Real-time drilling process monitoring for soil nailing works for slope upgrading works

De forage en temps réel pour la surveillance de processus travaux de clouage du sol pour la pente modernisation des œuvres

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ABSTRACT

Soil nailing is a commonly adopted technique for upgrading substandard slopes in Hong Kong. The Landslip Preventive Measures (LPM) Programme was first introduced by the Hong Kong Government in 1977 and the design and construction practices of slope upgrading works are continuously being improved by use of new technology and research. One of the innovative technologies, called Drilling Process Monitoring (DPM), has been developed by the Department of Civil Engineering of the University of Hong Kong (HKU) to monitor and record the drilling process of soil nailing works (Yue et al, 2004). Several sensors for recording position of drill chuck, pressure for percussion, thrust and rotation movement, are mounted onto a pneumatic rotary percussive down-the-hole drilling machine and its control panel. A set of data representing the whole drilling process is recorded automatically and continuously. The real-time DPM raw data together with the calculated penetration rate are presented graphically on a designated website.

Site trials of real-time drilling process monitoring were carried out at two sites under a Landslip Preventive Measures (LPM) Contract. One of the sites is a 20m high cut slope comprising bouldery Colluvium. The other is a 12m high loose fill slope. Some soil nail drillholes at the above two sites were selected for carrying out DPM with real-time monitoring. Some cavities and joints were suspected during drilling. Closed circuit television (CCTV) survey was conducted in those drillholes with suspected cavities and joints. In the DPM result of the selected drillholes, the deviation of penetration rate was correlated with the features such as cavities and joints in the drillholes as observed in the CCTV survey.

Real-time DPM for soil nailing works was confirmed to be an effective means of remotely verifying the depth of the hole and monitoring of ground conditions and progress. Portions of slopes with difficult ground conditions such as excessive grout loss or drillhole collapse can be identified in the early construction stage and a better planning or arrangement of site works can be made.

RÉSUMÉ

Clouage du sol est une technique couramment adoptée pour la mise à niveau des pentes inférieures à Hong Kong. Le glissement de terrain les mesures de prévention (LPM) Programme a été mis en place par le Gouvernement de Hong Kong en 1977 et de la conception et la construction de la pente l'amélioration des pratiques de travaux sont continuellement améliorées par l'utilisation des nouvelles technologies et la recherche. Une des technologies innovantes, appelé processus de suivi de forage (DPM), a été développé par le Département de génie civil de l'Université de Hong Kong (HKU) de suivre et d'enregistrer le processus de forage du sol clouer œuvres (Yue et al, 2004) . Plusieurs capteurs pour l'enregistrement de la position du plateau de forage, la pression pour la percussion, le mouvement de poussée et de rotation, sont montés sur un pneumatique rotatif percussion à la machine de perçage et de son panneau de contrôle. Un ensemble de données représentant l'ensemble du processus de forage est enregistré automatiquement et en continu. Le DPM en temps réel des données brutes avec le calcul de taux de pénétration sont présentés graphiquement sur un site désigné.

Site d'essais en temps réel des processus de suivi de forage ont été effectués sur deux sites dans le cadre d'un glissement de terrain les mesures de prévention (LPM) du contrat. Un des sites est une coupe de 20m de haut de pente comprenant bouldery colluvions. L'autre est un de 12 mètres de hauteur vrac pente. Certains sols drillholes clou à ces deux sites ont été choisis pour la réalisation de DPM avec surveillance en temps réel. Certaines cavités et de joints ont été suspectés au cours du forage. Télévision en circuit fermé (CCTV) enquête a été menée dans les soupçonne drillholes cavités et des articulations. Dans le résultat de la DPM, sélectionnez drillholes, l'écart de taux de pénétration a été corrélée avec les caractéristiques telles que des cavités et des articulations dans le drillholes ainsi que l'a relevé dans la CCTV enquête.

Real-time DPM pour clouer travaille le sol a été confirmé à être un bon moyen de vérifier à distance la profondeur de la fosse et le suivi des conditions de terrain et de progrès. Les portions de pistes difficiles conditions de terrain telles que les excès de coulis de perte ou de l'effondrement drillhole peuvent être identifiés au début du stade de la construction et l'amélioration de la planification ou de l'arrangement de site peut être faite.

Keywords : soil nail; landslip preventive measures, drilling process monitoring; closed-circuit television

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1 INTRODUCTION

1.1 *Background*

Evaluations of the application of DPM and field trials of the whole system have been conducted at various slope sites in Hong Kong by the Department of Civil Engineering of the University of Hong Kong (HKU) and the Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD) of the Government of the Hong Kong Special Administrative Region (Lam & Siu, 2004; Lai & Lo, 2008). Studies were mainly carried out in weathered rock strata such as decomposed Granite and volcanic Tuff. Studies have also confirmed that the drilling penetration rate changes within different types of ground conditions (Ho et al, 2007).

Based on the analyses by Yue et al, 2004, the penetration rate varies with the weathering grades of volcanic rock. The criteria for zoning weathered grades of volcanic rocks corresponding to penetration rates extracted from Yue et al, 2004, is shown in Table 1.

Table 1. Penetration rates in weathering grades of volcanic rocks (Yue et al, 2004).

Weathering Grades of Volcanic rock	**Penetration Rates (m/min)**
I, II to III	0.05 – 0.45
III – IV to IV	0.45 – 0.95
V	0.95 – 2.0
V – VI to VI	2.0 – 8.0

The latest production trial is to confirm the application to different ground conditions common in Hong Kong including Fill and Colluvium and that application of real-time DPM can be an instant and accurate means of estimating the depth of the hole and remote monitoring of ground conditions within the drillholes and drilling process.

1.2 *Background*

The DPM equipment mainly consists of 1 displacement and 5 pressure sensors. The displacement sensor is mounted onto the drilling rig "mast" and engages the steel loop chain of the drilling rig to record forward and backward movement of the drill string. The pressure sensors measure the required hydraulic pressure for percussion of the down-the-hole hammer, upward and downward thrust on the drilling bit, and clockwise and anti-clockwise rotation of the drill string (Lai & Lo, 2008; ETI, 2006a & 2006b). All of the pressure sensors are mounted onto the control panel of the drilling machine. Calibration for each drilling rig is required to ensure that appropriate parameters are adopted for data processing. A photograph showing the setup of the sensors on a typical rotary-percussion drilling rig is given in Plate 1.

Data is recorded at 0.5-second intervals and transmitted wirelessly to the control box and sensor box. The processed drilling data, which is uploaded to a remote server through the General Packet Radio Services (GPRS) mobile network, can be viewed in real time on a secure website of HKU (Lai & Lo, 2008).

1.3 *Background Closed-circuit Television (CCTV) Survey*

CCTV survey was carried out at selected drillholes, which allowed inspection of the ground conditions within the drillholes and correlation with the DPM results and subsequent soil nail grouting operations. Features such as local drillhole collapse, voids and joints were easily identified and recorded.

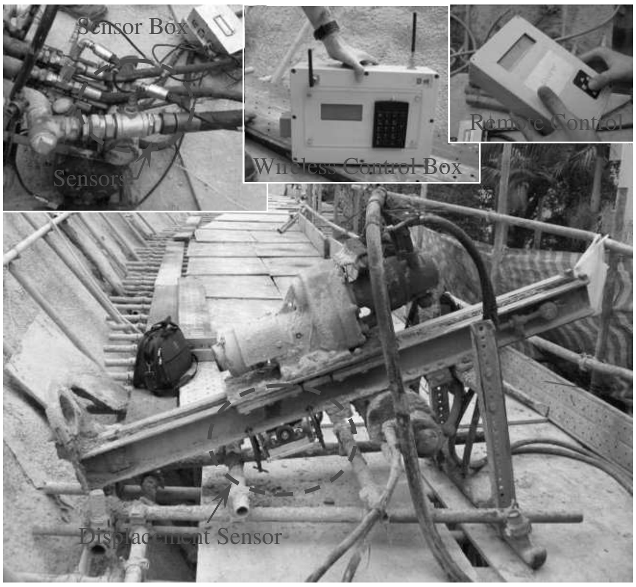

Plate 1. Setup of DPM sensors on a typical rotary percussion drilling rig.

1.4 *Details of Selected Sites*

Two sites were selected to carry out real-time DPM. Feature No. 11SW-A/CR34 is located in Mid-levels on Hong Kong Island. The feature is a 16m high cut slope with a 3m high reinforced concrete retaining wall along the toe. Based on the previous studies, geotechnical investigation, aerial photographs interpretation as well as previous and recent ground investigation (Arup, 2007a), the soil strata of the feature is a succession of Fill and Colluvium. Colluvium mainly comprises firm, yellowish red, sandy, clayey silt with sub-angular to sub-rounded fine to coarse gravel, cobble and boulder sized rock fragments (Arup, 2007a). Shear strength parameters of c' = 3kPa and ϕ' = 38° were adopted for Colluvium in the slope stability analysis. The DPM was selected to be carried out within the Colluvium with voids and cavities, and excessive cement grout losses were anticipated to be encountered at some of the drillholes. A simplified geological model of the feature is shown in Figure 1.

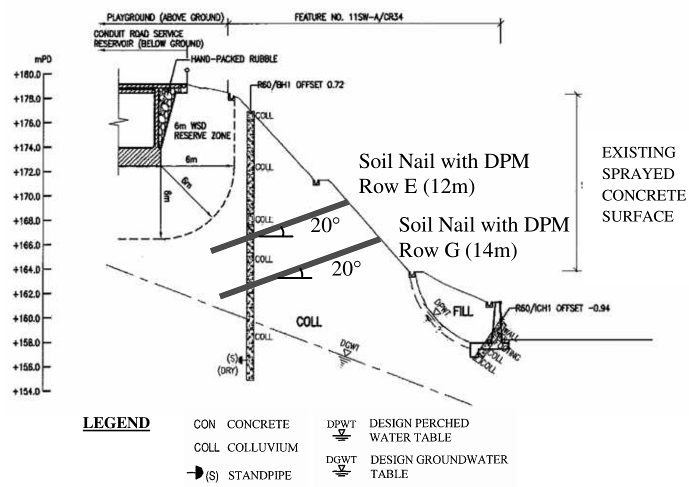

Figure 1. Geological model of Feature No. 11SW-A/CR34.

The other site, Feature No. 11SW-D/FR71, is a 6m high fill slope with a 7m high concrete retaining wall at the toe. According to the ground investigation and geotechnical study report (Arup, 2007b), the soil strata of the feature are interpreted as a succession of up to 8.0m of Fill underlain by Completely Decomposed Granite (CDG). The DPM was carried out within the Fill and CDG. The Fill comprises loose to dense, silty, fine to coarse sand with some angular to sub-angular fine gravel-sized quartz fragments and occasional angular to sub-angular fine to coarse gravel-sized highly decomposed Granite fragments. The CDG comprises extremely weak, moist, completely decomposed medium grained Granite (Arup, 2007b). In-situ relative compaction tests carried out in trial pits within the Fill found results varying between 72.6% and 95.3% of the maximum dry density. SPT-N values of 9 to 79 were obtained within the CDG (GCE, 2007). Shear strength parameters of $c' = 0$kPa and $\varphi' = 33$ and $c' = 5$kPa and $\varphi' = 37$ were adopted for Fill and CDG respectively in the slope stability analysis. The geological model of the feature is shown in Figure 2

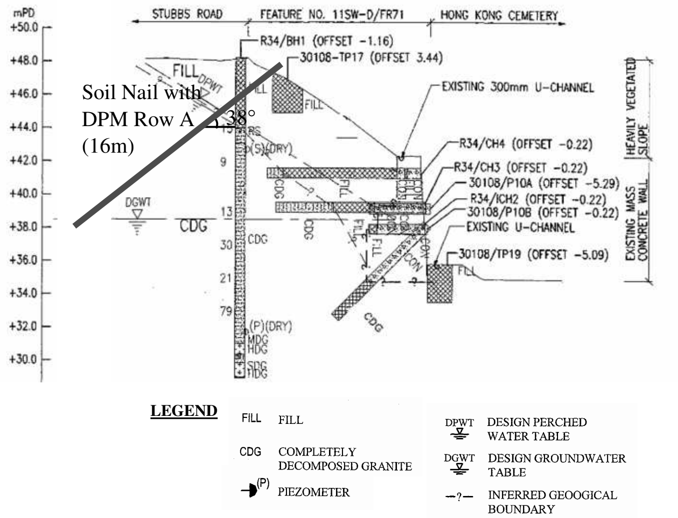

Figure 2. Geological model of Feature No. 11SW-D/FR71.

2 DPM RESULTS AND ANALYSIS

2.1 *DPM Data Collected at Feature No. 11SW-A/CR34*

The DPM was carried out at 4 numbers of 12m long drillholes (nos. E27 to E29 and E34) and 11 numbers of 14m long drillholes (nos. G24 to G29, G32, G34 and G36 to G38). The diameter of drillholes was 100mm with drillholes inclined at 20° to the horizontal with a 1.5m horizontal spacing. A geological section of the feature is shown in Figure 1.

The depth of drillholes was manually measured after drilling and compared with the depth from the DPM results. It is found that the difference of the manually measured and drillhole depth from DPM ranges from -0.4m to 0.6m which is within ±5% of the measured depth.

Drilling rate graphs (depth vs time graphs) were downloaded from HKU's designated secure website and retrieved. Average drilling rates ranging from 0.43 m/minute to 2.73 m/minute were obtained from DPM results at the above drillholes. CCTV survey was conducted at drillholes nos. E27 to E29, E34 and G29 to G31. The drilling rate graph for the DPM of 4 drillholes (nos. E27 to E29 and E34) is extracted and illustrated with some photographs recorded during CCTV survey which are shown in Figure 3.

From the drilling rate graph of Rows E and G drillholes of Feature No. 11SW-A/CR34 (Figures 3 and 4), the average drilling rate ranged from 0.43 m/minute to 2.73 m/minute. The relatively fast drilling rate (i.e. 2.73 m/minute) indicates that the drill bit was drilling through relatively soft materials while the slow drilling rate (i.e. 0.43m/minute) indicates that the drill bit was drilling through relatively hard materials such as boulder. The drilling rate from the DPM result for rock such as moderately and slightly decomposed rock tends to be less than 1 m/minute while the drilling rate for soil varies from 1 m/minute to over 2 m/minute as inferred from the previous studies (Lai & Lo, 2008).

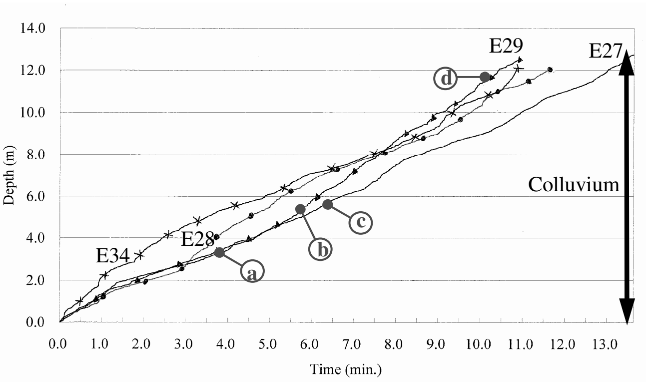

Figure 3. Depth vs Time Graph of DPM Results for Feature No. 11SW-A/CR34 (Soil Nail Row E).

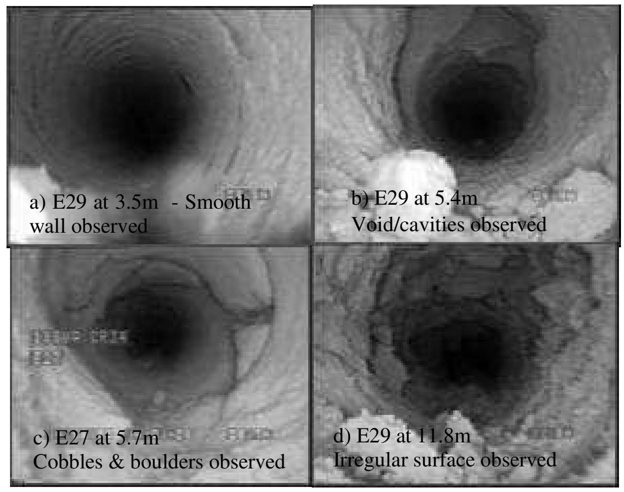

Plate 2. Photographs captured in CCTV survey.

In Figure 3, the graph gives consistent drilling rate of 1.07 to 1.30 m/minute at first 2m of drillholes nos. E27 to E29. From the depth of 2 to 4m, the drilling rate is about 0.64 to 0.83 m/minute. The relatively slow drilling rate indicates that the ground from 2 to 4m comprises relatively hard materials. From the depth of 4m onwards, the penetration rate become irregular and voids or cavities were probably encountered which are correlated with the CCTV survey. Some photographs of the CCTV survey were captured and shown in Plate 2.

The drilling rate graph for the DPM of the remaining 11 drillholes (nos. G24 to G29, G32, G34, and G36 to G38) is extracted and shown in Figure 4. The overall average drilling rate ranges from 0.76 m/minute to 1.30 m/minute as shown in Figure 4. In general, the drilling rate gradually increased from drillhole nos. G25 to G38, which was probably due to changes of soil strength along the slope. A significant variation of drilling rate is observed from of 9 to 12.5m depth in some drillholes (nos. G24, G25, G26 and G29). Penetration rates ranged from 0.56 m/minute to 5.6 m/minute. This indicates significant changes of ground conditions. High penetration rates of 2.07 m/minute and 5.6 m/minute were observed at the depth of about 10.6 to 12.1m and 9.2 to 9.8m of drillhole nos. G26 and G29, respectively, which indicates the presence of very soft soil and/or cavities. Excessive cement grout loss greater than 10 times of the theoretical volume of the drillhole was encountered at drillhole nos. G24, G26 and G27 and pre-grouting operation was adopted for drillhole nos. G28 and G29 to solve the grout loss problem.

2.2 *DPM Data Collected at Feature No. 11SW-D/FR71*

The DPM was carried out at 10 numbers of 16m long drillholes (nos. A8 to A11, A14 to A16, and A18 to A20). Diameter of drillholes was 100mm with drillholes inclined at 38° to the horizontal with a 1.5m horizontal spacing. A geological section of the feature is shown in Figure 2.

The depth of drillholes was manually measured after drilling and compared with the drillhole depth from the DPM results. The difference of the manually measured and drillhole depth from DPM ranged from -0.4m to 0.3m which is within ±3% of the measured depth.

Drilling rates ranging from 1.38 to 4.68 m/minute were obtained for the Fill layer from DPM results at the above drillholes. The depth vs time graph for the DPM of 6 selected drillholes is extracted for illustration and shown in Figure 5.

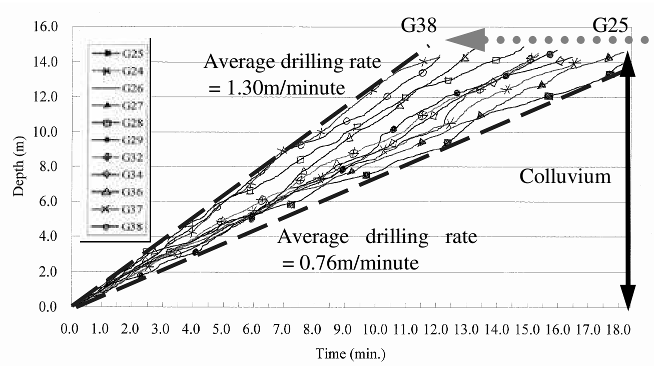

Figure 4. Depth vs Time Graph of DPM Results for Feature No. 11SW-A/CR34 (Row G).

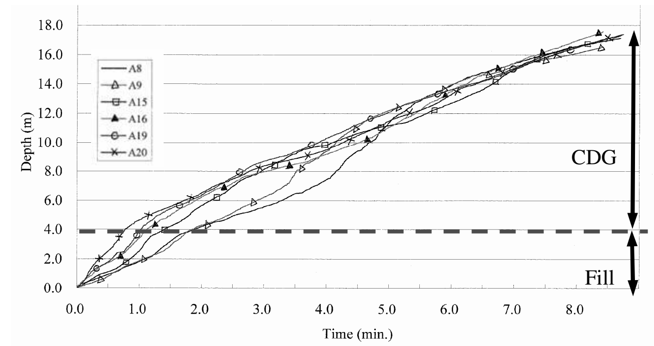

Figure 5. Depth vs Time Graph of DPM Results for Feature No. 11SW-D/FR71 (Row A).

A significant change in drilling rate from an average of 2.73 m/minute to an average of 2.02 m/minute is observed at the depth of about 4m as shown in Figure 5. This change of drilling rate may indicate a change in soil strength. With reference to the geological section of the slope in Figure 2, the Fill/CDG interface is about 4m below the slope surface at soil nail Row A which coincides with the change in drilling rate measured by the DPM. There was no large variation of drilling rate and excessive grout loss was not encountered at the drillholes at Feature No. 11SW-D/FR71.

3 CONCLUSION

Application of real-time DPM was confirmed to be an instant and accurate means of measuring the depth of the drillholes and monitoring the drilling process and ground conditions. Change in character of strata was observed from the drilling rate graphs and correlated with the ground investigation information and geological model. Potential difficulties such as excessive grout and drillhole collapse were identified at an early stage. It offered the project team an opportunity for a better planning or arrangement of site works and gave the designer an early review of the geological model, and hence minimize risks of construction delay and cost overrun for the subsequent upgrading works due to excessive grout loss, re-design and/or subsequent claims.

It is suggested that DPM could form a part of the requirements for test nails which are currently required to be installed and tested to verify ground conditions prior to the installation of permanent soil nails

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