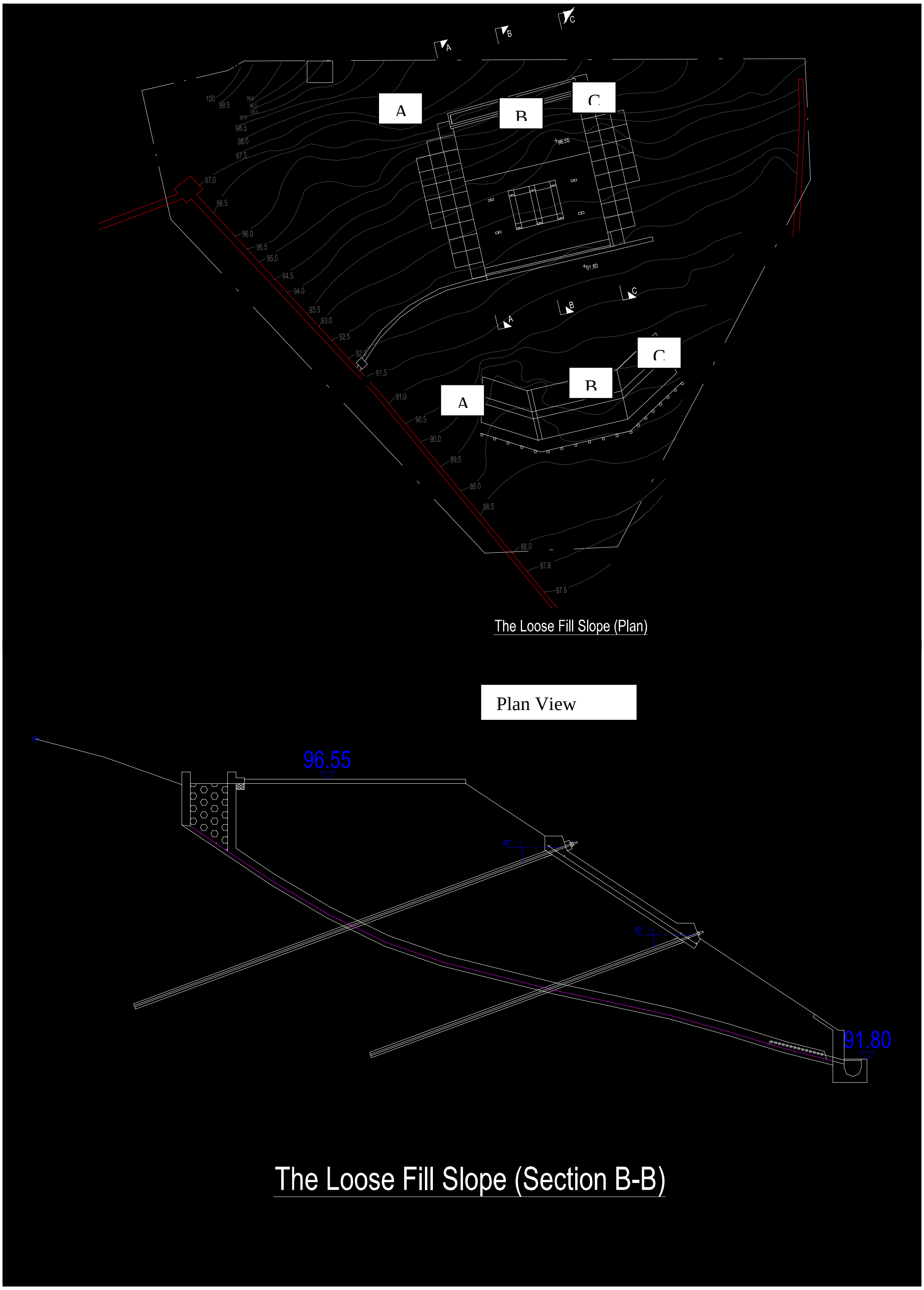

Figure 1 Plan and Section of Installed Soil Nails

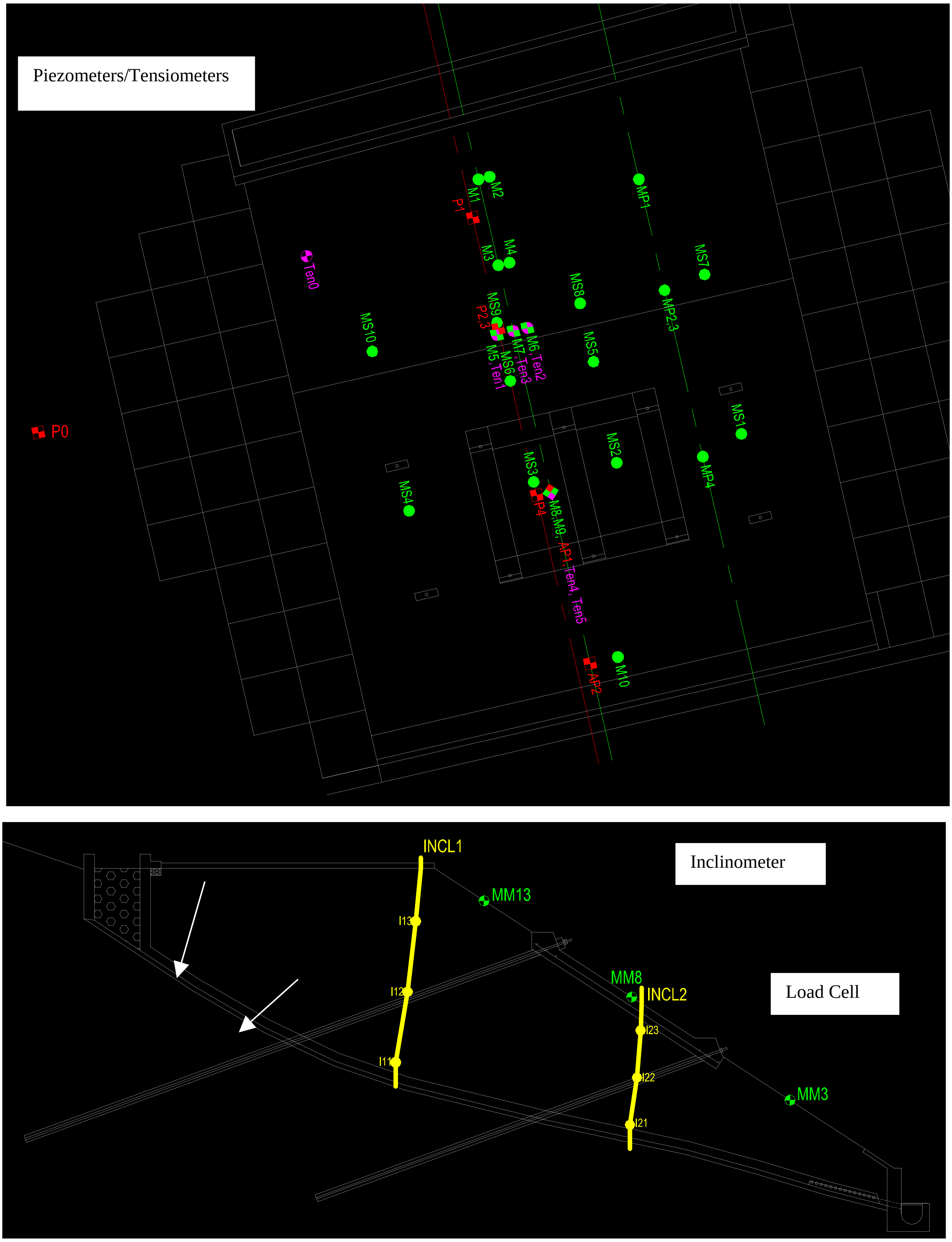

Figure 2 Instrumentation Details

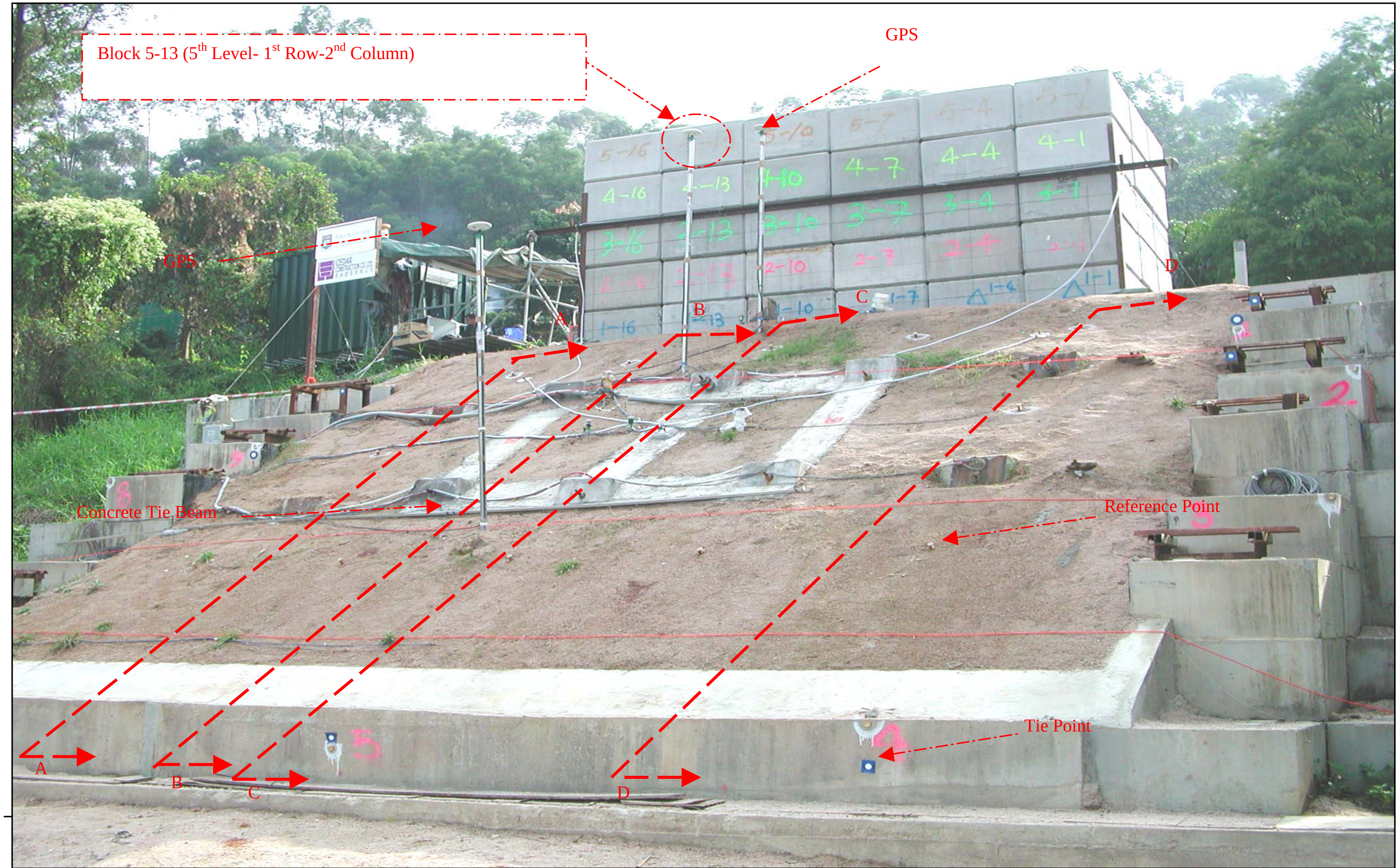

Figure 3 General Layout of Slope

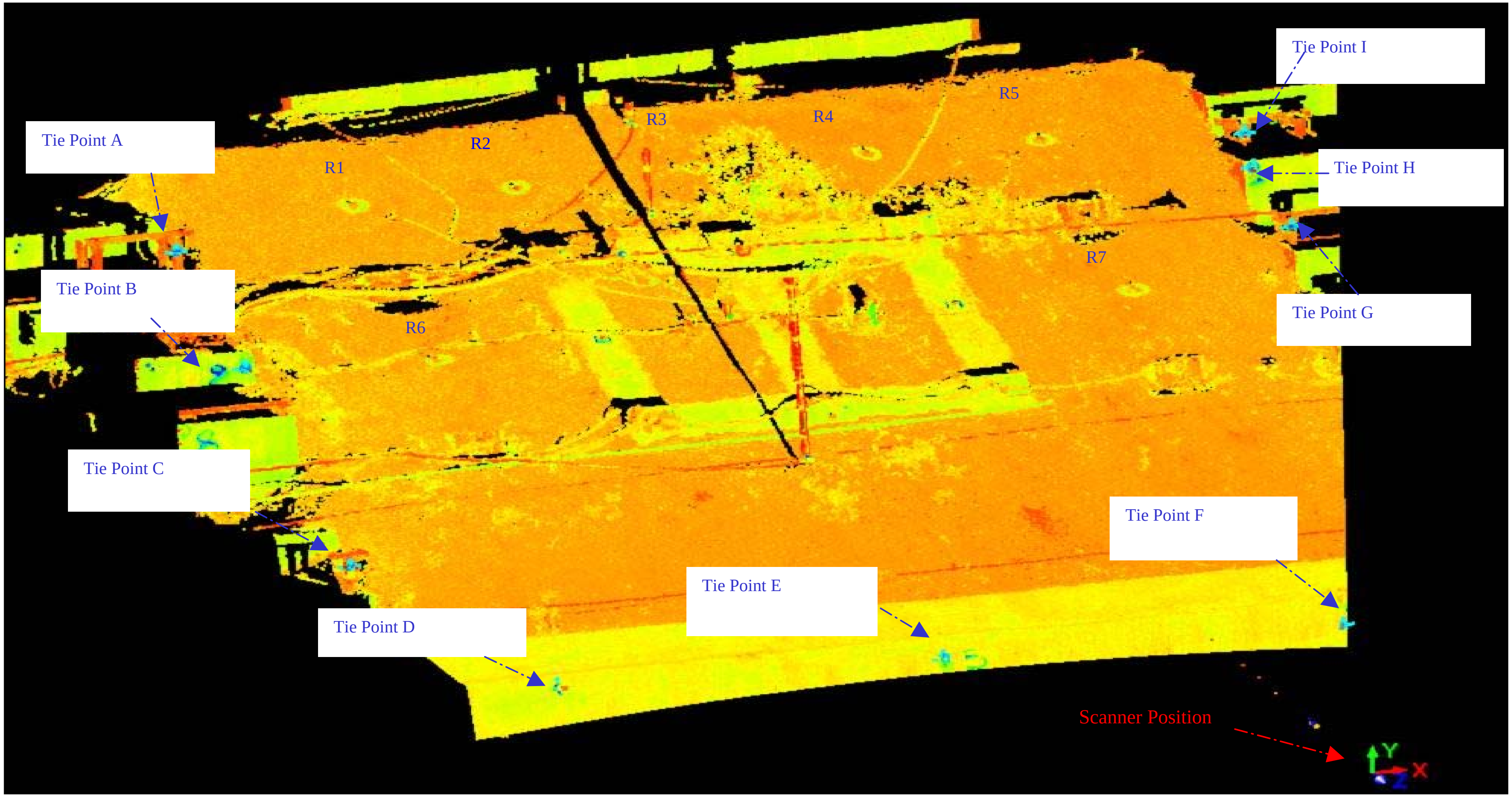

Figure 4 Overall View at 0930 hr, 23 November 2002

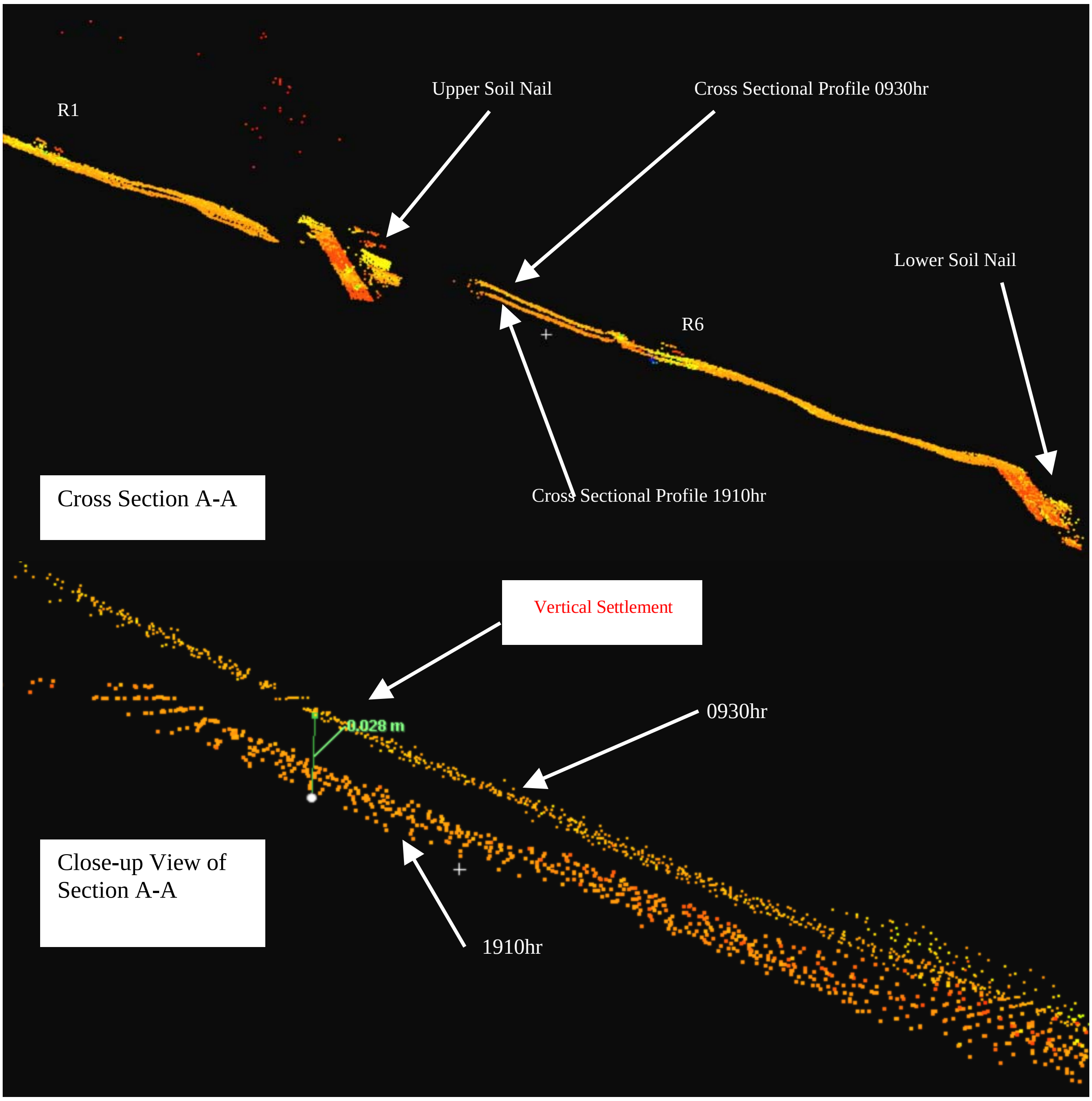

Figure 5 Point Cloud between Upper Soil Nail and R6

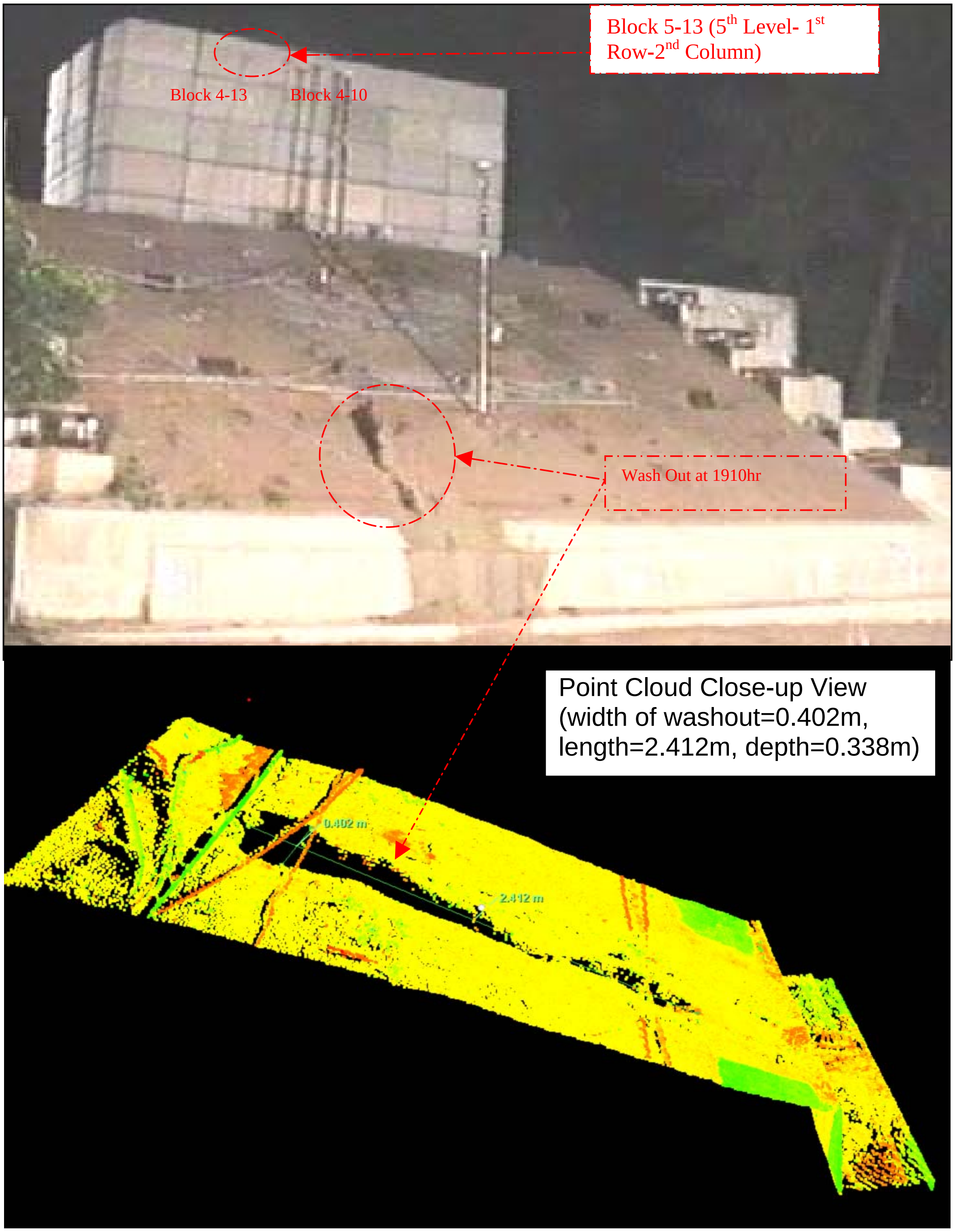

Figure 6 Washout observed at 1910hr, 23 November 2002

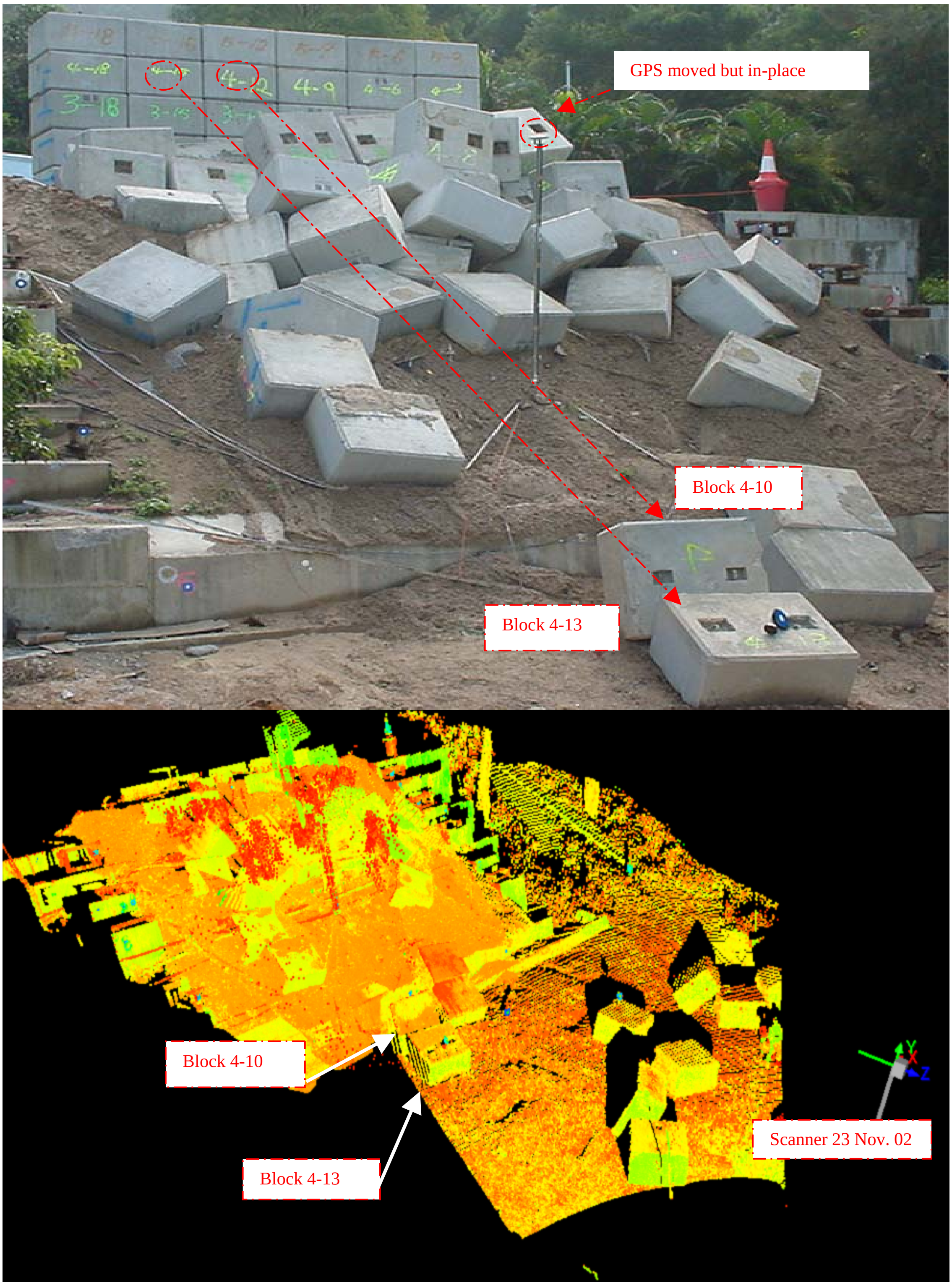

Figure 7 Blocks Toppled at 1930hr and Point Cloud

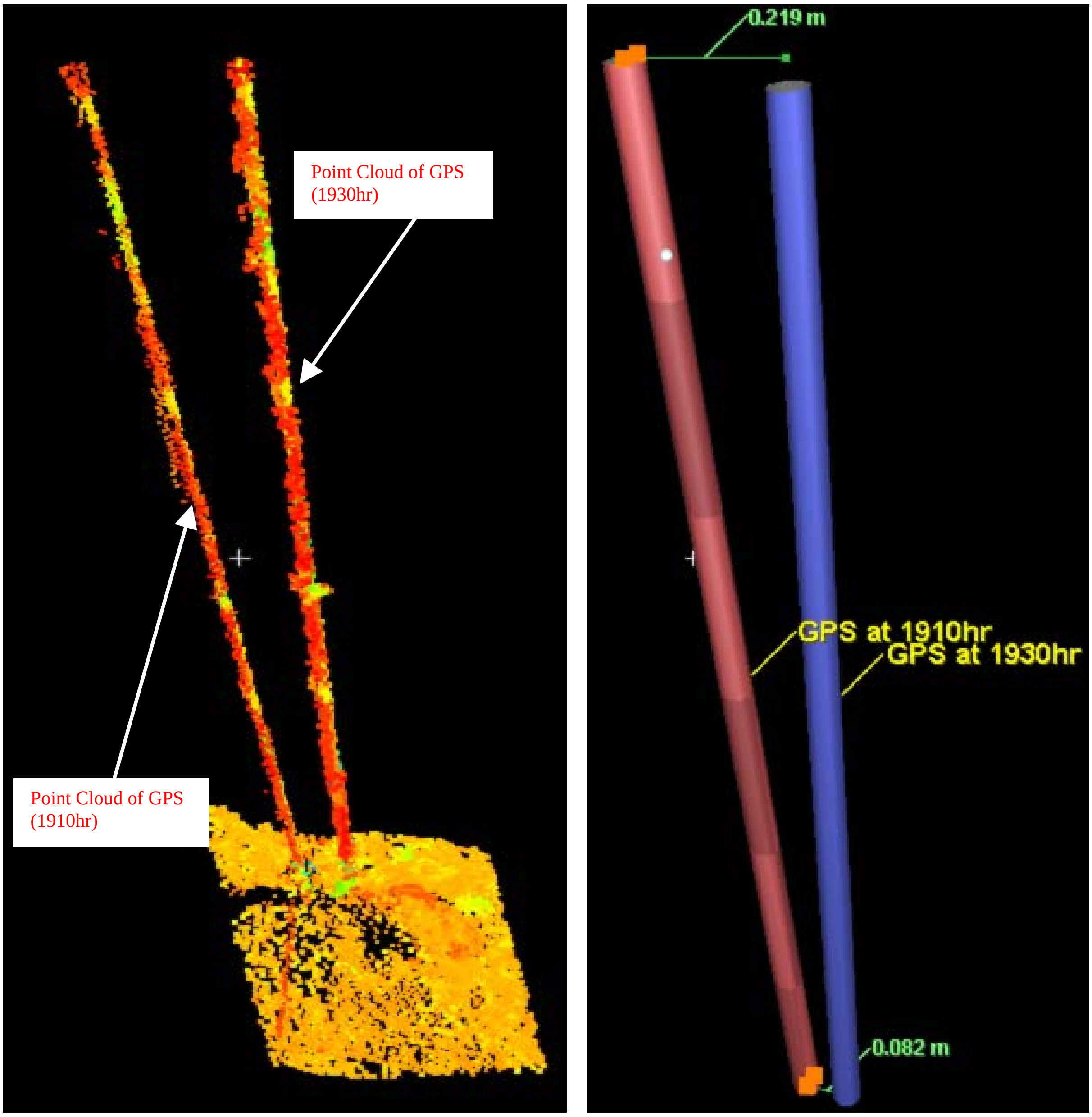

Figure 8 Modelling of GPS Positions

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.

Jacky Ng is a Technical Specialist at Leica Geosystems Ltd of Hong Kong, working with area of 3D Laser applications and GPS Monitoring in various area and he is specialized in Survey Sensors and Software Applications. Jacky has over 15 years of experience in Engineering Surveying Field Applications.

Andrew Wong is a Product Manager at Leica Geosystems Ltd of Hong Kong, working with area of 3D Laser System Applications & Structure Monitoring Survey Instrumentation and he is specialized in Surveying Automation and Monitoring Sensors Applications. Andrew has over 18 years of experience in Surveying Sensors Hardware and Software Applications.

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

Andrew Wong
Leica Geosystems Ltd of Hong Kong
Unit 1701-3, DCH Commercial Centre
25 Westlands Road, Quarry Bay
Hong Kong SAR
China
Tel. +852-2564-2299
Fax +852-2564-4199
Email: andrew.wong@leica.com.hk

Jacky Ng
Leica Geosystems Ltd of Hong Kong
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