

# A case study – Stabilization work to unstable crib wall in residual granite

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**ABSTRACT:** Many retaining structures built in early 1970's for supporting steep earth faces were found to be suffering from movement/failure which may be attributed to improper control in the selection of filling materials, poor drainage system and inadequate surface protection, etc. This paper describes the investigation, temporary and permanent stabilization works carried out to an existing 5 m to 7 m high RC crib wall which retained a sloping ground with an overall height ranging from 8 m to 11 m in close proximity to an existing road and houses in the Bukit Timah Granite formation in Singapore.

## 1 GENERAL

Failures of earth retaining structures due to soil disturbance attributed to the effect of infiltration resulting from prolonged rainfall were periodically reported in the residual soil in Singapore. The crib wall considered in the present study was found to be suffering from base failure after prolonged rainstorms and posed a risk to road users and the surrounding properties. This paper describes the temporary and permanent stabilization works, which were successfully executed through a well controlled

work sequences, field investigation/verification tests and instrumentation monitoring scheme.

## 2 CASE HISTORY

A 5 m to 7 m high crib wall supporting a 1V:1.75H cut slope consisting of residual soil from the Bukit Timah Granite formation with an overall height ranging from 8 m to 11 m above the surface of Dunearn Close (Figure 1) was found to be sliding outward during the seasonal prolonged rainfall period in 1996. The sliding of the crib wall had caused dam-

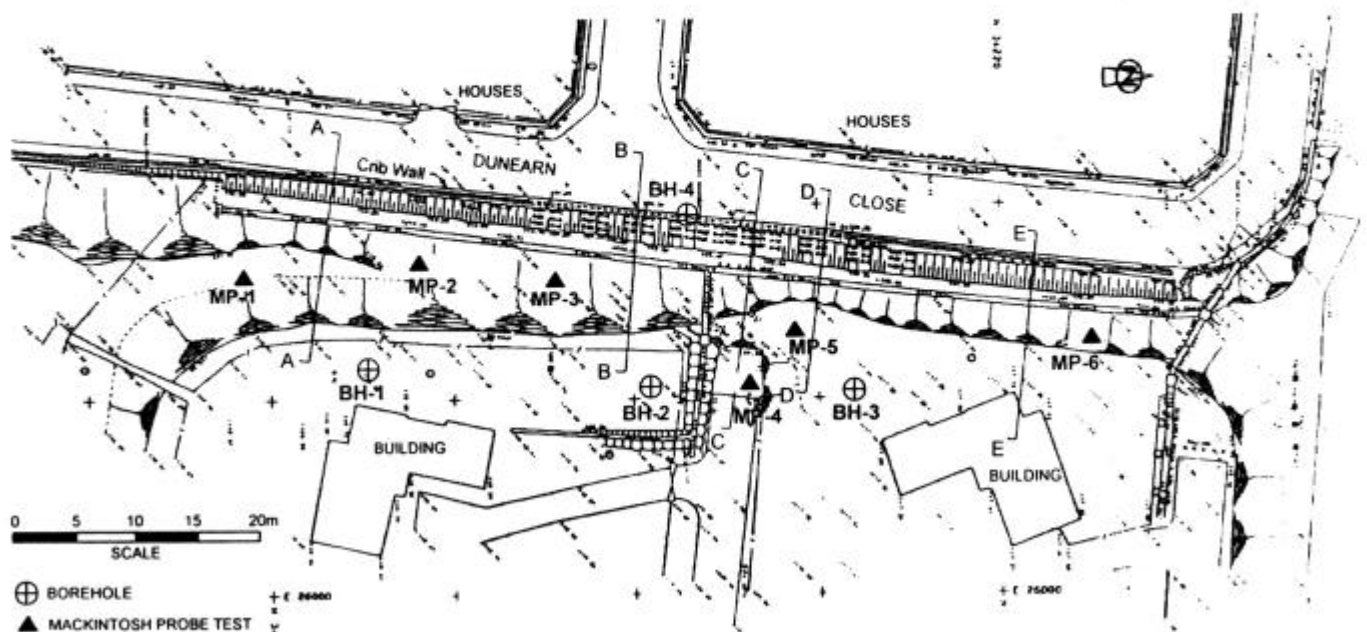


Figure 1. Site and borehole location plan.

age to the road-side drain at the toe of the wall and tension cracks developed at the top of the slope which posed risk to the residents and road users. The failure surfaces were immediately protected with temporary stabilization measures and detailed geotechnical investigation works were carried out to evaluate the possible causes of failure and to collect the necessary geotechnical parameters for the design of permanent stabilization works. The stability of the affected wall section was closely monitored by instruments prior to execution of the permanent stabilization works.

### 3 SITE AND SOIL CONDITIONS

A detailed site investigation consisting of topographical survey and soil investigation was carried out in the concerned areas for collection of necessary information for failure study and stabilization work design. Four boreholes and six Mackintosh Probe Tests were carried out at the site (Figure 1) to delineate the geotechnical profile for stability analysis and design of stabilization works. One water standpipe and two inclinometers were installed in the completed boreholes for monitoring of groundwater table and soil movement within the concerned area. Thirty survey prisms were installed on the crib wall to monitor the movement of the wall.

According to the results of site investigation (MAA 1996), the subsoil condition of the site belongs to the Bukit Timah Granite formation and consists of 2 to 6m thick layer of Silty CLAY (Layer 1,  $N < 10$ ) in medium stiff to stiff condition following by a layer of 3.5 to 7 m thick stiff to very stiff Silty CLAY/Clayey SILT (Layer 2,  $10 < N < 20$ ). The boreholes were terminated in very stiff to hard Clayey SILT with sand (Layer 3,  $20 < N < 40$ ) with sufficient penetration below surface of Dunearn Close (Figure 2). Subsoil retained by the crib wall was found consisting mainly of Layer 1 soil which is of low permeability and sensitive to water. No granular fills

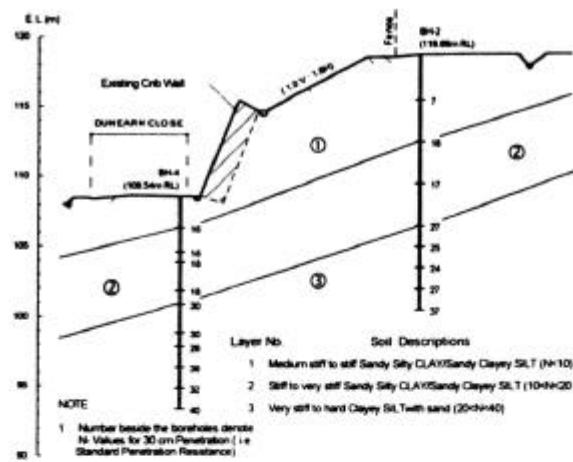


Figure 2. Soil profile.

and subsoil drains were provided in the construction of the crib walls. Groundwater level measured in the installed water standpipe was found at level slightly above the surface of Dunearn Close during the site investigation period.

### 4 SLOPE STABILIZATION ANALYSIS

Detailed stability analysis was conducted on the original wall/slope profiles to evaluate its adequacy for the stabilization works design. The stability of slope was analyzed based on the soil investigation results under the observed groundwater table and an assumed groundwater table at 1/3 the height of the crib wall to evaluate its safety in short and long terms, respectively. The results of stability analysis (Figure 3) indicated that all five selected slope sections were found to have inadequate factor of safety (i.e.  $FOS < 1.5$ ) against slip failure even under the low groundwater table (i.e. at EL108.5 m) observed during the soil investigation period. In view of the above reason and the uncertainties in the integrity of the existing crib wall which long term safety cannot be verified, stabilization measures consisting of restoration/reconfiguration of the slipped ground, re-

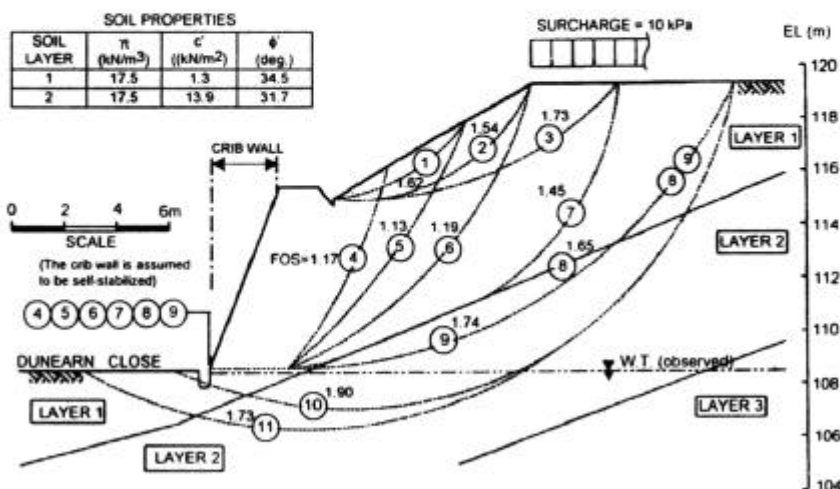


Figure 3. Stability analysis of existing slope (Section C-C).

placement of the unstable crib wall by using suitable retaining system were considered necessary for ensuring the long term safety of the existing slope and adjacent properties.

## 5 DESIGN OF STABILIZATION WORKS

According to results of stability analysis and information collected from the site inspection, it can be diagnosed that the failure could be attributed to the poor resistance of Soil Layer 1 and the inadequacy of the surface and subsoil drainage systems which resulted in weakening of the soil near the wall base as observed at site and possible build-up of porewater pressure under the effect of prolonged rainfall. In order to ensure long term safety of the existing slope and crib wall, the following stabilization measures were adopted. The design was carried out based on a minimum factor of safety of 1.5 under an assumed groundwater level at 1/3 the height of the retaining wall.

### 5.1 Reconfiguration of earth slope

One of the effective and practical methods to improve the stability of slopes and retaining walls is to reduce its sliding potential and lateral forces acting on the wall by trimming the slope to a more gentle profile. Figure 4 shows the typical profile of the reconfiguration scheme adopted in the present case where the effect of earth surcharge was reduced by trimming the existing slope within the slip area to a more gentle profile (i.e. 1V:1.8H) and reducing the height of crib wall by 1.5 m (i.e. EL114.0 m) to improve its overall stability. The reconfiguration scheme has been used as a temporary stabilization measure to minimize the risk of failure prior to completion of the permanent stabilization works.

### 5.2 Strengthening of existing crib wall

Due to the uncertainties in the integrity of the existing crib wall, a strengthening scheme consisting of anchored gunite wall (Figure 4) cast against the crib wall was selected as the permanent stabilization measure in view of its cost effectiveness, practicality and lower risk as compared with other schemes, e.g. complete replacement of existing crib wall with contiguous bored pile wall or conventional RC wall. Two rows of permanent ground anchors (i.e. at EL 112.5m & 110.5m) at 3 m horizontal spacing and 20° inclination (to avoid obstructing crib wall) were designed to achieve the required factor of safety (i.e. 1.5) against sliding in long term. The anchors (Double Corrosion Protection System) were designed for 15 tons working load using three number of 12.7 mm strands, with corrugated sheathing as the fixed length and cement grout mixed from OPC complying with British and local Standards. A fixed length of 11 m determined based on an allowable bond resistance of 1 x SPT-N (in kPa) and a free length of 12 m for upper row and 10 m for lower row were adopted in the anchor design.

### 5.3 Drainage system

In order to improve the drainage condition of the concerned areas for preventing the earth slope against possible soil saturation during the service period, horizontal drains were provided in the cut slopes above the crib wall. Intercept drains were also provided to divert the surface runoff to proper outlets to minimize the effect of infiltration. Weepholes were provided through the existing crib wall and the anchored gunite wall to avoid possible build-up of water pressure behind the retaining structures.

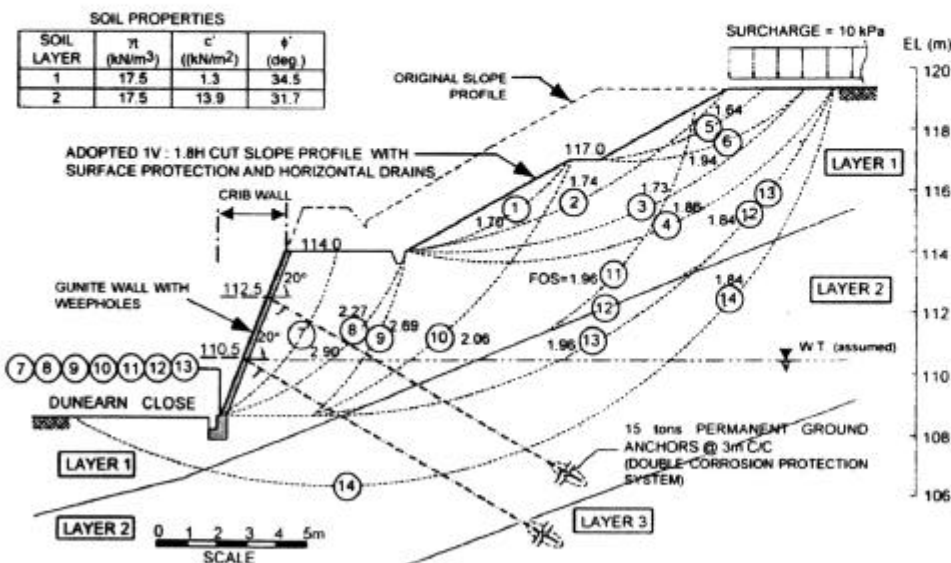


Figure 4. Stability analysis of permanent stabilization scheme (Section C-C).

#### 5.4 Surface trimming and protection

The uneven slope surface and surface cracks found at the upper part of the existing slope were properly treated by the removal of all disturbed/loose materials and sealing with cement-sand slurry, respectively. The finished slope surfaces were protected with grasscrete to improve its resistance against surface erosion in long term.

### 6 CONSTRUCTION OF STABILIZATION WORKS

As mentioned in the previous section, the stabilization works were carried out in two stages, i.e. temporary stabilization by reconfiguration of slope and permanent stabilization by anchored gunite wall with drainage and surface protection works. In view of the importance of the anchored wall to the performance of the slope stabilization works, all the installed ground anchors (total 69 nos.) were proof tested to 150% working load and then locked off at 110% working load. The performance of anchors was also evaluated by Extended Acceptance Tests and Suitability Tests conducted on selected anchors.

### 7 ANCHOR TESTS

Sixty-one nos. of Acceptance Test (or Proof Load Test, 1 cycle), five nos. of Extended Acceptance Test (3 cycles) and three nos. of Suitability Test (7 cycles) were conducted on the installed anchors to verify its carrying capacity and to evaluate its performance. According to the test results as shown in Figure 5, all the installed ground anchors have been successfully stressed up to the maximum test load and passed the performance tests with elastic and permanent displacement varying from 38 mm to 50 mm and 4 mm to 45 mm recorded, respectively. The elastic displacement of anchors recorded in both Acceptance Test and Suitability Tests were found to be well distributed within the elastic limit, i.e. between  $0.9L_{free}$  and  $(L_{free} + 0.5L_{fixed})$  and meet the acceptance criteria (Figure 6). However, larger permanent displacement value was recorded during the Suitability Tests due to the cyclic loading process carried out under the Suitability Test.

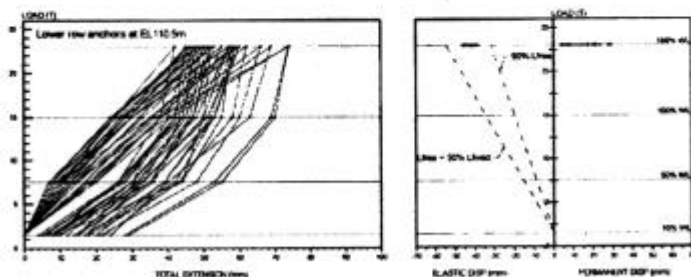


Figure 5. Results of acceptance tests.

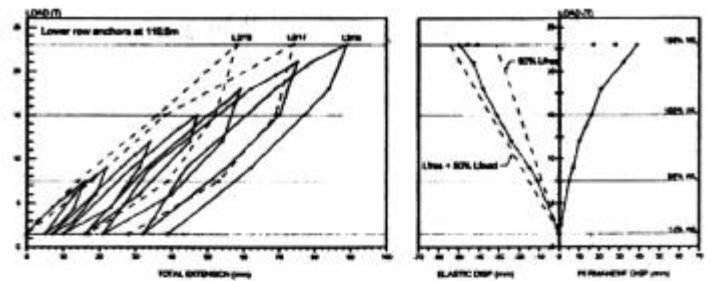


Figure 6. Plots of elastic and permanent displacements of acceptance tests and suitability tests.

### 8 FIELD PERFORMANCE

The performance of the field works have been monitored by instruments, e.g. survey prisms, inclinometers and standpipes during the construction period and for about 7 months after the completion of works. Figure 7 shows the ground movement recorded by the inclinometer with non-critical movement values of 5 mm observed during construction of permanent stabilization works and 32 mm observed since the completion of soil investigation works. The movements of crib wall recorded by the installed survey prisms during the temporary and

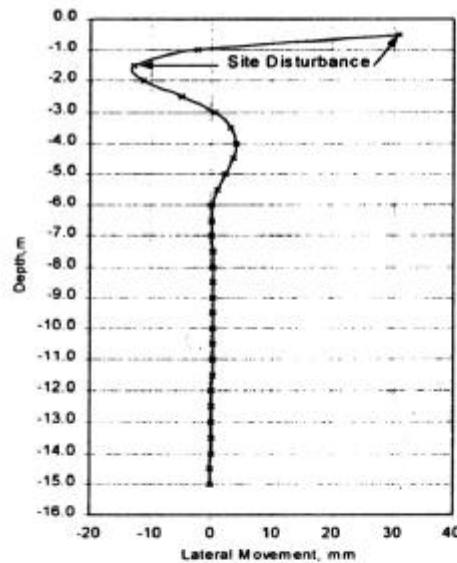


Figure 7. Ground movement profile (I-1).

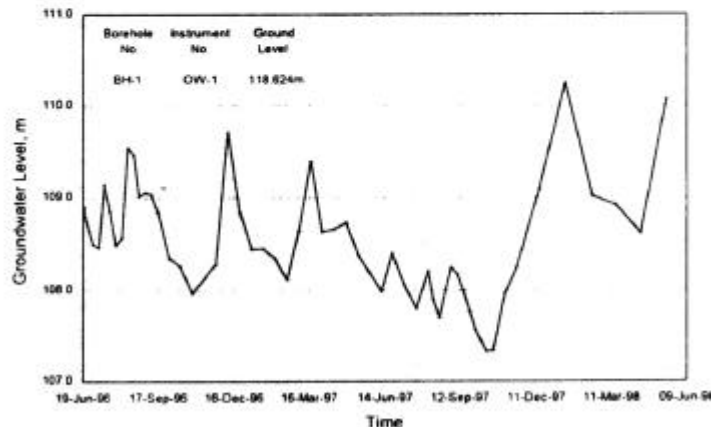


Figure 8. Groundwater table measurements.

permanent stabilization works period were found to be minor (i.e. not exceeding 6 mm). Survey of prisms installed on the completed anchored wall showed satisfactory performance with negligible movement values (i.e.  $\leq 3$  mm) recorded during the maintenance period. Groundwater table observed in the installed standpipe was found to fluctuate between EL107.3 m and EL 110.2 m during the present observation period (Figure 8). The highest groundwater level observed during the rainy season is close to the design level (i.e. 1/3 wall height) adopted in the permanent stabilization work design.

## 9 CONCLUSIONS

1. The case history illustrates the importance of filling materials, drainage system and surface protection to the long-term stability of retaining wall and slope in residual soil from the Bukit Timah Granite formation in Singapore and the necessity of proper construction sequences in minimizing possible risk in the execution of stabilization works.

2. The allowable bond resistance value of 1 x SPT-N (in kPa) adopted in the anchor design was proven to be valid for the residual soil from the Bukit Timah Granite formation as in the present case.

3. Possible fluctuation of groundwater table which is essential in ensuring the long-term stability of slope shall be carefully assessed and considered in the design. It is good practice to adopt a design groundwater table at 1/3 (minimum) the height of the retaining wall. Suitable fill materials and proper drainage and surface protection systems shall also be provided in the earth retaining structure design.

4. The permanent stabilization works to this unstable crib wall have been successfully completed through detailed investigation/analysis, proper work sequences, stringent supervision and adequate field tests with minor disturbance to the surrounding properties during construction.

## REFERENCES

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- MAA, 1996, Report on Geotechnical Study for Stabilization Work to Existing Crib Wall/Slope at Dunearn Close, Singapore.
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