Stabilisation of Landslides using DSM columns in New Zealand

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Abstract:

Deep Soil Mixing (DSM) was first introduced in New Zealand in 2002. Since then the technique has been used on over 150 projects. The vast majority of these involved the remediation of landslides and mudslides along the roading network.

Many of these sites were subject to previous failed attempts to stabilise the slope using other techniques such as conventional retaining walls, mass excavation and re-compaction, buttress toe supports and deep cut-off drainage.

The complex and relatively young geology of the North Island of New Zealand incorporates a huge range of different soil types from very weak, highly sheared, fissile tertiary mudstones to very recent under-consolidated volcanic deposits as well as sensitive highly crushable pumiceous sands and silts. When coupled with the unique climate and high earthquake risk, these factors have resulted in some of the highest rates of soil erosion on earth.

DSM has been used to stabilise slopes in all of these geological units with remarkable success. To date, no failures or further significant movement have been reported on the roading network which have been treated with DSM columns.

This paper will describe in detail three case histories where significant challenges and risks needed to be overcome and will further detail the design philosophy and FEM-based design methods used. The solution to these problems illustrate the need to fully understand the relevant mechanisms, which in these cases were not strength driven, and also to understand in detail the DSM installation process and subsequent impact on ground behaviour.

Introduction:

Since its introduction in 2002 to New Zealand, over 150 slip and landslide sites have been remediated using DSM. In this time considerable gains in the understanding of the importance of the overall "group effect" of the columns and necessary design checks which are required to ensure a successful outcome have been made. This has led to importance revisions in the design approach adopted.

Case Study No. 1:

Kaiianga Slip – Ruatoria

The road at Kaiianga runs through an active shallow landslide, 180m below the head scarp. The cause of the failure mechanism is a combination of toe erosion and high contrast in permeability between the upper residual soil layers and the underlying moderately weathered rock layers. The problem is exaserbated by the high shrink/swell characteristics of the residual soil, which result in a high exent of fissuring in the drier summer months and hence are more susceptible to rapid ingress of precipitation during the early part of the wet winter months.

Every year, during heavy winter rainfall events, the unsealed road gets washed away and the community in the hinterland is completely cut-off. A number of solutions had already been tried at the site, including re-grading the road, reducing the slope angles and installing extensive drainage works.

Given the success of DSM on the local state highway network, the local Council considered a DSM option. While only limited site investigation information was available (CPT's to 7m) a preliminary design indicated that a DSM based solution would be viable and economic based on targeting only the faster shallower movements.

Figure 1: *Satellite Image of Kaiianga Slip (Courtesy Google Earth Pro)*

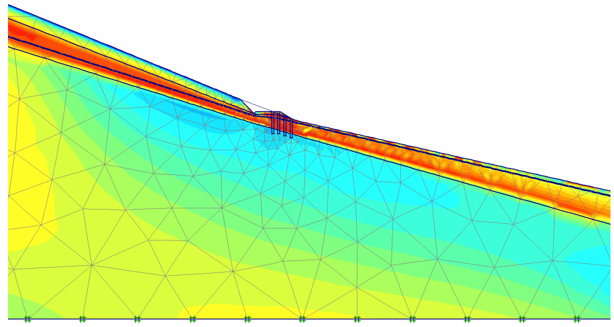

Figure 2: *Plaxis analysis cross-section showing critical failure mechanism under High groundwater table*

The initial back-analysis of the slope captured the shallow infinite slope failure well (refer figure 2 above). However, the installation of the columns and modelling of the group effect was more difficult as a result of the contractive behaviour of the soil. Figures 3a & b 4a & b below show the pre- and post-DSM installation results. In this case, the contrubution of the confining pressure of the columns (volumetric expansion of binder injection) needed to overcome the contractive nature of the soil. This required a reduction in column spacing from the originally adapted design.

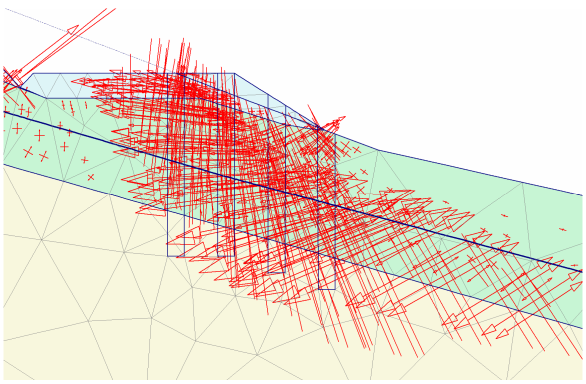

Figure 3a: *Shear Strains pre-installation*

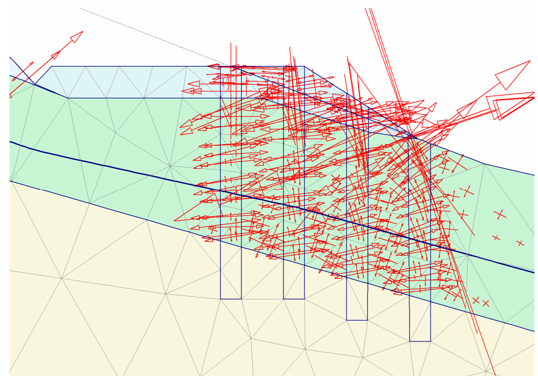

Figure 3b: *Shear Strains post-installation (reflecting volumetric expansion of column installtion)*

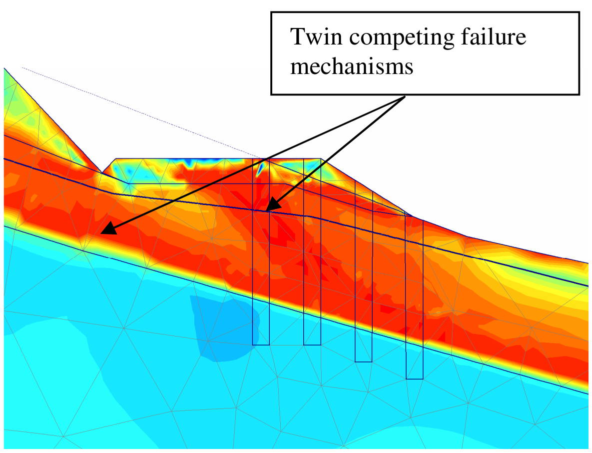

Figure 4a: *Critical Mechanisms prior to installation*

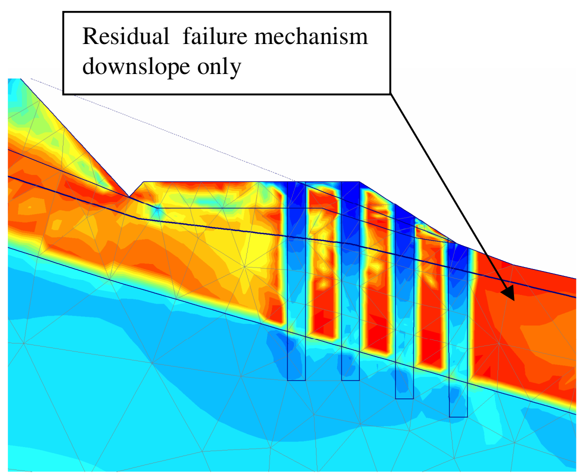

Figure 4b: *Treated Zone following installation*

The project has been sucessful to date with the DSM columns preventing a failure of the road for the first time over successive winter seasons.

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Case Study No. 2: Ogles 3 Slip

As with the site at Kaiianga, the site at Ogles 3 lies within an active landslide. However, both the topography and geology are significantly different. The site is underlain by highly sheared and broken extremely weak to very weak mudstone and has a long history of movement.

Previous attempts to remediate the site include installation of deep drainage, deep well pits (circa 1990) and the construction of a 4m deep toe butress fill in the paddock, immediately downslope of the road. While the latter has significantly reduced the rate of movement of the road; creep movement has, however, continued to affect the serviceability of the road. As part of the site investigation carried out, extensive testing of the materials was carried out. This included seismic CPT of the upper layers, triaxial testing of the residual soil and embankment fill parameters, in-situ rising head tests at two critical layers within the profile and the installation of an inclinometer.

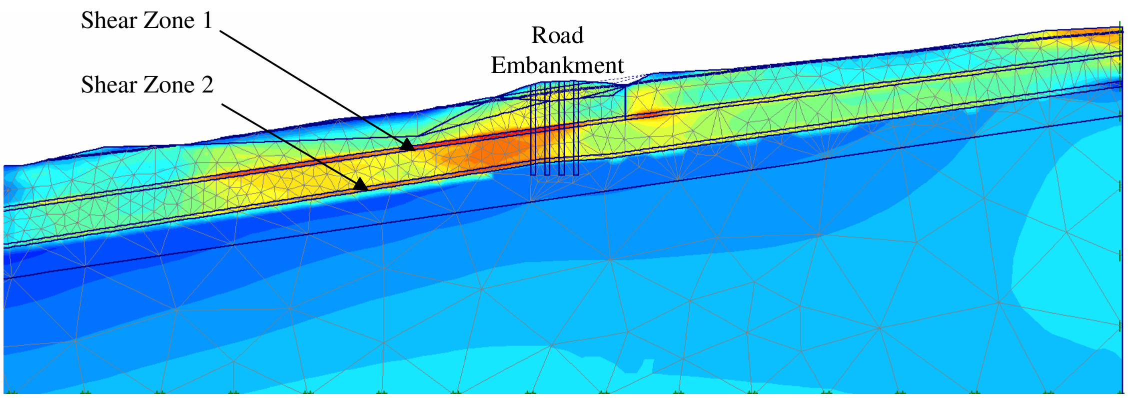

Figure 5: *Plaxis Design profile forOgles 3 site indicating two shear zones*

Using the parameters obtained from the laboratory testing, the back analysis of the slope indictaed that the FoS under a high groundwater table was in the order of 1.5. However the road embankment was still subject to deformation. This indicated that the slope "failure" was not a typical Mohr Coloumb type strength failure, but was being caused by a response to two phenomena namely (a) transient groundwater flow and (b) the response to a dynamic load of a truck passing through the site when the site was in a fully staurated state. This resulted in an temporary (split second) instantaneous undrained failure of the slope.

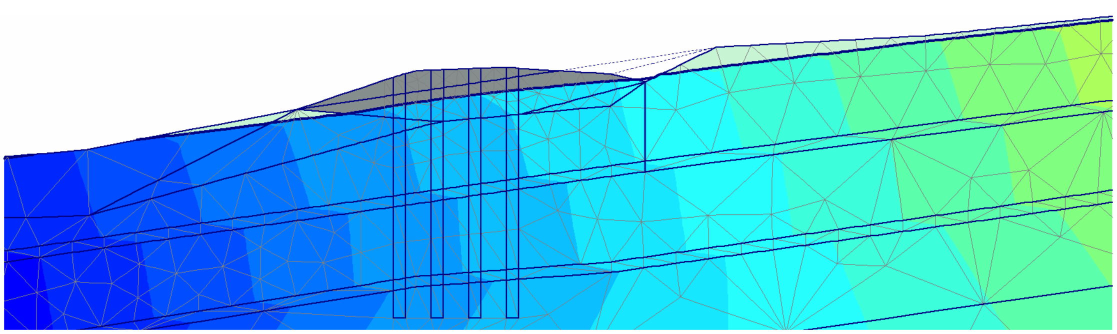

Figure 6: *Output from transient groundwater flow reflecting measured groundwater head profile on site*

While exact correlation between the FE model and the in-situ groundwater profile could not be obtained, given the tight timeframe (only 2 months allowed from commencement of site investigattion works to completion of the works), the model did indicate a very good correlation between the deformations predicted by the model when compared to the deformations obtained in the field by the installed inclinometer (16mm and 13mm respectively). This was deemed sufficiently close to ensure that the model was calibrated correctly for this analysis.

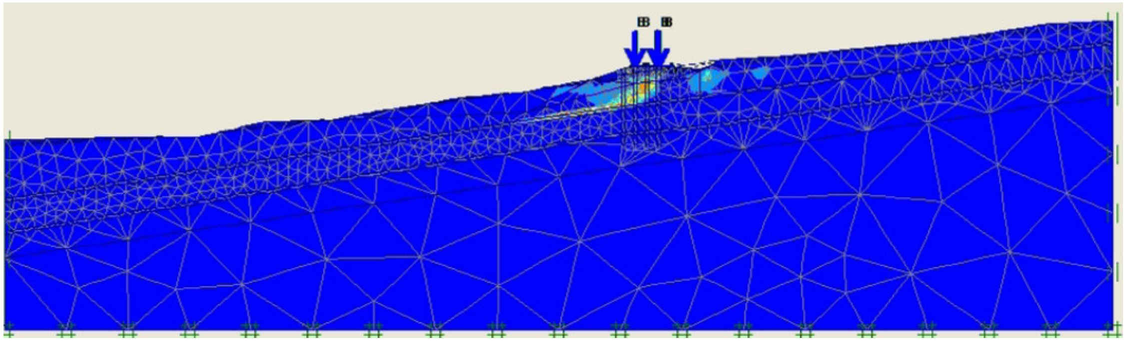

Figure 7: *Dynamic phase analysis simulating truck passing through site under fully saturated conditions*

Figures 6 & 7 above show the FE model outputs for the transient groundwater flow analysis and the dynamic loading analysis..