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Design of a large soil box for studying soil-nail interaction in loose fill

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ABSTRACT: Soil nailing has become a common technology for stabilization of slopes and retaining walls. However, its application to stabilize loose fill slopes is seldom as there is a lack of quantitative understanding of the soil-nail interaction in the loose fill. This paper presents a test apparatus for investigating the pullout resistance of nails as a function of vertical pressure, relative compaction and degree of saturation of the loose fill. The test apparatus consists of a large box of length 2.0 m, width 1.6 m and height 1.4 m; two portal frames of length 2.4 m and width 2.0 m; and a pulling device. A row of five nail bars can be accommodated in the box. Preliminary results were also presented on the behavior of steel bars embedded in loose completely decomposed granite fills.

1 INTRODUCTION

In Hong Kong, soil nailing has been extensively used for stabilizing cut slopes and retaining walls. Its application in loose fill slopes is seldom. There are thousands of fill slopes in Hong Kong. Many of these slopes are substandard and required to be upgraded to the current geotechnical standards. One possible and economical way to stabilize these slopes is the use of soil nails. However, there is a lack of quantitative understanding of the interaction behaviour of soil nails with a loose fill, which restricts the application of soil nails to stabilization of loose fill slopes.

The objective of this paper is to present a large laboratory testing apparatus for the investigation of the pullout resistance of nails as a function of a number of variables. These variables include vertical pressure, relative compaction and degree of saturation of the loose fill. The large laboratory testing apparatus was designed and fabricated by the research team of the Jockey Club Research and Information Centre for Landslip Prevention and Land Development, Department of Civil Engineering, The University of Hong Kong. This study is part of an ongoing group research project entitled "Behaviour of Loose Fill Slopes and Its Stabilization with Soil Nails", which was recently initiated by two research teams from The University of Hong Kong and The Hong Kong University of Science and Technology.

2 BACKGROUND

2.1 *Old fill slopes*

The rapid economic growth in the 1950's and 1960's brought tremendous infrastructure development, which required formation of platforms for roads and buildings. At that time, fill slopes were often constructed by end-tipping without proper compaction. Among the 54,000 registered man-made slopes in Hong Kong, there are approximately 6000 old fill slopes.

The current standards for new fill slopes construction require that fills should be compacted to at least 95 % of the maximum dry density according to the standard proctor test (GEO, 1984). According to the new standards, many of the pre-1977 fills are considered to be loose and required to be upgraded.

2.2 *Modes of instability*

There have been failures of loose fill slopes in Hong Kong. In the landslides occurred at Sau Mau Ping in 1972 and 1976, the mud avalanches killed a total of 89 people.

Sun (1999) reviewed the fill slope failures in Hong Kong and the advances made in conceptual understanding of liquefaction failures of loose soils. Yim and Siu (1997) and Wong *et al.* (1997) discussed the modes of instability of the loose fill slopes: static liquefaction, sliding and washout. The major failures in loose fill slopes that caused loss of lives and damage to properties are understood to have involved static liquefaction.

Loose fill slopes comprise partially saturated soils and maintain suction. When water ingress into the slope occurs, degree of saturation increases and the suction start to diminish. During the process, strength of the soil decreases and applied stress increases as a result of increase in weight of the soil. If the slope is steep and the amount of water ingress is large, undrained shearing can occur when shear displacement exceeds a certain limit. This causes structural collapse of the loose material that transfers the load wholly or partly onto the pore water leading to rapid increase in the pore water pressure. This further reduces the shear strength of the soil and trigger flow type failure. Debris of the failure is usually more mobile than that of other type of failures and can cause severe devastation.

2.3 *Conventional method of loose fill slope stabilization*

After the 1976 Sau Mau Ping failure, the government of Hong Kong set up an Independent Review Panel for the recommendations of appropriate actions (Hong Kong Government, 1977). The panel's principal recommendation for loose fill slope stabilization comprised the excavation and recompaction of the top layer to a vertical depth of not less than 3 m; and provision of a drainage layer under the recompacted material at the toe of the slope.

The recompaction has been used to enhance the stability of the loose fill slopes along with other methods such as flattening of slope angle, surface protection methods and retaining walls. Law *et al* (1999) reviewed the effectiveness of upgrading loose fill slopes by the recompaction method and concluded that there is general improvement in the performance of the slope after recompaction. However, this method is not suitable for congested sites. In many cases, it is difficult to implement the conventional method due to the presence of existing services and mature trees. There is therefore a need to search for alternative methods to enhance stability of the loose fill slopes.

2.4 *Possibility of using soil nails*

In Hong Kong, soil nailing has become a common method for enhancing stability of the existing slopes (Powell and Watkins, 1990). This is extensively used in soil cut slopes and retaining walls. Based on the experience gained in hundreds of cut slop stabilization, a prescriptive design method has also been developed for use of soil nails to upgrade soil cut slopes (Wong and Pang, 1996). The use of soil nails to stabilize the loose fill slopes would have definitely advantages in overcoming the difficulties encountered by the conventional methods. But, there is a lack of quantitative understanding of the behaviour of loose fills and interaction behaviour of soil nails in the loose fills. On the request of the Geotechnical Engineering Office (GEO), the Geotechnical Division of Hong Kong Institution of Engineers (HKIE) formed a subcommittee to study the application of soil nails in loose fill slopes (HKIE, 1998). Prior to this study, a report entitled "The Use of Soil Nails to Upgrade Loose Fill Slopes", was prepared by Dr. B. Simpson for GEO (Ove Arup and Partners, 1996).

In 1998, the subcommittee published a draft report entitled "Soil Nails in Loose Fill - A Preliminary Study" (HKIE, 1998). This report reviewed the past works and provided interim design guidelines for application of soil nails in loose fill comprising completely decomposed granite (CDG) having at least a 75% relative compaction.

Fill slopes in Hong Kong are commonly built of CDG soils. The conclusions drawn in the HKIE study were based on the results of an extensive conventional laboratory testing on loose CDG soils (Law *et. al.*, 1997).

However, the report states "it is of concern that soil nails may not work in loose fill due to two reasons. The first is that the soil may develop high pore water pressures and flow around the soil nails and the second is that the soil either side of the failure zone may be too weak to provide a secure anchorage for the soil nails". The reliability of behaviour of soil nails in heavy rainstorms is therefore questionable. The report also discussed the possibility of using field and large-scale laboratory experiments for further investigation.

2.5 *The current research project*

The current group research project may be considered as the second phase of the studies carried out by HKIE's Geotechnical Division. The current project is aimed primarily at studying the liquefaction behaviour of loose CDG fill slopes in Hong Kong and their potential stabilization with soil nails. It consists of a number of major research components. The research team of The University of Hong Kong is responsible for field and large scale laboratory testing, and numerical modeling.

3 LABORATORY TESTING

Many field and laboratory tests have been performed worldwide to investigate the general behaviour of soil nails. The research works were, however, not focused on loose fill materials. The interaction behaviour of soil nails and the potential failure mechanisms in loose fills are to be investigated.

Several researchers have attempted to study behaviour of soil nailed structures by using laboratory tests: large-scale model test, centrifugal test, large direct shear box test, and pullout test.

For testing individual nails, large direct shear box tests and pullout tests were used. The shear box tests were carried out mainly for evaluating contribution of tension and bending of soil nails. For example, a large direct shear box (3.0 m length × 1.5 m width × 1.5 m height) was used to study soil-nail interaction at the University of Wales, Cardiff. Barr *et al.* . (1991) reported the design details of the shear box.

The reported laboratory pullout tests on soil nails are few compared to the research works with field pullout testing. Milligan *et al.* (1997) studied the bond mechanisms between grouted nails and soils by laboratory pullout tests. The test apparatus consisted of a tank (1.0 m length × 1.0 m width × 0.6 m height) and a mechanical drive to pull the nails at a constant rate. The boundary stresses were controlled through water-filled rubber bags located both at the top and at the sides. Preliminary tests were carried out on a grouted nail of 100 mm diameter installed in sand and clay. It was reported that the instrument package used in this test allows direct measurement of contact normal and shear stresses on the nail.

Franzen (1998) used a large laboratory setup to study pullout resistance of driven bare nails in dry poorly graded fine sand. The laboratory set-up consisted of a large box (4.0 m length × 2.0 m width × 1.5 m height), a water-filled rubber cushion at the top for application of vertical pressure, and a pulling arrangement. The box can accommodate three nails at 1.3 m spacing. The pullout tests were performed in a force-controlled manner under three different vertical pressures, *i.e.*, 25, 75 and 125 kPa.

The materials used in the previous studies in other countries were sands or clays. The current testing program is distinguished by the investigation of the interaction of nails with loose CDG fills under a fully saturated situation.

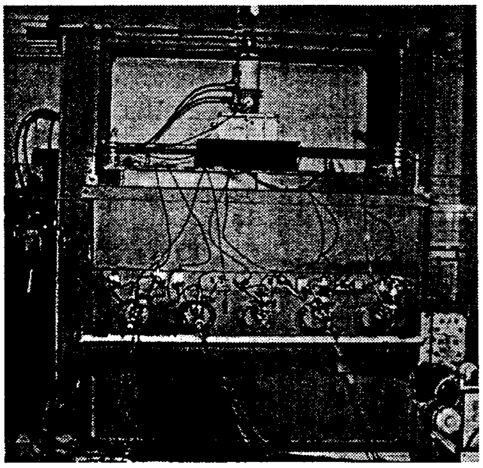


Figure 1. View of the test apparatus.

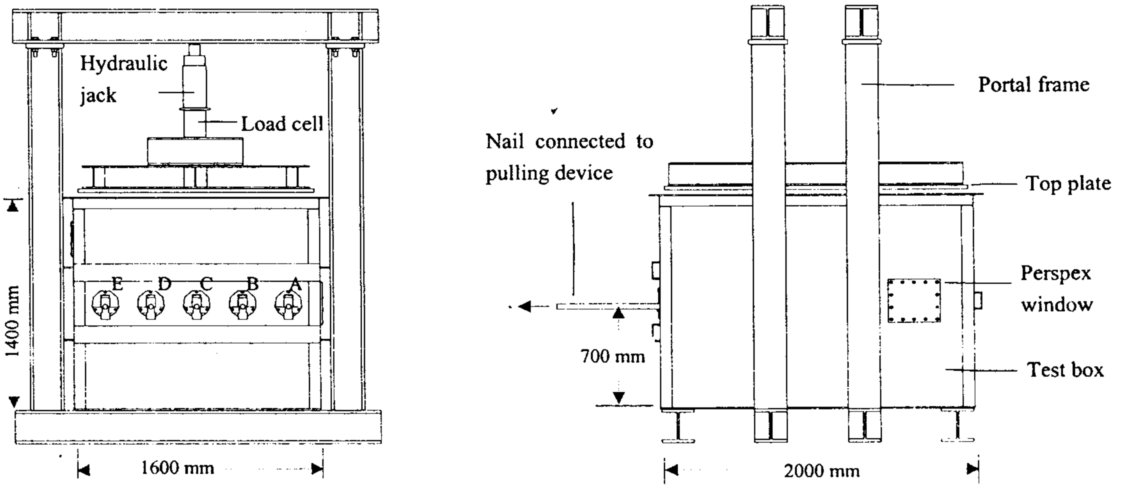
4 DESIGN OF A LARGE SOIL BOX

The apparatus is illustrated in Figures 1 and 2. This consists of a large box of length 2.0 m, width 1.6 m and height 1.4 m to accommodate soil samples and nails; two portal frames of length 2.4 m and width 2.0 m for application of vertical pressure; and a pulling device.

4.1 *Test box*

The box is built of steel and is rigid enough for a vertical loading range up to 150 kPa. The inside is lined with stainless steel sheet to minimize side friction. Steel angles are used along the edges to join the steel plates. The box is waterproof for the investigation of water effect.

Five holes in the front wall allow the nails to stick out for pulling. A row of five bare nails can be ac-



(a) Front

(b) Side

Figure 2. Main features of the apparatus.

commodated in the box. The space of the box filled with loose fill is considered to be large enough to avoid effects of other factors on an individual nail when a pullout test is being carried out for the nail. For grouted nails, two of the holes (B & D, see Fig. 2a) can be used.

4.2 *Application of vertical pressure*

In the previous laboratory tests, fluid-filled rubber cushion was used to apply the vertical (or lateral) confining pressures. The pressure was generated by pumping air or water to the fluid-filled cushion placed between the boundary and a rigid wall.

In this approach, there are at least two concerns: (a) relatively large area (2.0 m × 1.6 m) to be covered by the cushion and (b) amount of settlement caused during the application of vertical pressure.

For the current study, it is therefore decided to apply the vertical pressure by two jacks mounted on a rigid steel plate sitting on top of the fill. The jacks act against the portal frames straddling over the box. Columns of the portal frames also act as stiffeners to the box. The top steel plate is of 25 mm thickness and it is stiffened by a set of steel sections.

The applied vertical load is measured by a load cell positioned between the jack and the top plate (Fig. 2a) automatically. Pressure distribution at the level of nails will also be measured by using earth pressure sensors. Five numbers of Linear Voltage Displacement Transducers (LVDT) installed at the corners and the middle of the top plate are used to measure settlement of the fill at the top.

Capacity and stroke of the jacks are 500 kN and 160 mm respectively. The intended test range of vertical pressure is 25 - 100 kPa, which is equivalent to the overburden pressure of a fill of 1 to 5 m.

4.3 *Arrangement for saturation of soil sample*

Soil sample is saturated by pumping water to the bottom of the box. A layer of perforated pipes, fixed inside the box 50 mm above the bottom, is used to supply water. The pipes are wrapped by a fine wire mesh and covered by coarse aggregates placed at the bottom of the box up to 150 mm height.

Water can be pumped into the box at a slow rate, 150 litre per hour. A flowmeter is used to control the flow. Stand pipes connected to the bottom of the box can be used to monitor water level. Also, two perspex windows provided in both sidewalls at different heights can be used to observe rising water level.

Settlement and vertical load change during the introduction of water to the box can be measured automatically by the load cells and the LVDTs installed on the top plate.

4.4 *Pullout device*

The load applicator of a direct shear box test apparatus is modified and used as the device for application of the pullout loading. The device permits the pullout test to be conducted in a displacement rate-controlled manner (0.025 – 1.300 mm / min). A displacement rate-controlled test allows the measurement of the load-displacement behavior up to the post-peak state. The pullout force is measured by a load cell installed between the nail and the pulling device. A LVDT is used to measure the displacement of the bar when it is being pulled out horizontally. The pulling device is aligned with longitudinal direction of the nail buried partially in the fill within the rectangular box. During the pullout test, the pulling device is fixed to a base that is firmly secured to the concrete ground in the laboratory. A universal joint is used to connect the load cell and the nail in order to reduce influence of any misalignment.

5 PREPARATION AND TEST PROCEDURE

In order to refine the set-up and testing procedure, tests have been carried out on bare steel bars. All the transducers used in these tests were calibrated. Readings were taken automatically through a data acquisition system.

5.1 *Preparation of loose fill in the box*

Soil sample is prepared to a required density by filling the box in a series of 50 mm lifts. The amount of soil needed for each 50 mm lift to achieve the required density is weighed. The mass is poured and spread in the box. If compaction is required, the lift is slightly and manually compacted. During the placement of sample, steel bars are embedded and aligned carefully at the level of the holes. The box is filled up to 1350 mm, leaving 50 mm at the top for placing the plate.

5.2 *Vertical pressure*

The top plate is placed on the fill. Clearance between the top plate and walls of the box is 5 mm. Portal frames are then assembled. Finally, hydraulic jacks, load cells and LVDTs are installed.

5.3 *Pullout test*

The first series of pullout tests are carried out with self-weight of the top steel plate. During the testing, readings of the pullout force and displacement are taken every five seconds. Vertical pressure is then applied by the jacks. The applied load and corresponding settlement are measured by the load cells and the LVDTs respectively. A period of minimum two days is allowed after each vertical loading so that pullout tests can be conducted under stable stress conditions. When the stable stress conditions are reached, the second series of pullout tests are performed on the nails. Application of vertical pressure and pullout tests are repeated as necessary.

6 PRELIMINARY RESULTS

6.1 *Soil sample*

The material used in the preliminary tests is a CDG soil excavated from a hillside slope in Shau Kei Wan, Hong Kong. Approximately 6 m^3 of soil samples were taken from the hillside slope at the depth between 0.5 m to 2 m. Figure 3 presents particle size distribution of the CDG soil. In particular, it is noted that the CDG soil has 16 % fines. According to the soil classification system in GEO-Guide 3 (GEO, 1988), the soil can be classified as reddish brown, well graded, silty, fine gravelly SAND. The maximum dry density of the material is 1600 kg/m^3 and the optimum moisture is 20%. The sample was prepared to a dry density of 1280 kg/m^3, corresponding to 80% of the maximum dry density. Table 1 presents the values for each lift.

Table 1. Density of the CDG fill before testing.

Depth above the bottom of the fill (mm)	Bulk density (kg / m^3)	Moisture content (%)	Dry density (kg / m^3)
1200	1500	17.32	1278.55
1150	1500	16.98	1282.27
1100	1500	16.85	1283.70
1050	1500	17.12	1280.74
1000	1500	17.20	1279.86
950	1500	17.25	1279.32
900	1500	17.30	1278.77
850	1500	17.22	1279.65
800	1500	17.18	1280.08
750	1500	17.36	1278.12
700	1500	17.25	1279.32
650	1500	17.42	1277.47
600	1500	17.40	1277.68
550	1500	17.35	1278.23
500	1500	16.80	1284.25
450	1500	16.74	1284.91
400	1500	16.90	1283.15
350	1500	16.92	1282.93
300	1500	16.90	1283.15
250	1500	17.00	1282.05
200	1437.5	12.76	1274.83
150	1437.5	12.76	1274.83
100	1437.5	12.42	1278.69
50	1437.5	12.42	1278.69
Average	1489.5	16.37	1280.05

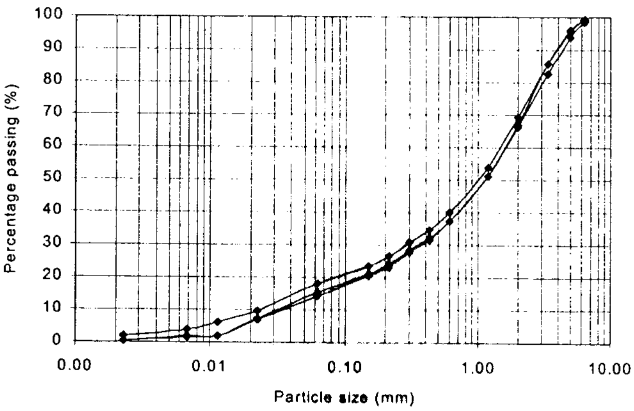


Figure 3. Particle size distribution of the soil sample used.

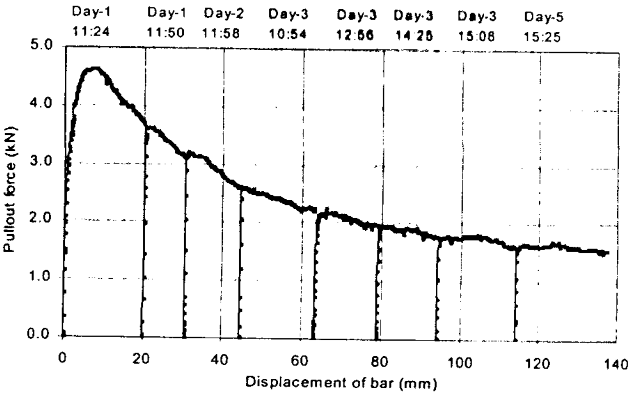


Figure 4. Pullout test results of a ribbed bar.

6.2 *Load-displacement curve*

Ribbed bars of 25 mm diameter were used in this test. Buried length of the bars was 1.5 m. A typical result of pullout test, which was carried out under 55 kPa vertical pressure, is shown in Figure 4.

There are two important parameters concerning the pullout test: total pulling displacement needed to reach residual pullout force, and pulling rate. These two parameters depend on soil type and surface characteristics of nails.

Travel of the pullout device was 25 mm. The results of pullout test carried out up to 20 mm displacement showed that the bar should be further pulled to reach its residual pullout force. At the end of each stage of pulling, load was released. After adjusting the screw thread of the pulling device, the bar was pulled again. This was repeated until the curve became flat. It is interesting to note that, in each stage, the curve followed the previous portion even after two days time. The pullout test results show that displacement should exceed 80 mm to obtain residual pullout force. The pulling speed used in this test is 1.3 mm/min. Influence of the variation of pulling rate is to be studied.

6.3 *Density measurement*

At the end of the test, while removing the fill, insitu density of the sample was measured with depth by the sand replacement method. For each 100 mm depth, the density measurement was taken at three different points. Table 2 presents the average values of the densities taken at three points for each 100 mm depth.

In this test, the maximum vertical pressure applied was 150 kPa and corresponding total settlement of the top plate was 40 mm. Overall increase in the bulk density of the fill due to the application of vertical pressure is between 1.5 and 3 %. Increase in density at the top is higher. At the bottom of the box, the density was found to be lower. It may be due to the presence of coarse aggregate layer, which was used to cover the perforated pipes.

Table 2. Density of the CDG fill after testing.

Depth above the bottom of the fill (mm)	Bulk density (kg / m^3)	Moisture content (%)	Dry density (kg / m^3)
1150	1578.4	15.45	1367.1
1050	1527.8	14.50	1334.3
950	1511.1	15.75	1305.4
850	1501.5	15.92	1295.3
750	1517.1	15.95	1308.4
650	1518.1	15.14	1318.4
500	1522.6	15.57	1317.5
400	1530.2	15.29	1327.3
300	1498.2	15.28	1299.6
200	1499.2	15.00	1303.6
100	1446.2	15.12	1256.3
Average	1513.7	15.36	1312.1

7 SUMMARY AND RECOMMENDATIONS

A large laboratory apparatus has been devised for testing soil nails in loose fill under a controlled manner. This set-up can be used to investigate pullout resistance of soil nail as a function of vertical pressure, relative compaction and degree of saturation of the loose fill. This apparatus is currently being used to test steel bars for refinement of the set-up and test procedure.

Future tests will be carried out on grouted nails. The fill will be saturated to get a similar situation that occurs in a slope during a storm. Pullout tests will be performed on the grouted nails installed in the loose saturated materials. The nail will be loaded at different speeds to investigate influence of the pulling rate on pullout resistance.

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REFERENCES

Barr, B.I.G., Davies, M.C.R. & Jacobs, C.D. (1991). A Direct Shear Box – Some Initial Results of Tests on Soil Nails. Ground Engineering, March, pp 47-50.

Franzen, G. (1998). Soil Nailing – A laboratory and field study of pullout capacity. Doctoral thesis, Department of Geotechnical Engineering, Chalmers University of Technology, Sweden.

GEO (1984). Geotechnical Manual for Slopes (Second Edition). Geotechnical Engineering Office, Civil Engineering Department, The Government of HKSAR.

GEO (1988). Guide to Rock and Soil Descriptions. Geotechnical Engineering Office, Civil Engineering Department, The Government of HKSAR, 186p.

HKIE (1998). Soil Nails in Loose Fill – A Preliminary Study. Geotechnical Division of the Hong Kong Institute of Engineers, 86p.

Hong Kong Government (1977). Report on the Slope Failures at Sau Mau Ping, August 1976. Hong Kong Government Printer, 105p.

Law, K.T., Lee, C.F., Luan, M.T. & Zhai, Y. (1997). Laboratory investigation of fundamental behaviour of loose fill under shear. Department of Civil and Structural Engineering, The University of Hong Kong

Law, K.T., Lee, C.F., Luan, M.T., Chen, H and Ma, X. (1999). Appraisal of Performance of Recompacted Loose Fill Slopes, GEO Report No.58, Geotechnical Engineering Office, Civil Engineering Department Hong Kong, 86p.

Milligan, G.W.E., Chang, K.T. & Morris, J.D. (1997). Pullout resistance of soil nails in sand and clay. Proceedings of the third international conference on Ground Improvement Geosystems, pp 415-422.

Ove Arup and Partners (1996). The Use of Soil Nails to Upgrade Loose Fill Slopes. Ove Arup and Partners, London. Report for GEO, Job number 51849.

Powell, G.E. and Watkins, A.T. (1990). Improvement of marginally stable existing slopes by soil nailing in Hong Kong. Proceedings of the International Reinforced Soil Conference, Glasgow, pp 241-247.

Sun, H.W. (1999). Review of Fill Slope Failures in Hong Kong. GEO Report No. 96, Geotechnical Engineering Office, Civil Engineering Department, The Government of HKSAR, 87p

Wong, H.N., Ho, K.K.S., Pun, W.K. & Pang, P.L.R. (1997). Observations from Some Landslide Studies in Hong Kong. Proceedings of the Seminar on Slope Engineering in Hong Kong, Geotechnical Division of Hong Kong Institution of Engineers, Balkema, pp 277-286

Wong, H.N., and Pang, L.S. (1996). Application of prescriptive measures to soil cut slopes. GEO Report No. 56, Geotechnical Engineering Office, Civil Engineering Department Hong Kong, The Government of HKSAR, 52p.

Yim, K.P. & Siu, C.K. (1997). Stability Investigation and Preventive Works Design for Old Fill Slopes in Hong Kong, Proceedings of the Seminar on Slope Engineering in Hong Kong, Geotechnical Division of Hong Kong Institution of Engineers, Balkema, pp 295-302.