AN INNOVATIVE ALTERNATIVE TO CONVENTIONAL SHEAR KEYS IN SITE DEVELOPMENTS USING DEEP SOIL MIXING - A Case Study from Wainui, Rodney District

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BACKGROUND

In early 2006, the developer of a site at Wainui in Rodney District, commissioned an Engineer's report into the suitability of the land for development as a clean fill site. The site, which comprises grazing land at the head of a gully, is located on the southern side of Haruru Road. It is rectangular in shape and approximately 3.8 hectares in area. The existing site contours (and proposed drainage) are shown in Figure 1.

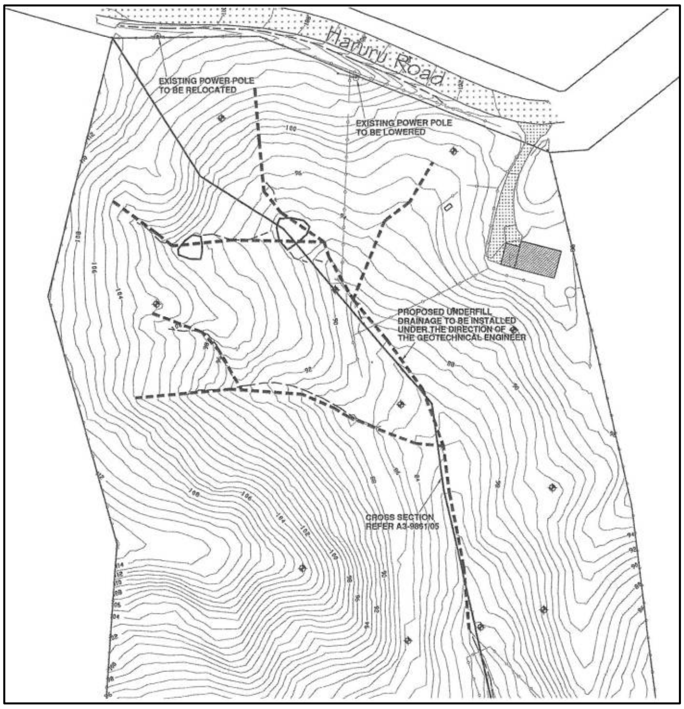


Figure 1: *Plan view of site showing contours (1m) and proposed drainage works.*

The Site Investigation Report stated that the site consisted of 2-5m of stiff to hard silts and clays which are residual soils weathered from the underlying rock formation which is inferred to be interbedded sandstones and siltstones of the Waitemata Group.

The Engineer's report recommended that an earth bund be constructed at the base of the gully. This bund was to be constructed to act as a shear key excavated a minimum of 1m into the underlying, slightly weathered, bedrock and retain the proposed fill behind it . This bund would be constructed in heavily compacted layers to a maximum height of 10m. A typical cross-section of the proposed bund is shown in Figure 2 below.

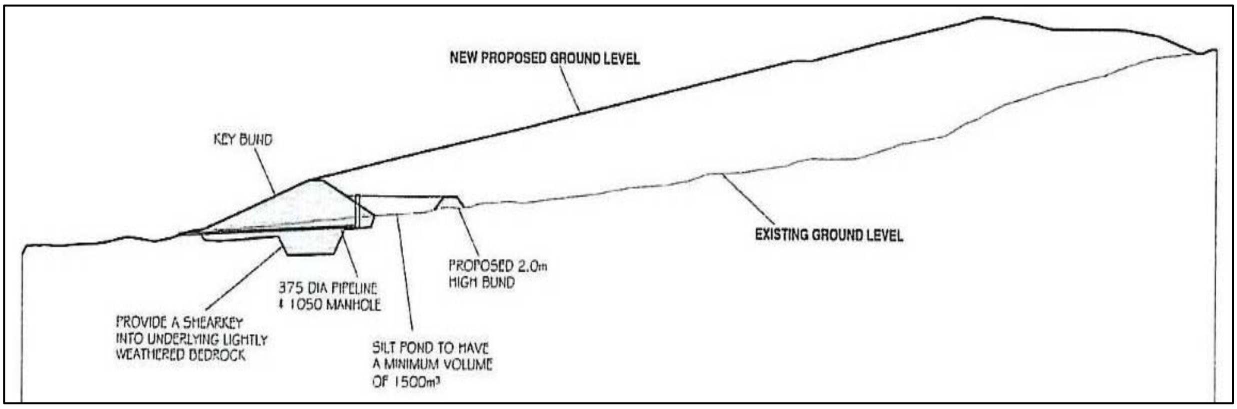


Figure 2: *The proposed conventional shear key.*

Following discussions with the client, Hiway Stabilizers Environmental (HSE) submitted an alternative design which utilised Colmix DSM (Deep Soil Mixing) columns, drilled sufficiently far into the slightly weathered Waitemata, in-lieu of the excavated shear key to provide stability to the bund and prevent any potential slips from occurring at the residual soil/ weathered rock interface. This design was carried out by SKM and peer-reviewed by Dr. Ka-Ching Cheung of Peters & Cheung. In November, 2006, the client accepted the DSM-based alternative and instructed the work to be carried out.

INTRODUCTION TO COLMIX DSM

Colmix DSM (Deep Soil Mixing) was originally developed by Bachy Soletanche; the world's largest Geotechnical Engineering Contractor, based in France. Colmix DSM was introduced to New Zealand in 2003 after HSE identified a need for this technology in the Road Maintenance and Civil Construction markets.

Transit NZ Northland Region were involved in launching Colmix DSM technology and provided the first slip repair project. Due to the large number of slips on the Northland State Highway network and the success of the first trial project, Colmix DSM has since been used to remediate various slip mechanisms; circular, translational, settlement, sidling fill. Close to 100 projects have been completed to date in many ground conditions including: allochton, alluvium, waitemata, sidling fill and papa.

The Colmix DSM system consists of twin 300mm diameter hollow stemmed augers. The augers counter-rotate to provide a mixing action as they drill, and are capable of reaching a depth of 8.5m with the standard setup, or 11.5m with a mast extension. As the augers advance into the ground, a slurry mix is pumped from a batching plant through the hollow drill strings to the cutting heads. The slurry doubles as the drilling fluid for lubrication and contains the prescribed ratio of additive to create the stabilised soil column. The entire mixing process is computer controlled. A schematic of the system is shown in Figure 3, while the rig itself is shown in Figure 4.

Two important elements of the Colmix DSM process are that the soil is forced into lateral compression during installation (i.e. it is never allowed to relax) and the columns are compacted as the augers are extracted. These two elements are designed to maximise the soil/column interaction and ensure a high degree of homogeneity in the columns.

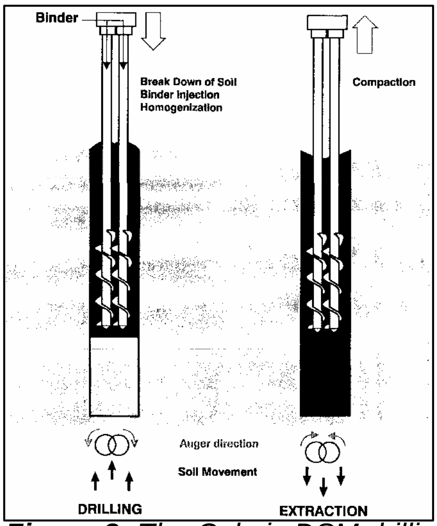


Figure 3: *The Colmix DSM drilling process*

Figure 4: *The Colmix Rig*

COLMIX DSM DESIGN

Colmix DSM columns are designed to form a reinforced soil block. They are generally designed on a replacement ratio basis, where the aggregated properties of the individual columns and the surrounding soil are used for the strengthen soil block. Latest generation finite element software (such as Plaxis or FLAC), allows the designer to analyse the achieved group effect of the columns and the subsequent change in effective stress regime within the soil block. The individual columns are generally designed using the following parameters:

Design Parameter	Design Value
Unconfined Compressive Strength (UCS)	1.5MPa
Cohesion	750kPa
Stiffness (E)	360MPa

Table 1: *Design Parameters for Colmix Columns*

The accepted alternative design was based upon founding the bund on the installed Colmix DSM columns. The final design recommended that 6 rows of columns be drilled to a depth of 5m – a total of 108 columns. The final Colmix DSM design is shown in Figures 5 and 6.

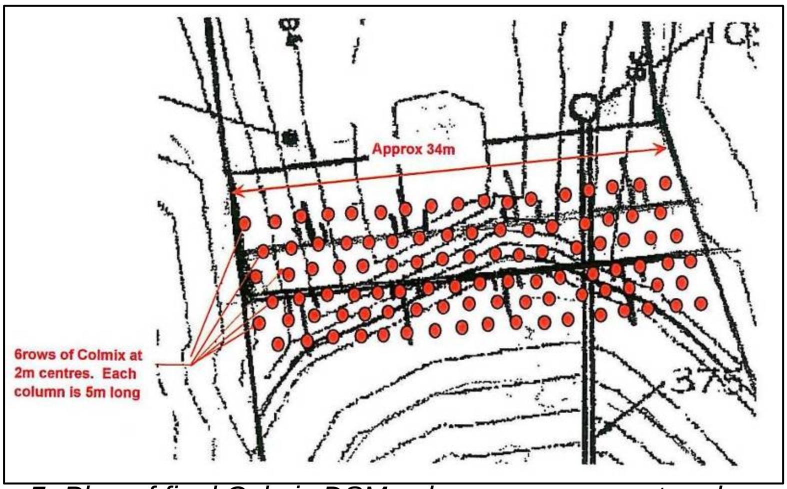


Figure 5: *Plan of final Colmix DSM column arrangement underneath the bund*

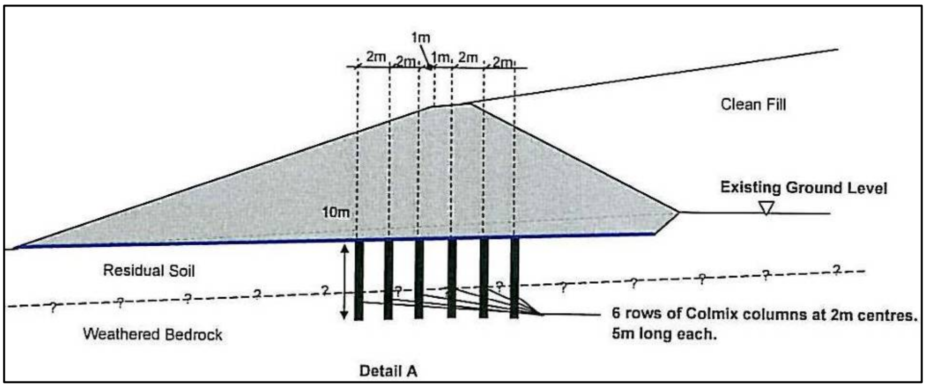


Figure 6: *Cross section of proposed Colmix DSM columns beneath the bund*

COLMIX DSM COLUMN CONSTRUCTION

HSE mobilised the plant and construction crew to site in December 2006. The columns were installed in 4 days. In addition to the Colmix columns for the shear key, a series of nine additional trial columns were constructed, to a depth of 5m in order to demonstrate the effect of different grout mix designs on the consistency of the Colmix columns. Figures 7 & 8 show the columns being installed.

Figures 7 and 8: *Construction of Colmix columns*

For the trial columns, three mix designs were used. Mix design 1 used a cement only based grout, Mix Design 2 used an additional 6% lime and Mix Design 3 used an additional 12% lime. After a six week period, the columns were excavated to a depth of 4.5m and representative cores were taken from all three Mix Designs. The results showed that the consistency of the columns improved considerably with the addition of lime. Figures 9 &10 show the exposed columns and Figure 11 & 12 show samples of the cores taken.

Figures 9 & 10: *Photos showing exposed trial columns*

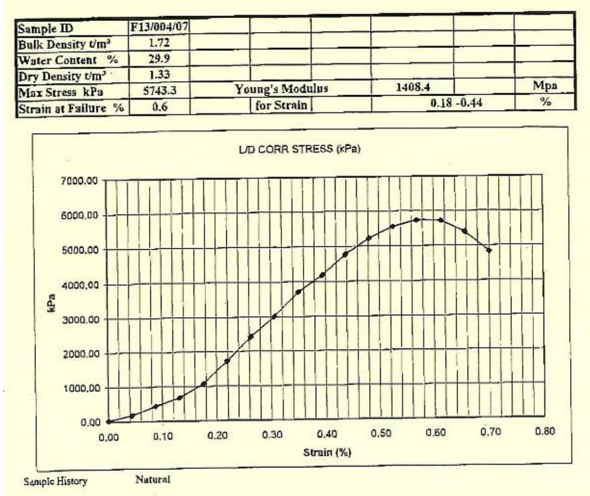
Figure 11: *Sample core Mix Design 1 (Cement Only)*

Figure 12: *Sample cores Mix Design 2 (Homogenous Columns with 6% lime)*

QUALITY ASSURANCE

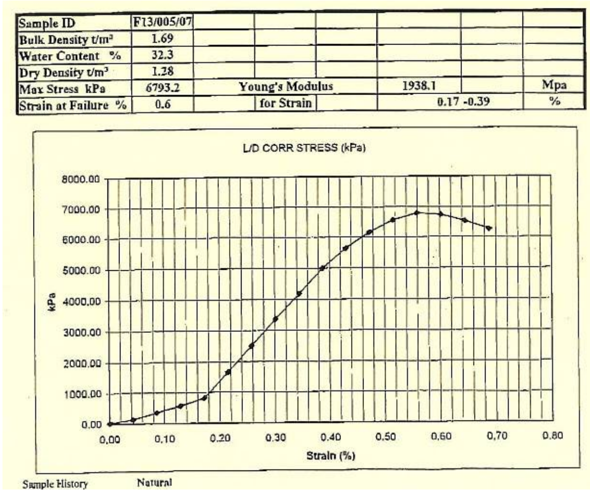
The mixing process in the Colmix DSM system is completely computerised, with detailed printouts available for grout application rate, drill rate, compaction rate, depth achieved and drilling resistance (hi/lo). The system does not, however, determine the suitability of the grout mix selection. This needs careful planning and testing!

At Wainui, the core samples were taken from the two of the three Mix Designs and were tested by Opus International Consultants Laboratory to determine their unconfined compressive strength after curing. The results are given in Figures 13, 14 & 15 below.



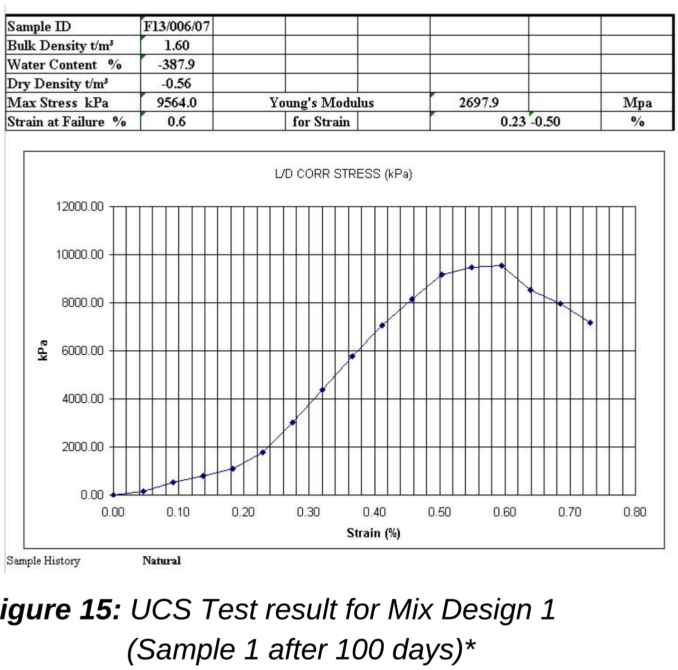
Sample ID	F13/004/07			
Bulk Density t/m³	1.72			
Water Content %	29.9			
Dry Density t/m³	1.33			
Max Stress kPa	5743.3	Young's Modulus	1408.4	Mpa
Strain at Failure %	0.6	for Strain	0.18 -0.44	%

Figure 13: *UCS Test result for Mix Design 2 (Sample 1 after 67 days)**



Sample ID	F13/005/07			
Bulk Density t/m³	1.69			
Water Content %	32.3			
Dry Density t/m³	1.28			
Max Stress kPa	6793.2	Young's Modulus	1938.1	Mpa
Strain at Failure %	0.6	for Strain	0.17 -0.39	%

Figure 14: *UCS Test result for Mix Design 2 (Sample 2 after 67 days)**



Sample ID	F13/006/07			
Bulk Density t/m³	1.60			
Water Content %	-387.9			
Dry Density t/m³	-0.56			
Max Stress kPa	9564.0	Young's Modulus	2697.9	Mpa
Strain at Failure %	0.6	for Strain	0.23 -0.50	%

Figure 15: *UCS Test result for Mix Design 1 (Sample 1 after 100 days)**

*(Courtesy of Opus International Consultants Laboratories)

	Design target	Mix Design 2 Sample 1	Mix Design 2 Sample 2	Mix Design 1 Sample 1
No of days cured	28	67	67	100
Mix Design	Varies	Cement +6% lime	Cement +6% lime	Cement only
UCS (MPa)	1.5	5.743	6.793	9.564
Young's Modulus (MPa)	360	1408	1938	2697

Table 2: *Summary of UCS test results (hence no cohesion measured)*

CONCLUSIONS & DISCUSSION

The results from the trial at Wainui indicate that, with careful selection of an appropriate grout mix design, Colmix DSM columns can achieve high levels of homogeneity and strength characteristics well above the design criteria in stiff silts and clays as well as in the underlying rock formation. While Colmix DSM technology has generally been used in New Zealand in the roading sector, for the remediation of slips and road failures, its application as a potential alternative to conventional shear keys appears very promising following the results of this trial.

The installation of DSM columns has a number of advantages, namely:

- They can be installed in a substantially shorter time period
- They can be installed all year round and are not weather dependant
- The construction risk can be greatly reduced as no large excavations are required for installation and the working footprint is considerably smaller
- They are generally cost-competitive against conventional earthworks shear keys
- Better long-term performance as less dependency on additional drainage works

One could argue, given the large difference between assumed design parameters and obtained parameters in the field, that sufficient redundancy is built in to the design process. This certainly seems to be the case for Mix Designs 2 & 3 (results for 3 not published but similarly high). However, despite cement only mixes (Mix Design 1) tending to give even higher strength characteristics, the replacement ratio design criteria requires good homogeneity of mixing across the full width of the columns and hence poorly mixed columns may not satisfy this criteria sufficiently. The relatively low design parameters used for the individual columns do, however, take some account of localised deviations.

As previously stated, the correct grout design mix and application rate are important. There can be some difficulty in mixing and preparing laboratory samples and this can require considerable experience. This is a recognised issue worldwide with DSM technology. Five years of testing in New Zealand has, however, resulted in good correlations being achieved between properly prepared laboratory test samples and cores taken from in-situ columns. These results show that the cores consistently obtain higher strengths than equivalent laboratory samples. In addition, a database has been developed of appropriate mix designs for various soil types.

ACKNOWLEGMENTS

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