The Design and Installation of Soil Nail Slope Stabilization Schemes using 'Snail'

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SYNOPSIS
This paper describes the design and installation of two soil nail slope stabilization schemes. The first is at Broughton Heath near Chester and the second is adjacent to Underbridge 314 in Gateshead. The design for both schemes was undertaken using the 'Snail' computer program which is used extensively throughout North America. The slope at Chester is 11.5m high, 62° from the vertical and is 'permanent works', whilst the slope at Gateshead is 10.5m high, 15° from the vertical and is 'temporary works'. Pull-out tests were also carried out at Gateshead where the plate and reinforcement bar movement were independently monitored. Both of these schemes have demonstrated that soil nail designs using 'Snail' can provide quick, simple, economic and aesthetically pleasing methods of stabilizing slopes.

INTRODUCTION
In recent years the use of soil nailing in the UK has gradually become more common place as a cost effective solution to a wide range of geotechnical problems. These include, but are not limited to the following:

- Steepened slopes (for example to allow for motorway widening)
- Support of near vertical excavations
- Stabilization of existing slopes

Soil nailing techniques are frequently adopted throughout Europe and North America and the author believes that projects involving soil nailing will become increasingly popular in the United Kingdom in future years. The design and analysis of a soil nail scheme is particularly complex and there are many different methods available. The author has used various design techniques and prefers the 'Snail' computer program as developed by CalTrans (California Department of New Technology, Materials and Research). This method of analysis has been developed by practicing engineers over a number of years. It allows the designer the scope to adjust many aspects of the proposed soil nail scheme to ensure that an accurate model is obtained. This paper describes the use of 'Snail' in two different soil nail projects.

DESIGN (GENERAL)
The 'Snail' computer program uses a bi-linear wedge analysis for failure planes exiting at the toe of the wall and a tri-linear wedge for failure planes developing below the wall toe. It is a fully balanced force equilibrium equation with all of the inter slice forces included.

The 'Snail' computer program requires the following minimum information to run:

- Project description (optional)
- Wall geometry
- Reinforcement parameters
- Soil parameters (up to two different layers may be input if required)
- Search limits

Additional data may be required if one or more of the following options are used:

- Surcharge (two varying surcharges can be input)
- Earthquake acceleration
- Water surface
- Limiting search to specific nodes
- Slope above and below the Wall
- Varying reinforcement parameters
- External horizontal force
- Specified failure plane

'Snail' is a simple DOS program (size 233kb) which uses iterative techniques to find a solution. This used to take over five minutes per analysis on a '386' personal computer, however this has been reduced to around five seconds on the latest pentium based machines. Due to its American origins the 'Snail' program requires all of the input parameters to be in imperial units (fortunately this is not as complicated as one may think), hopefully a metric version will be available in the near future.

The program calculates the minimum factor of safety through each of 10 equally spaced failure planes considering the following failure mechanisms (between the specified search limits).

- Failure due to the soil nail reinforcement 'snapping' in tension
- Failure by the soil mass 'punching' outwards and around the head plate
- Failure via the soil nails 'pulling out'

The program can be used for slope stability analysis with and without soil nail reinforcement.

BROUGHTON HEATH, CHESTER

This site consists of a 54m wide by 20m long slope to the rear of numbers 18, 19 and 20 Windermere Gardens, Broughton Heath, Chester. Access to the site, which is also a nature reserve, is restricted. The slope has an overall height of 11.5m and has an average slope angle of 62° from the vertical. The slope was formed approximately six years ago using poorly compacted fill material which has been showing signs of movement over recent years. This movement manifested itself in tension cracks up to 15mm wide and cumulative settlement of 200mm at the rear of the gardens. The ground movement caused drainage pipes to leak which further accelerated the cracking / settlement. There was a clear risk that further slippage would occur if the slope was not stabilized, with possible serious damage to the foundations of the adjacent high quality properties.

Following a detailed site investigation and consultation with various parties it was decided that the most suitable method of stabilizing the slope was to undertake a soil nail solution, whereby the slope fill was effectively 'pinned' down to the underlying natural strata.

Design

This design was unusual due to the requirement for relatively long soil nails to ensure that an adequate bond length into the stiff underlying boulder clay was obtained. A long soil nail subsequently led to a large drill rig and a large scaffold platform. In order to mitigate these costs the number of rows of soil nails was reduced to a minimum and they were installed on a 5.5m 'slope distance' spacing. The minimum factor of safety in the 'Snail' soil model without soil nails is 0.71 which rises to 1.41 with the proposed soil nails fully installed. A few extracts from the 'Snail' computer output are given in figures (i) and (ii).

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****************************************************
*   CALIFORNIA DEPARTMENT OF TRANSPORTATION
* DIVISION OF NEW TECHNOLOLY, MATERIAL & RESEARCH
*      OFFICE OF GEOTECHNICAL ENGINEERING
* Reinforced Soil Systems & Earthquake Engineering
*   Date: 11-22-1994        Time: 19:36:44
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--------- WALL GEOMETRY ---------

Vertical Wall Height = 37.70 ft
Wall Batter = 62.0 degrees
First Slope Angle-above the wall = 7.0 degrees
First Slope Length from Wallcrest = 45.10 ft
Second Slope Angle = 0.0 degrees
Second Slope Length from 1st Slope = 100.00 ft
Third Slope Angle = 0.0 degrees
Third Slope Length from 2nd Slope = 0.00 ft
Fourth Slope Angle = 0.0 degrees

--------- SLOPE BELOW THE WALL ------

There is NO SLOPE BELOW THE TOE of the wall

--------- SURCHARGE ---------

THE SURCHARGES IMPOSED ON THE SYSTEM

Begin Surcharge - Distance from toe = 116.4 ft
End Surcharge - Distance from toe = 148.0 ft
Loading Intensity - Begin = 237.3 psf/ft
Loading Intensity - End = 237.3 psf/ft

--------- SOIL PARAMETERS ---------

Unit Weight, GAM1 = 124.80 pcf
Friction Angle, PHI1 = 21.0 degrees
Cohesion, COH1 = 0.0 psf
Bond Stress, SIG1 = 1.45 psi

Unit Weight, GAM2 = 131.10 pcf
Friction Angle, PHI2 = 25.0 degrees
Cohesion, COH2 = 59.3 psf
Bond Stress, SIG2 = 14.50 psi

Coordinates of Two points Defining Boundary for soil 2

POINT	X-Direction	Y-Direction
1	XS1 = 0.0 ft	YS1 = -8.2 ft
2	XS2 = 118.1 ft	YS2 = 36.1 ft

--------- EARTHQUAKE ACCELERATION --------

Horizontal Earthquake Coefficient = 0.00 (a/g)
Vertical Earthquake Coefficient = 0.00
Horiz. Force applied to the Wall = 0.0 Kips

--------- WATER SURFACE ---------

The Water Table is defined by three coordinate points.

X(1)-Coordinate = 0.00 ft Y(1)-Coordinate = -6.0
X(2)-Coordinate = 97.00 ft Y(2)-Coordinate = 32.0
X(3)-Coordinate = 165.00 ft Y(3)-Coordinate = 42.0

--------- SEARCH LIMIT ---------

The Search Limit is from 0.0 to 150.0 ft

You have chosen NOT TO LIMIT the search of failure to specific nodes.

--------- REINFORCEMENT PARAMETERS ------

Number of Reinforcement Levels = 4
Horizontal Spacing = 6.10 ft
Diameter of Reinforcement Element = 1.26 in
Yield Stress of Reinforcement = 71.70 ksi
Diameter of Grouted Hole = 4.50 in
Punching Shear Capacity = 60.00 kips

--------- (For ALL Levels) ---------

Reinforcement Lengths = 40.20 ft
Reinforcement Inclination = 30.0 degrees
Vertical Spacing to First Level = 2.60 ft
Vertical Spacing to Remaining Levels = 8.20 ft

Figure i Extracts from the 'Snail' computer input data

	MINIMUM SAFETY FACTOR	DISTANCE BEHIND WALL TOE (ft)	LOWER FAILURE PLANE ANGLE (deg)	LOWER FAILURE PLANE LENGTH (ft)	UPPER FAILURE PLANE ANGLE (deg)	UPPER FAILURE PLANE LENGTH (ft)
NODE 2	1.465	86.7	0.0	43.4	42.4	58.8

```
Reinf. Stress at Level  1 =  25.428 Ksi (Pullout controls...)
                        2 =  22.480 Ksi (Pullout controls...)
                        3 =  29.988 Ksi (Pullout controls...)
                        4 =  34.201 Ksi (Punching Shear controls..)
```

	MINIMUM SAFETY FACTOR	DISTANCE BEHIND WALL TOE (ft)	LOWER FAILURE PLANE ANGLE (deg)	LOWER FAILURE PLANE LENGTH (ft)	UPPER FAILURE PLANE ANGLE (deg)	UPPER FAILURE PLANE LENGTH (ft)
NODE 3	1.455	94.6	0.0	37.9	35.6	69.8

```
Reinf. Stress at Level  1 =  28.744 Ksi (Pullout controls...)
                        2 =  27.100 Ksi (Pullout controls...)
                        3 =  30.189 Ksi (Pullout controls...)
                        4 =  34.430 Ksi (Punching Shear controls..)
```

	MINIMUM SAFETY FACTOR	DISTANCE BEHIND WALL TOE (ft)	LOWER FAILURE PLANE ANGLE (deg)	LOWER FAILURE PLANE LENGTH (ft)	UPPER FAILURE PLANE ANGLE (deg)	UPPER FAILURE PLANE LENGTH (ft)
NODE 4	1.423	102.5	0.0	41.0	34.1	74.3

```
Reinf. Stress at Level  1 =  26.141 Ksi (Pullout controls...)
                        2 =  24.780 Ksi (Pullout controls...)
                        3 =  30.865 Ksi (Pullout controls...)
                        4 =  35.202 Ksi (Punching Shear controls..)
```

	MINIMUM SAFETY FACTOR	DISTANCE BEHIND WALL TOE (ft)	LOWER FAILURE PLANE ANGLE (deg)	LOWER FAILURE PLANE LENGTH (ft)	UPPER FAILURE PLANE ANGLE (deg)	UPPER FAILURE PLANE LENGTH (ft)
NODE 5	1.412	110.5	0.0	44.2	32.7	78.8

```
Reinf. Stress at Level  1 =  23.260 Ksi (Pullout controls...)
                        2 =  22.180 Ksi (Pullout controls...)
                        3 =  31.117 Ksi (Pullout controls...)
                        4 =  35.489 Ksi (Punching Shear controls..)
```

	MINIMUM SAFETY FACTOR	DISTANCE BEHIND WALL TOE (ft)	LOWER FAILURE PLANE ANGLE (deg)	LOWER FAILURE PLANE LENGTH (ft)	UPPER FAILURE PLANE ANGLE (deg)	UPPER FAILURE PLANE LENGTH (ft)
NODE 6	1.440	118.4	0.0	47.3	31.3	83.1

```
Reinf. Stress at Level  1 =  19.878 Ksi (Pullout controls...)
                        2 =  19.734 Ksi (Pullout controls...)
                        3 =  30.503 Ksi (Pullout controls...)
                        4 =  34.789 Ksi (Punching Shear controls..)
```

Figure ii Extracts from the 'Snail' computer output data

Installation

A total of 114 number soil nails were installed in four number rows along the length of the slope, see figures (iii) and (iv).

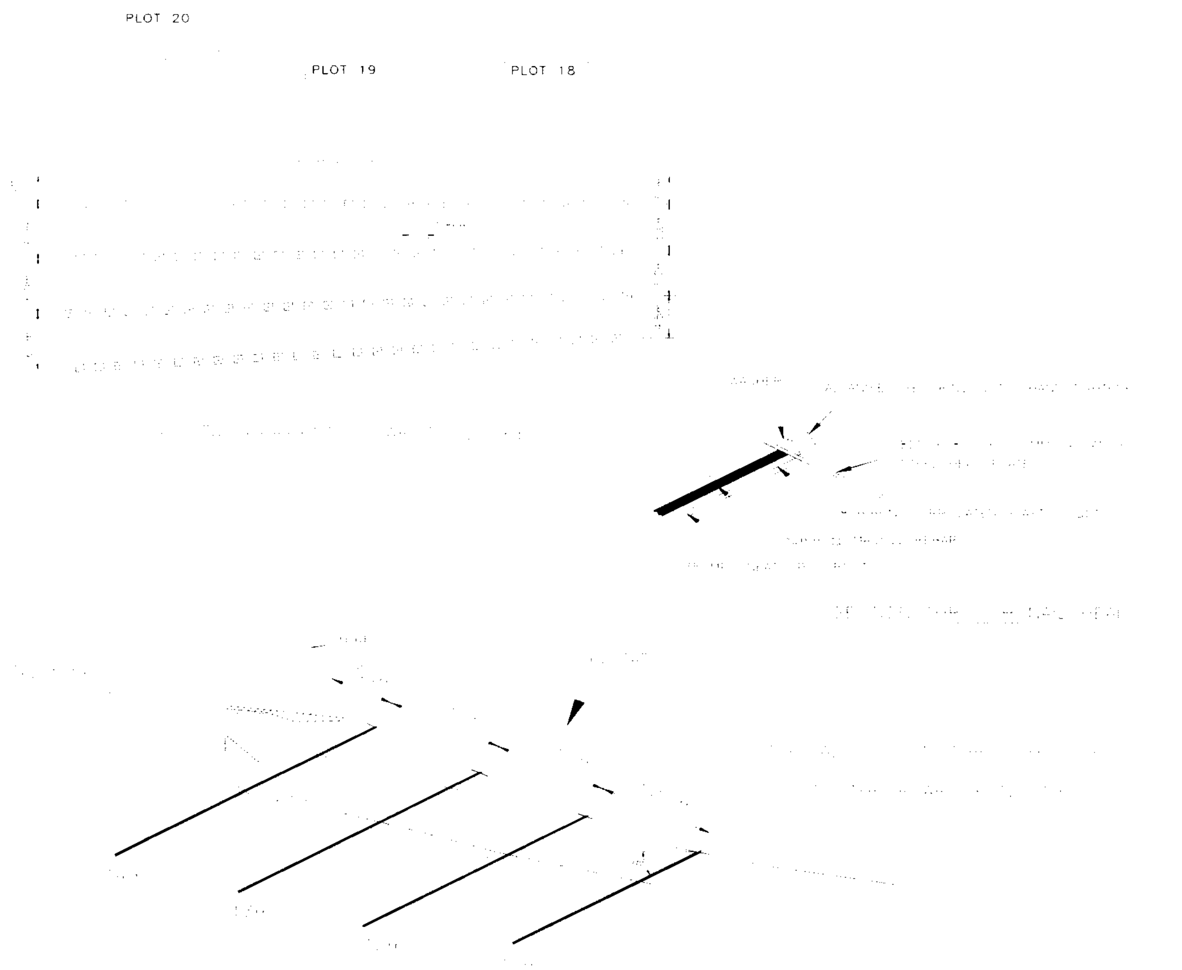

Figure iii Soil nail scheme at Broughton Heath, Chester.

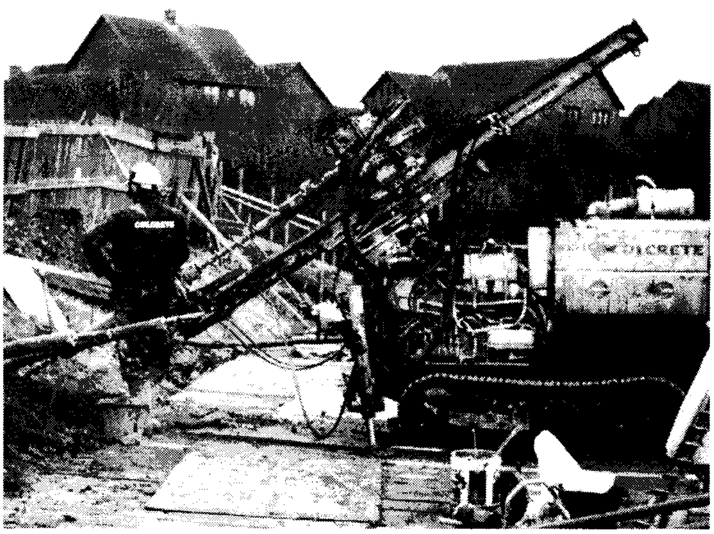

Figure iv Drilling of soil nails

The 120mm nominal diameter soil nails were formed with a 4.5 tonne diesel powered Wirth drill rig using case and auger drilling techniques. Upon completion of boring a 32mm ∅ MAC500 reinforcement bar within a corrugated U.P.V.C. duct (corrosion protection) was inserted to the full depth. The soil nails were then grouted using a colloidally mixed neat ordinary portland cement grout which was pumped down the central duct and forced up around the annulus. Following initial curing of the grout the duct was trimmed level with the slope and all of the exposed reinforcement bar was liberally painted with two coats of galvafroid paint. A large 0.8m x 0.8m x 0.012m galvanized steel head plate was then nominally tightened onto the slope, bedded on mortar where there were any voids. A large head plate was deemed necessary due to the large spacing between horizontal rows.

During the works a small number of water pockets were encountered and it was decided to install a number of perforated drainage pipes. These were inclined upwards at 5° from the base to assist in reducing any detrimental pore water pressure build-up within the slope. These works were successfully completely within the eight week programme period with minimum disturbance to both the residents and the environment. The author recently visited the site and was impressed with how quickly the reserve has returned to its natural state, see figures (v) and (vi).

Figure v Soil nail slope 2 years after completion

Figure vi Soil nail head plate 2 years after completion

UNDERBRIDGE 314, GATESHEAD

This interesting project involved soil nails, ground anchors and minipiles adjacent to a busy railway line. Miller Civil Engineering were the main contractors for this complicated roadway underpass widening scheme which culminated with the slide-in of a new railway bridge during a weekend possession. The temporary soil nails were required along each side of the embankment to enable a steep temporary excavation to be formed and thus allow the new construction works to proceed.

Design

This design was complicated by the potentially poor embankment fill material (minimal site investigation data available) and the dynamic loading from the frequent passing trains. Furthermore, the top of the wall is only 3.5m from the nearest railway line. Following discussions with various parties (including category III checker Geotechnics Ltd.) an average 1.0m x 1.0m triangular grid was decided upon with 8.0m long soil nails at 20° below the horizontal. The soil nails were temporary (in use for less than three months) and therefore no specific corrosion protection was incorporated into the design. In view of the steep nature of the wall it was decided to specify a 1.5m wide x 0.15m deep reinforced concrete 'cap' to protect the top edge from splaying away. A total of 10 levels of soil nails were required and this gave a minimum factor of safety of 1.50 in the 'Snail' analysis. This high factor of safety was considered prudent in view of the limited knowledge of the fill material and the close proximity of the live railway lines. The excavated surface was covered with a plastic matting to contain the fines which in turn was covered by a stronger geogrid. Finally 0.45m square steel plates were nominally tightened against the face to secure the matting/geogrid. The design required all nails/coverings and head plates to be fully installed before commencing the excavation to the next level.

Installation

A total of 147 number x nominal 100mm ∅ soil nails were installed, see figures (vii) and (viii). Each soil nail was again tremie grouted with a neat cement grout and then a 25mm ∅ Gewi reinforcement bar was inserted to the full depth. The soil nails were bored using Casagrande C6 crawler rigs using air flushed rotary percussive drilling techniques. This method of drilling ensured that any unknown obstructions could be quickly penetrated.

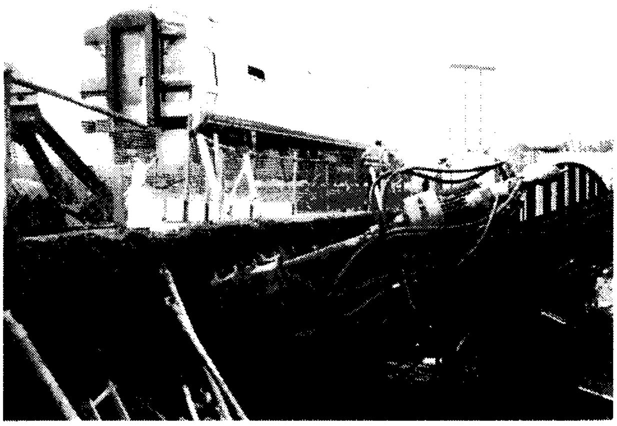

Figure vii Commencement of drilling at Gateshead

Figure viii Completed soil nail slope at Gateshead

Track Settlement

A comprehensive monitoring system was undertaken by the main contractor and it was noticeable that the nearest railway lines underwent greater settlement than expected. Frequent ballasting (up to twice a week) was required during the later stages of the soil nail wall construction. After the soil nailing / excavation works were complete the settlement quickly reduced to negligible amounts. A certain amount of movement is inevitable within a soil nailed wall as the restraining forces are developed, this is normally of the order of 0.3 to 0.4% of the retained height. The author believes that the significant track settlement at Gateshead could possibly be attributed to the following:

- Dynamic load effects
- Poor embankment fill
- Very wet weather
- A flexible geogrid

The author wishes to emphasize that although the movements were greater than expected there was never any sudden movement, neither was the overall safety of the wall ever in doubt.

Soil Nail Tests

Two soil nails pull out tests were carried out to verify the following:

- The grout ground bond stress
- The nail head punching capacity

The first test was carried out towards the base of the wall and involved measurement of the nail and head plate movement independently, see figures (ix) and (x). A grout ground bond stress of 48 KN/m^2 and a nail head punching capacity of 106 KN was determined which confirmed the adequacy of the design parameters. The first test was stopped due to the head plate starting to buckle. The second test was a simple pull out test applied to a soil nail near the top of the wall. This gave a grout ground bond stress of 58 KN/m^2 and a nail head punching shear of 128 KN.

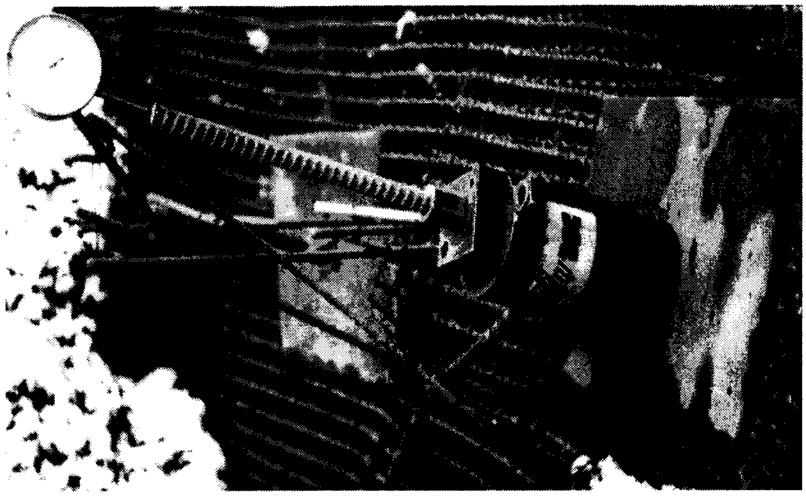

Figure ix Soil nail pull out test

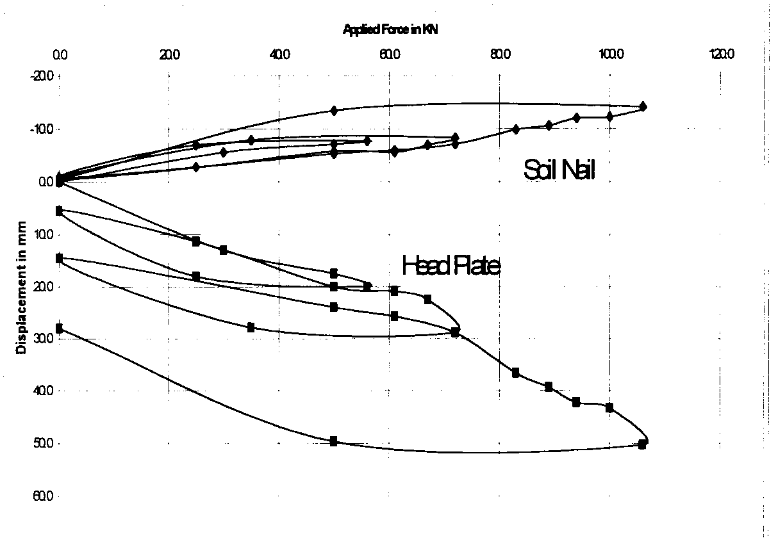

Figure x Soil nail pull out test results

CONCLUSIONS

This paper demonstrates that a variety of soil nail designs can be simply and efficiently carried out with the 'Snail' computer program. Furthermore, that the program allows the designer to consider a wide range of variables in the soil nail model. In addition, great care should be taken when installing soil nails into embankment fills and / or dynamic loads are present. Finally, that the elasticity of the surfacing on the cut face should be fully taken into consideration.

ACKNOWLEDGEMENTS

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REFERENCES - 'Snail' computer program manual.