An update of Deep Soil Mixing in New Zealand

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ABSTRACT

This paper presents recent developments in the use of deep soil mixing (DSM) technique in New Zealand. Although road slip repair has traditionally been the primary application of deep soil mixing, recent innovations include liquefaction mitigation and foundation improvement for civil engineering structures. The benefits of deep soil mixing are illustrated through case studies. This paper provides an update to the paper that was presented at the 9th Australia / New Zealand Conference on Geomechanics in 2004.

1 INTRODUCTION

New Zealand's geology generally comprises a range of young and geotechnically challenging soils. In particular Northland and the Gisborne region on the North Island's east coast are prone to instability of road structures. As a result, New Zealand roads have long suffered from over and under slip settlements, many associated with increase pore water pressure build-up and/or weak soil properties. A photograph of a typical road under slip is shown in Figure 1.

Figure 1 (left): A typical New Zealand road under slip.
Figure 2 (right): The Colmix C1300 rig

The engineering methods and available technologies in New Zealand for dealing with these soils have often been limited to certain traditional techniques, with sometimes inconsistent and often poor results. These methods include H-pile, timber retaining walls, soldier pile walls, drainage based solutions and gravity structures such as gabion walls and granular buttress structures. In the majority of cases DSM can provide an effective alternative treatment.

In 2002, Hiway Stabilizers took delivery of a "wet" soil mixing system named Colmix, which Hiways considered to be most appropriate for New Zealand applications. This is a proprietary method developed by Soletance Bachy, utilising multiple augers to achieve highly efficient mixing and resultant soil mixed columns – the system is illustrated in Figure 2. Binder slurry is mixed in a batching plant and pumped through the hollow stemmed augers where the grout is discharged at the drill head. The batching, pumping and drilling is a computer controlled and monitored process ensuring complete quality control throughout the mixing and drilling process. Binder mix designs are selected based on the soil characteristics and the results from laboratory reactivity testing of site samples.

The auger arrangement comprises twin overlapping discontinuous flight augers. Binder is injected during the insertion phase to achieve soil homogenisation and lubrication of the mixing tool. During the extraction phase, the augers are reversed and along with an applied downward thrust, thus providing efficient compaction of the soil column.

2 APPLICATIONS FOR DSM IN NEW ZEALAND

2.1 SLIP REPAIR

Topographically Northland, even though of limited height, is quite rugged. Gisborne region comprises some very steep terrain with contours increasing in elevation up to 1000 meters running inland towards the Kahitatea Ranges. Roads are particularly prone to slip movement, particularly where they are built on such soft deposits without proper cleanout of the gully floor first.

The typical geomorphology throughout Northland and Gisborne Regions is characterised by numerous shallow-seated failures within the slopes. Such shallow failures have been observed on gentle slopes of 5^o to 15^o because of the low residual strength and creep movement. Much of the Northland Allochthon soil is highly plastic and has a high shrink/swell potential, which exacerbates the soil's susceptibility to creep. The soils found in the Gisborne region are composed primarily of young alluvium soils that are derived from soft calcareous sedimentary rocks. They are particularly prone to erosion – for although the area makes up only 3% of New Zealand's land area, it accounts for 26% of all silt washed into the sea. Due to the characteristics of the Northland and Gisborne geology, several deformation and failure mechanisms are observed, including rotation and translational slips, settlement, bearing capacity failure and creep.

In 2004, Transit New Zealand awarded the NZ Road Innovation Award to Hiway Stabilizers for its successful application of DSM as a road maintenance method. Over 43,000 lineal metres of DSM columns and some 75 slips have been repaired over the last 4 years. The slip repairs have been performed all year round providing major advantages over other systems. Although various challenges have been encountered on the 75 sites repaired in NZ by DSM, all repairs have been successfully implemented with no need to resort to additional conventional repairs after DSM has been used.

2.2 LIQUEFACTION PREVENTION

If the materials on any particular site fall within a particular grading, there is potential for liquefaction to occur in a seismic event. Experience and familiarity with the DSM system operated in NZ has enabled DSM to be incorporated as a method of protection against liquefaction for new structures.

DSM columns have been constructed on two projects to date using a cellular arrangement to prevent lateral spreading and minimise liquefaction potential. Both sites are situated in Tauranga and underlain by marine sands, as a result of being situated close to sea level and on foreshore or reclaimed soils. The columns are positioned to allow adjacent column overlap of 50 to 70mm, thus creating a continuous wall of DSM columns to an appropriate depth. This method of construction prevents liquefaction due to 3 reasons:

1. The treated soil walls restrain shear deformation of the soil during an earthquake. The dynamic earth pressure forces are resisted primarily by the treated soils, thus resulting in less deformation and the development of substantial inertia forces.

2. Regardless of the superior strength provided by the treated material within the cell walls, some inertia forces will develop within the untreated materials that are enclosed within the cells. When cells are constructed via. the use of DSM, the untreated material is constrained and prevented from displacing out of the immediate vicinity, therefore further eliminating the development of significant inertia forces.

3. The bearing loads of civil structures have an effect upon materials that have the potential to liquefy in a seismic event. When the bearing capacity loads are resisted by the DSM treated soil, the structure's contribution to liquefaction potential is reduced.

2.3 DSM FOUNDATIONS

When large civil structures, particularly buildings, are constructed, ground conditions often require extensive foundations to be constructed beneath the structure. In many instances these foundations include drilled/bored, reinforced concrete piles. Piles such as these are constructed with a very high standard of quality assurance, although they are time consuming and costly to install. DSM was first used on a building foundation in NZ in 2005, and this is discussed as a case study below.

3 CASE STUDIES

3.1 Portland road slip repair

3.1.1 Failure mechanism
The site has at least a 50 year history of settlement. Previous remedial attempts, which include excavation and replacement, deep well drainage, deep counterfort drains, and buried horizontal drainage, did not effectively address the slip mechanism. While these solutions have slowed the slip movement; settlement up to 250mm depth was present in the site in 2003. The primary mechanism for the observed settlement is likely to be bearing capacity of the soil layer underlying the road embankment.

3.1.2 Subsurface conditions
The slip comprises of a 1.5m deep embankment fill over 4.5m of soft to very soft clay layers. High groundwater levels occur at the Portland site as the site is in close proximity to a river subject to tidal actions.

3.1.3 Remedial works
The Portland slip was repaired with 4 rows of DSM columns across the road width over a 45m road length. The columns were spaced at 2.5 x 3.5m intervals, to a depth of 7m below ground level. The Portland remedial works were designed assuming 0.8 MPa UCS design strength, and the design factors of safety adopted were 1.5 and 1.1 for the normal and extreme groundwater conditions, respectively. The remedial works were completed in 18 working days.

3.1.4 Economics
The DSM remedial option provided 39% savings over a traditional 15m H-pile wall with tie backs and 4m deep counterfort drains.

3.1.5 Post construction monitoring
Nails were installed on the pavement following the completion of the DSM columns. The movement of the nails was monitored in three surveys over eight months. Insignificant vertical and lateral movements were observed in the post construction surveys, where the maximum settlement in the road surface has been approximately 10 mm.

3.2 Auckland, State Highway 1 Northern Motorway - Okura slip repair

3.2.1 Failure mechanism
A new 15 km long section of Northern Motorway, known as Alpurt Section A, was opened in late 1999. In December 2005 a 70m long section just outside of the shoulder on an 8m high embankment slipped to cause a 0.6m high head scarp. The head scarp occurred just outside the crash barrier, but threatened the road shoulder and pavement. Traffic protection measures were installed, and the slip was monitored. As of July 2006, the scarp had increased to 1m in height.

3.2.2 Subsurface conditions
Construction records and onsite borehole investigations indicated that the roading embankment was constructed from clay fill material that was placed wet of optimum due to constraints at the time

of construction. The slip was determined to be primarily rotational as the embankment upon which this new section of State Highway One was constructed was only seven years old, and bearing capacity failure of the underlying materials appeared unlikely. The underlying material consisted of natural alluvial clays which have been proven as suitable for a cement based "wet" DSM process in the past.

3.2.3 Remedial works
A DSM solution was adopted that involved the drilling of 83 columns drilled to a depth of 8.5 m. The columns were divided into 7 rows of which 4 were constructed at the base of the slope, and 3 were constructed adjacent to the pavement shoulder. Safety factors of 1.5 and 1.2 were adopted for the normal and extreme groundwater conditions, as displayed in Figure 4. The remedial works, as illustrated in Figure 5, were completed in 2.5 weeks.

3.2.4 Economics
The remedial project was initially designed as a rockfill buttress support; however a design build offer incorporating DSM was accepted. The alternative DSM option allowed for savings of 18% of the conforming option, which amounted to NZ$200,000. The DSM was some $500,000 lower than a bored pile retaining wall which was also proposed.

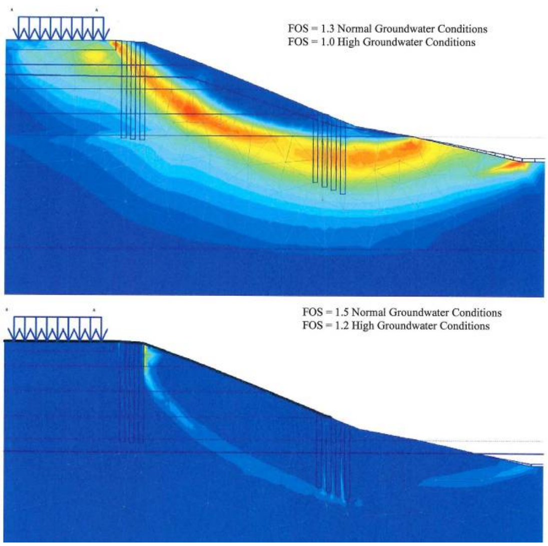

Figure 4: Modelling of the slip at Okura before and after installation of columns.

Figure 5: Installation of DSM columns at Okura.

3.2.5 Post construction monitoring
Stringent design analysis review and QA procedures were required for this project and resulted in three quality assurance monitoring measures being adopted for construction monitoring. Samples of treated soil were collected onsite during construction and laboratory tested to confirm design strength had been achieved. An inclinometer was installed after construction and is monitored monthly, and the displacement of survey pins is measured every month. At 28 days curing the 10 percentile sample strength was 2.0 MPa (design = 1.5 MPa). As of one year after completion the inclinometer has deflected less than 2mm, while survey pins at the top of the slope have settled less than 10mm.

3.3 Tauranga Waste Water Treatment Plant liquefaction mitigation

3.3.1 Failure mechanism
Soils underlying a proposed extension to Tauranga's Waste Water Treatment Plant were determined to be susceptible to liquefaction in a seismic event. The factor of safety against liquefaction was determined to be between 0.3 and 0.7 at varying depths below existing ground level.

3.3.2 Subsurface conditions

Investigation logs indicated that the site geology generally comprised pumiceous sands to a depth of greater than 25m. The density of sand increased with depth; therefore two layers were modelled by the engineers at the design stage. A salt-water estuary was immediately adjacent to the site, resulting in a generally high water table.

Figure 6: Tauranga WWTP site.

Figure 7: Overlapping columns creating cells.

3.3.3 Remedial works

The 500mm wide DSM wall was constructed to provide a 70mm overlap - this created 8.5m cells upon which the liquefaction mitigation design was based. 171 columns were constructed in total. The perimeter wall encompassed 62 m^2 with 7 cells created by internal walls. Construction took place in March 2006 and required a great deal of attention to be placed on the location of each column due to the required overlaps and the presence of substantial services due to being located in the WWTP. Columns were drilled to 11.5m maximum depth, creating significant construction challenges. The site and cells created by overlapping columns are illustrated in Figures 6 and 7.

3.3.4 Economics

An economic evaluation was not conducted as the alternative option to DSM would have involved dig-out and replacement of approximately 500m^3 of material, in addition to the construction of substantial foundations, expensive dewatering and ground retention structures.

3.3.5 Post construction monitoring

The design parameters adopted for the DSM columns included a UCS strength of 2.5 MPa at 28 days. Seven treated soil samples were collected on site and their UCS was measured after 28 days curing. The minimum strength recorded was 4.0 MPa.

3.4 Knox Street carpark

3.4.1 Failure mechanism

A multi-story reinforced concrete carpark building had been proposed for Knox Street, Hamilton. The building foundation was designed utilising strip footings and no piles. However, the presence of a 3m deep layer of incompetent low strength silty sand material from ground level down would not support the proposed foundation design.

3.4.2 Subsurface conditions

A geotechnical investigation by Tonkin and Taylor determined that 0.5m of imported fill overlay silts and sands from the Hinuera Formation to a depth of 12. Below this depth silt and clay from the Puketoka formation was evident. The upper 3m was of primary concern to Tonkin & Taylor, who recommended that at least the upper 3m were able to be treated with DSM columns to achieve a strength of 2 MPa.

3.4.3 Remedial works

The building was designed to be founded on raft footings, and it was these footings that the DSM columns were designed to support. The number of columns required under each raft varied from 8 to 200, depending on the load that each raft was required to restrain. The foundation design required each of the 539 columns to obtain a UCS of 2.5 MPa and be capable of supporting a bearing capacity varying between 0.75 and 2.0 MPa. The columns extended to depths of between 2.5 to 3.5 metres, and the contract was completed in 14 days.

3.4.4 Economics

Had the DSM option not been available, an extensive foundation redesign and/or substantial excavation of insitu material would have been required.

3.4.5 Post construction monitoring

Due to the DSM columns being permanently placed below the reinforced concrete building, post construction monitoring has not been conducted. Being an "alternative" design and the first application of DSM for building foundations, the pre-contract investigations plus construction monitoring were increased to a high standard. The building is performing as expected and no concerns have been raised since construction was completed. The carpark is shown in Figure 8.

Figure 8: Knox Street Carpark, Hamilton – Inaugural use of DSM in building foundations.

4 CONCLUSIONS

Insitu wet process deep mixing has proven to be successful in a wide range of soft and problematic soils in New Zealand. Utilisation of DSM solutions provides a fast, economical solution with enhanced QA and durability after repair. DSM can treat multiple failure mechanisms, and as a consequence of the methodology, ongoing maintenance is not required. DSM provides a relatively aesthetic solution that preserves existing landforms, and slip scars are able to be rehabilitated.

DSM has been proved to provide cost effective solutions with proven performance. Other less tangible benefits such as speedier construction, reduced traffic and construction disruption are also evident.

The DSM process has gained familiarity throughout New Zealand, and is now recognised and accepted road maintenance method. Further recent advances have included liquefaction mitigation and foundation treatment for civil structures. The DSM process has continued to develop its excellent track record by providing a fast and economical alternative to more conventional designs.