DOUBLE CORROSION PROTECTION OF LONG SOIL NAILS AT DEEP BAY LINK – A CASE HISTORY

Nick Koor[1] & Anson Cheung[2]

Abstract: Preliminary soil nails up to 30 m in length were installed at the Deep Bay Link project to test the effectiveness of grouting long nails. The nails incorporated a double corrosion protection system consisting of a corrugated HDPE sheath. Each preliminary nail was successfully tested to two times the design load and several were exhumed to inspect the grouted nail section. Grout was seen to have completely filled the internal and external void around the corrugated sheath with excellent contact between the grout and the surrounding saprolite. Permanent soil nails with double corrosion protection up to 28 m long are now being successfully installed at the site.

INTRODUCTION

Deep Bay Link (Figure 1) is a duel-three lane trunk road providing a strategic link between the Hong Kong Shenzhen Western Corridor and the existing Yuen Long Highway. Due to its strategic nature the HK$4.0B project has been fast tracked with a construction period of 28 months. Gammon Construction Ltd. are the Main Contractor for the northern section and construction is currently underway and due to be open to traffic by end-2005. The link traverses the broad low lying valley separating Yuen Long and Tuen Mun and is primarily supported by a reinforced concrete viaduct except where the road passes through the northern extremity of the Tsing Shan Range (Figure 1) in a 40 m deep cut. Soil nails support the cut which has up to 60° side slopes and nails up to 28 m long. It is the soil nailed slopes in the northern part of the project which are the subject of this paper.

THE SITE

Topography

The northern part of the site through which the road is in cut is characterised by a north south trending valley surrounded by rounded granitic hills. The valley bottom is at about +40mPD and the surrounding hill slopes have elevations ranging from about +60 to +80mPD which slope gently towards the valley at about 30°. Ephemeral streams drain into the valley from the surrounding hills. The natural terrain is generally sparsely vegetated with small trees and shrubs with some areas of gulley erosion where the vegetation is sparse.

Geological Setting

The Hong Kong Geological Survey Yuen Long Sheet 6 indicates that the site of the major cut is located in an area underlain by regionally metamorphosed fine grained granite. A major slip strike shear zone which trends north-east separates the fine grained granite from Tuffs and Tuff Breccias of the Tuen Mun Formation about 200 m to the south-east. Zones of intense shearing along this shear zone have produced mylonites within both the granite and volcanic rocks of the area. Quartz veins and minor quartzphyric rhyolite dykes are also

[1] Senior Resident Geotechnical Engineer – Ove Arup & Partners Hong Kong Ltd
[2] Resident Geotechnical Engineer – Ove Arup & Partners Hong Kong Ltd

Figure 1 - Deep Bay Link & associated road transportation routes in Western New Territories – Hong Kong

present within the granite. Quaternary superficial deposits occur within the valley floors and are generally termed debris flow deposits on the geological sheet but they may be better named colluvium. Little colluvium is shown to exist on the granitic side-slopes.

CUT SLOPE DESIGN

Ground Conditions

Detailed ground investigation consisting of vertical drillholes, trial pits and laboratory testing confirmed that the site is underlain by metamorphosed fine grained granite with little or no colluvium being present. The granite is variably weathered with continuous Grade III rock as encountered in the drillholes at between 5 and 40m below existing ground levels, the shallower being in the base of the valley. Mylonite zones were also encountered in the drillholes and later observed in the cut slope face. Groundwater levels range between 0 and 20m below existing ground levels.

Slope Design

Limits set on land-take for the project predicted the adoption of either steep soil nailed slopes or some form of vertical retaining structure supporting a cut slope. Due to programme and cost considerations it was decided to adopt the steep soil nailed solution (Figure 2) as

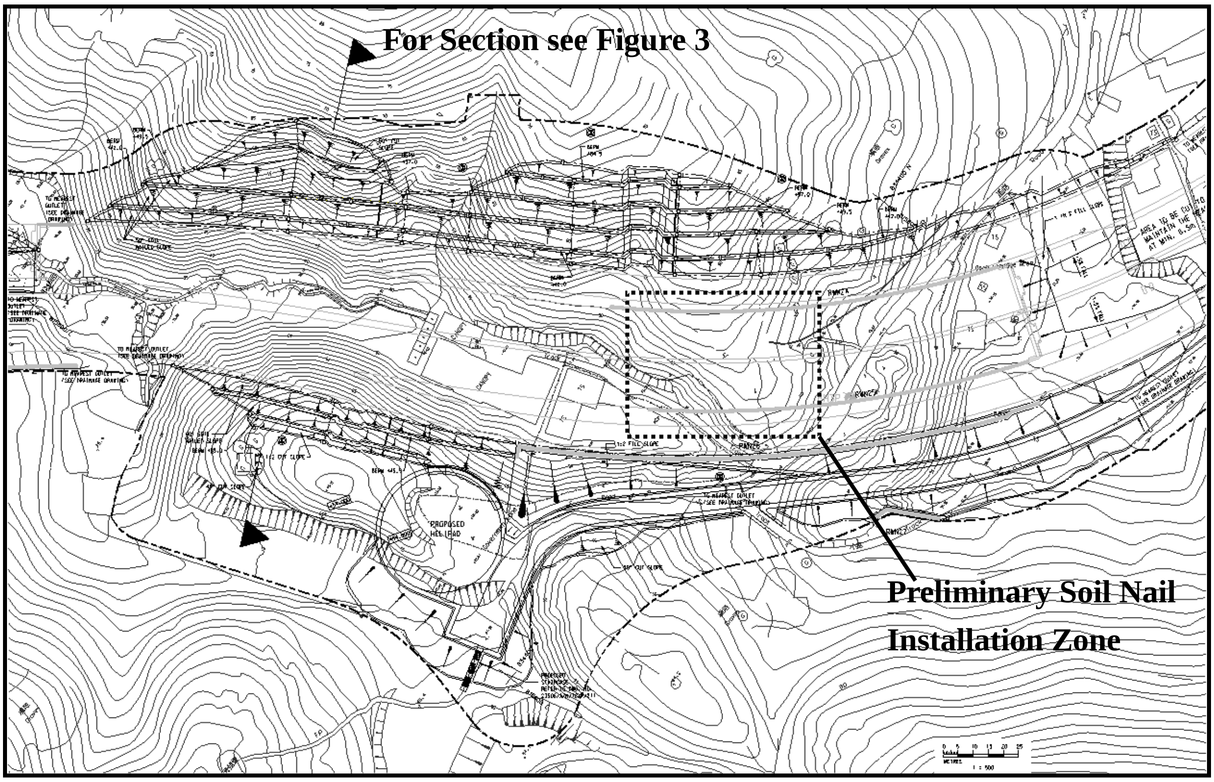

Figure 2 - Layout of cut slopes at northern end of Deep Bay Link

these would be quicker and cheaper to construct. Soil nailed slopes were designed with slope angles of between 50° and 60° incorporating over 2000 soil nails. Slopes up to 40 m high with up to five berms have been designed using conventional techniques used in Hong Kong (Figure 3). Due to the relatively steep side slopes and conservative design groundwater levels adopted, the nails supporting the lower two berms are up to 28 m long and have a design load of up to 460kN. The slope design life is 120 years.

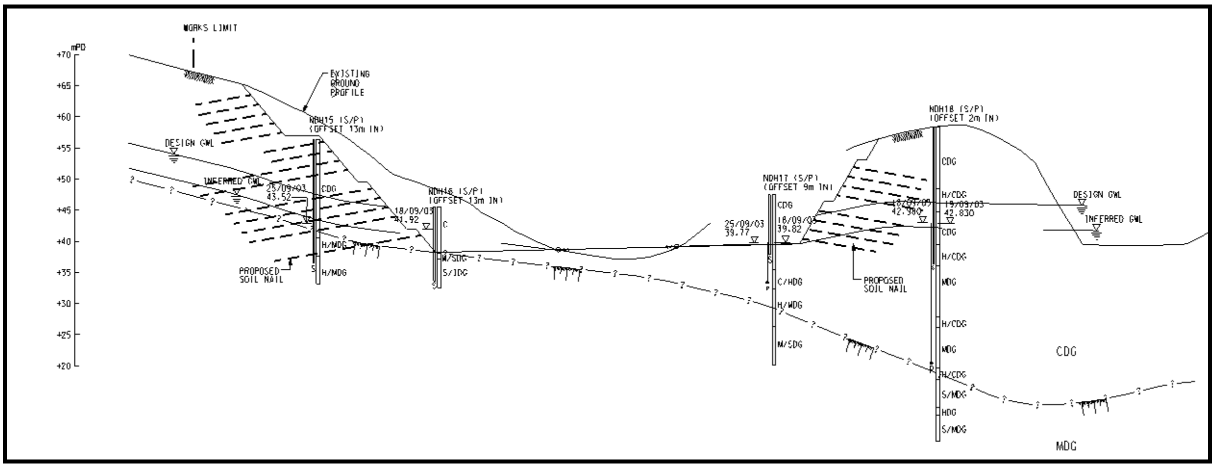

Figure 3 - Typical section through cut slopes at northern end of Deep Bay Link

Ground Aggressivity

In order to assess the potential corrosion of any steel elements installed in the slopes, a series of tests were made during the ground investigation to determine ground aggressivity. The testing and corrosivity assessment followed the recommendations made by Murray (1993). The results of the testing are summarised in Table 1. The results indicate a ranking mark of -6 which indicates that the soil condition is likely to be aggressive and therefore corrosion protection is required. This result agrees with the study reported by Shiu & Cheung (2003) where they state that a significant portion of the local (Hong Kong) soils has a high corrosion potential.

Table 1 - Aggressivity table

Item	Measured Value	Marks
Soil Composition	Material containing not more than 75% and 10% of particles passing the 63 micron and 2 micron BS sieve sizes respectively. The material passing the 425 micron BS sieve, when tested in accordance with BS 1377, have a plasticity index less than 6	0
Groundwater level at buried position	Soil nail reinforcement will be submerged under design groundwater table	-4
Resistivity (ohm – cm)	10,000 or more	0
Moisture Content	Average 25.5%	-1
pH Value	Average 5.2	-2
Soluble Sulphate (ppm)	Average 105	0
Cinder and Coke or made ground	None	0
Redox potential	Average 417	+2
Presence of sulphate and hydrogen sulphide	0.09% (None)	0
Presence of carbonate	0.18% (Trace)	0
Chloride ion (ppm)	200	-1
	Total	**-6**

Buildabiltiy and Corrosion Protection

Several factors have to be taken into account when designing long soil nails in corrosive ground conditions. They are; the buildabiltiy of the nail; what corrosion protection system to use and; potential grouting difficulties. These three critical elements need to be considered holistically rather than in isolation.

The high nail design loads require the use of standard 50 mm deformed bars (F_y = 460N/mm^2) or smaller diameter (c.36mm) high yield bars such as that manufactured by Dywidag or Macalloy (F_y =1080N/mm^2). Other options such as carbon fiber strands were considered, but at the time of design such systems had not been used in Hong Kong and therefore the time constraints for Government approval ruled out their use. The pros and cons of using the two bar types are at Table 2. Due to the obvious practical difficulties in installing 28 m long 50 mm deformed bars the high strength bar option was investigated further as lead-in times for material ordering and shipment were available within the Contract period.

Table 2 - Pros & cons for different bar options

Attribute	Standard Bar (50 mm)	High Strength Bar (36 mm)
Availability	Easily available in Hong Kong	Limited number of manufacturers
Weight	Very heavy and difficult to man-handle	Much easier to man-handle
Testing	Most laboratories in Hong Kong set-up to test	Difficult to test with modifications required to test rigs
Corrosion Protection	Standard zinc protection	Zinc protection not recommended – use other methods such as plastic sheaths
Quality Control	Variable depending on source	Very good quality
Lead-in Time	Short	Long – three months or more

At the time of designing the nails there was no real guidance in Hong Kong on what corrosion protection measures are applicable to soil nails for different ground conditions. From the test results it was considered that the steel needed full corrosion protection. Concerns regarding the potential for hydrogen embrittlement of high strength steel elements which have been zinc coated, Arup (2003), meant that an alternative to standard zinc coating was required. Options such as heat shrunk plastic or epoxy coatings to the bars were considered, but finally a double corrosion system was adopted consisting of a HDPE corrugated full length sheath which surrounds the bar and is filled with grout *in lieu* of the zinc coating. Manufactures of the high strength steel provide such double corrosion systems which compliment their range of bar sizes and include couplers, spacers and end cap with integral grouting tube. The Main Contractor opted for the Dywidag-Systems International double corrosion protection system (Plate 1). This consists of a 100 mm diameter sheath with end cap for the 36 mm diameter high strength bar to be installed into a 150 mm diameter hole.

Plate 1 - Dywidag-Systems International soil nail double corrosion protection system

In order to address the constructability and grouting issues relevant to such long nails, eight preliminary soil nails up to 30 m long were installed at the site, load tested to two times the design load and exhumed for inspection. It is believed that at the time of writing that these soil nails are the longest installed with a double corrosion protection system in Hong Kong.

PRELIMINARY SOIL NAILS

Installation

The eight nails were installed at a location (Figure 2) which would later be within the bulk excavation for the cut slope formation so that there was; an opportunity to expose the nails after testing; inspect the grouting and the grout/soil contact; and take samples to be saw cut so that the full nail cross-section could be visually inspected. The preliminary nails also gave the Contractor an opportunity to test different installation sequences and systems. Preliminary nail details are summarised in Table 3. Initially the soil nail hole was designed to be 150 mm in diameter. However, due to difficulties in keeping the alignment of the hole straight for such long nails the sheath and steel bar could not be fully installed. The hole diameter was increased to 165 mm and installation become easy taking less than half and hour. Internal and external packers were used to isolate the test length and the nails were grouted using standard grouting equipment with the annulus between sheath and soil being grouted prior to the internal void. The sequence for the construction of the soil nails with double corrosion is at Figure 4.

Pull out Test Results

Each preliminary nail was tested to two times the design load using standard testing equipment. All the preliminary nails passed the pull-out tests, the results are at Table 3.

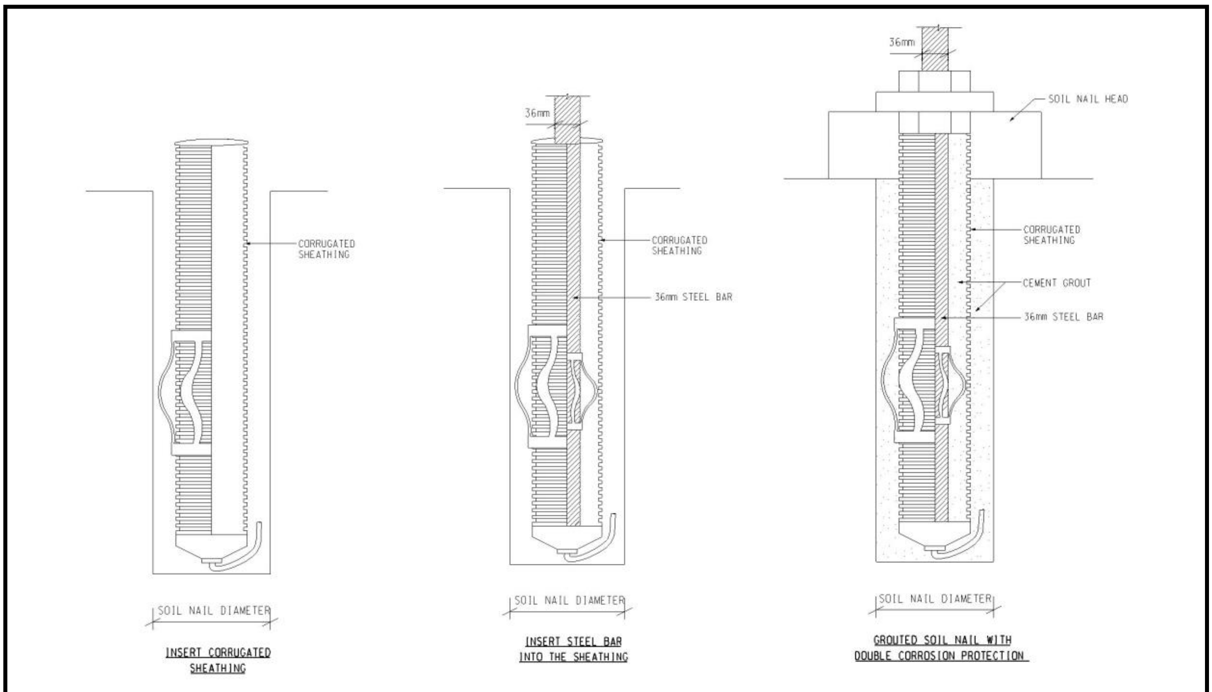

Figure 4 - Installation sequence of soil nail with double corrosion protection system

Table 3 - Preliminary nail details and results of pull-out tests

Soil Nail No.	Dywidag Bar Size (mm)	Nail Diameter (mm)	Bar Length (m)	Bond Length (m)	Effective *in situ* Vertical Stress (kN/m3)	Test Load (kN)	Max Shear – Soil/Grout (kN/m^2)	Measured Residual Movement (mm)	Measured Maximum Movement (mm)	Allowable Residual Movement (mm)
PT1	36	165	20	2.0	189.7	95	92	1.42	8.0	6.0
PT2	36	165	25	2.0	217.1	100	96	2.56	11.9	6.0
PT3	36	165	20	4.0	175.2	205	99	4.80	15.3	12.0
PT4	36	165	25	4.0	181.8	240	116	4.43	21.8	12.0
PT5	36	165	20	6.0	100.8	210	68	4.77	13.3	18.0
PT6	36	165	25	6.0	114.4	235	76	2.41	12.2	18.0
PT7	36	165	30	6.0	134.5	225	72	2.32	21.1	18.0
PT8	36	165	30	8.0	109.8	280	68	1.61	27.8	24.0

Nail Inspection

Once tested, three of the longest nails were carefully excavated (Plate 2) to allow close inspection of the nail and to facilitate sampling. Samples were also taken from the exposed grouted sections and saw cut (Plate 3). Several observations were made:

(1) The grout was continuous over the bond length (Plate 4) with no signs of voids apart from close to the packer.
(2) Some grout escaped past the external packer (up to 2 m) which generally formed a coating around the drillhole surface with a void between the grout and the sheath.
(3) Nail PT6 showed signs of crown collapse in the drillhole. The grout within the over-break contained inclusions of soil.
(4) The grouted diameter measured on nail PT6 ranged from 165 to 180 mm.
(5) The grout over the bonded length had excellent contact with the ground (Plate 4).
(6) The nails deviated from the design inclination of 10° to the horizontal by up to 10° for the 30 m long nail PT8.

(7) The saw cut sections revealed continuous sound grout in both the internal and external annuli (Plate 5).

(8) The corrugated sheath tended to float during the grouting of the outside annulus however the steel bar remained central (Plate 5).

The installation, testing and exhumation of the preliminary piles demonstrated that the corrugated sheath and steel bar could successfully be installed to up to 30 m and that the nails could be fully grouted to their distal end. This gave the designer and Contractor confidence to proceed with the permanent works installation.

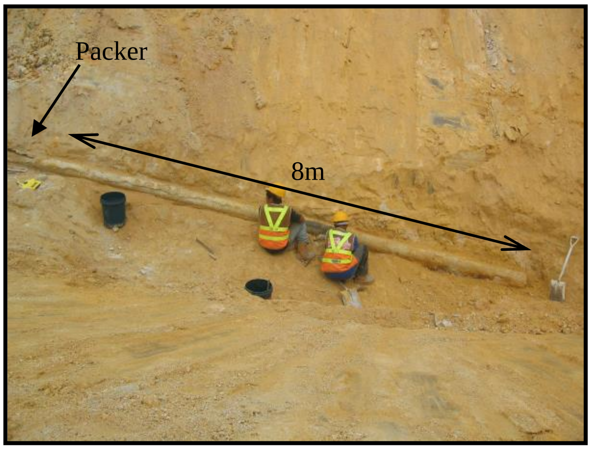

Plate 2 - Preliminary soil nail **Plate 3 - Pr**

being exposed **being saw cut**

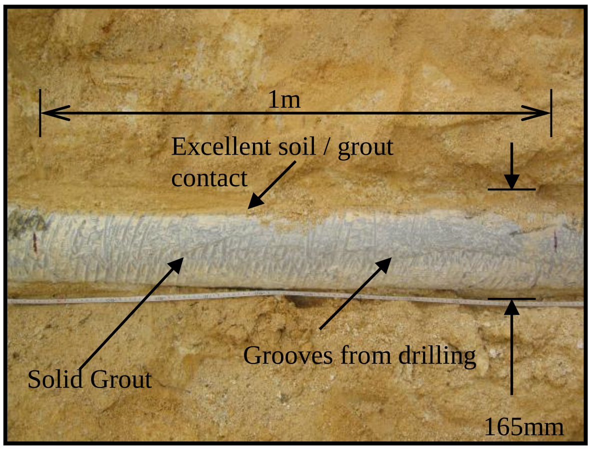

Plate 4 - Exposed preliminary soil nail

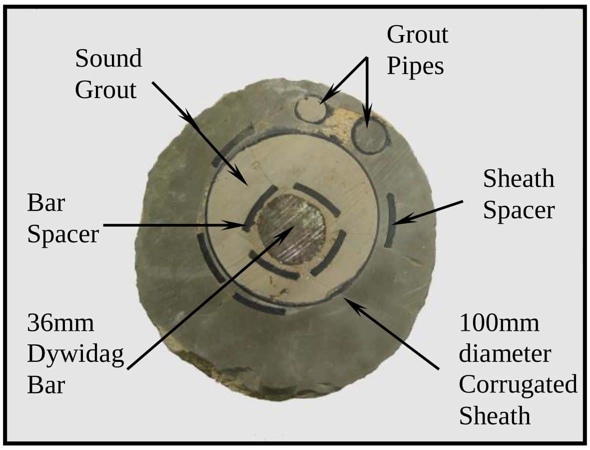

Plate 5 - Section through grouted preliminary soil nail

PERMANENT NAIL CONSTRUCTION

At the time of writing approximately 430 nails with double corrosion protection between 24 and 28 m long have been successfully installed at Deep Bay Link (Plate 6). Initial difficulties were experienced using standard Hong Kong soil nail grouting equipment. The Contractor was not able to fully grout these long nails and there was leakage from the outside annulus into the central annulus. The Contractor has modified his grouting procedure by using slightly larger diameter grout pipes (increased ID from 13 to 17mm), utilizing a pressure grout pump (HD Engineering Ltd GP60) and simultaneously grouting both annuli. On average each 28 m long nail takes about 3 hours to drill in saprolite, 15 to 20 minutes to install the corrugated sheath and steel bar and 15 minutes to grout.

Plate 6 - General view of 40m high cut slope at northern end of Deep Bay Link during soil nail installation (March 2005)

DISCUSSION & RECOMMENDATIONS

The preliminary soil nail installation programme at Deep Bay Link demonstrates that nails up to 30 m long can be successfully installed and grouted using off-the-shelf double corrosion protection systems. As successful installation is very much contractor and ground condition dependent it is recommended that similar trials as these are made on projects where long nails are required. Zinc coating high strength steel is not recommended due to the possibility of hydrogen embrittlement. Grouting the annuli should be carried out simultaneously to avoid sheath floatation and possible grout leakage from the outer to inner annulus or *vice-versa*. For such long nails it is more efficient to use pressure grouting pumps with larger smooth bore grouting pipes than normal to ensure a continuous grouting process. Care should be taken when specifying nail diameters for long nails with double corrosion systems and designers should allow at least 30 to 40mm clearance between the sheath and the drillhole wall to allow for installation difficulties. The maximum drillhole deviation of 10° measured for the 30 m nail affects the horizontal nail capacity by less than 5% and is therefore considered not to be a concern bearing in mind the conservative design methodologies adopted in Hong Kong. Shiu and Cheung (2003) observation that many soils in Hong Kong are aggressive is supported and the authors recommend that the use of carbon fiber soil nail strands be further developed for Hong Kong conditions.

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