LIME & CEMENT STABILISATION

FOREST INDUSTRY APPLICATIONS

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Introduction:

Lime and Cement Stabilisation has been and will continue to be considered where producing a better roading product cheaper is the objective and motivation. The treatment will also be used where stabilising in situ soils or so called inferior local aggregates produces an equal or better final product at a lower price.

This paper will summarise New Zealand-wide observations of various roading practitioners, the roading network owners, and suggests a rapid cost/benefit analysis to compare conventional construction costs to one or more stabilisation construction cost techniques.

In most cases, by using stabilisation to modify the insitu material, the owner, by improving what is already there, avoids the need to import extra roading material.

What is Stabilisation?

Stabilisation modifies weak soils and aggregates by changing the physical and chemical characteristics of the soil. An increase in load bearing capacity and pavement strength results. In the majority of stabilising exercises between double and tenfold increase in strength is readily achieved.

The use of a small quantity of stabilising agent (lime, cement and other types) substitutes for large quantities of imported aggregate. Typically 1 tonne of cement/lime replaces six to twenty tonnes of river-run/crushed aggregate.

There are two basic reactions in the stabilisation process. The base exchange reaction occurs in clay type soils. In this reaction, ionic bonds between the calcium and hydroxyl ions present in the Quicklime bond silicates within the clay particles are formed. The outcome is seen as the clay visibly changing from plastic behaviour to become a coarser and friable material.

The cementation reaction is the gluing action between discrete particles within the pavement. This occurs with Cement Stabilisation.

Stabilisation decreases the shrinkage and swelling characteristic of the existing material, dramatically increases the CBR and compression strength, and eliminates the capillary action of water from "underneath" and the infiltration of water from above the stabilised platform

The type of soil to be stabilised determines whether lime stabilisation or cement stabilisation or a combination of the two is the most appropriate treatment. Lime is most effective in plastic soils, clays and clayey gravels. Lime does not react effectively with some organic or volcanic soils, acid soils or soils of high salinity, or soils with an appreciable amount of sulphate.

Cement reacts well with sands and gravels with low clay content, produces less spectacular strength improvements with soils of high sulphate content and volcanic soils. Some organic soils, soils of high salinity, acid soils generally do not produce significant strength improvements with cement. As a general rule of thumb plastic soils will react with lime and granular materials such as sand will react with cement.

While routine standardised laboratory tests will give empiral and statistically rigorous results, the practitioner in the field can gain some very sound indications of the site material response to stabilisation with a mere ice-cream container, a measuring spoon of stabilising material (lime/cement/etc) and some water.

Literally ten minutes in the field, making the test mould with your own hands, leaving it in the boot of the car for 24 hours, and then soaking the mould in water will tell you whether stabilising should be investigated further. If the mould disintegrates in water then stabilising has not occurred, so go no further. If the mould stands alone or softens only slightly, the indications are that stabilisation has occurred and that stabilisation of your pavement and subgrade may not only be viable, but may be a money saver. One manufacturer has available Sample Kits so you or someone you can ask can do these tests.

These simplistic and apparently amateurish in-field evaluations can be corroborated by relatively low cost and simple laboratory tests.

The Laboratory tests mimic what will occur during construction.

Samples of the insitu material from the site are mixed with varying percentages of the stabilising agent. The percentage of stabilising agent used in construction generally is in the range of 1 % to 5 %.

Four moulds are made up, one with say 1.5 %, 3 %, 4.5 % stabilising agent and the others with say, 1.5 %, 3 %, 4.5 % stabilising agent. After curing they are soaked in water for four days and then subjected to a CBR test. The results are plotted and the optimum amount of stabiliser to be added is derived from the plotted CBR values on the graph.

Sometimes a combination of lime and cement is used. In these circumstances the lime reacts with the plastic clay fine material and renders it receptive to the cementation action of the Portland Cement.

Construction Methods:

The construction of a stabilised pavement is akin to conventional pavement construction techniques.

The one difference is that the ionic and cementing actions impose limits on the time from initial mixing of the stabilising agent into the road and the final compaction. In the case of cement, that time is two to three hours, and in the case of lime up to seven days.

The Stabilising methodology is simple and foolproof providing the sequence is followed. The allocation of the plant resources should be balanced so that the final compaction is achieved before the final 'set' of the stabilised pavement occurs.

The sequence can be summarised: -

1 Rip and pre-shape the road to the final shape.

2 Pre-wet the existing material to near optimum moisture content.

3 Spread the stabilising agent on the surface.

4 Spray the stabiliser on the surface with the predetermined amount of water to ensure the ionic and chemical reactions will occur.

5 Mix the stabilised material into the pavement material, with a Stabilised Unit which will create a homogenous material.

6 Check the Moisture Content of the mixed layer is within the range that will achieve the required compaction.

7 Shape the layer by grader to the final road or platform profile.

8 Compact using the appropriate rollers.

9 Final trim with a grader.

10 Surface Finish and Cure, (ie., keep surface moist). The sequence is used in two consecutive stages when both lime and cement are used in the construction.

Lime is mixed with the insitu material first, and after the initial ionic bonding, has activated (physically observable by the clay content become friable even when melted) the cement is then mixed into the material. Cement is always second because its setting time is short and the strength development is rapid.

The constraints to stabilised pavements subgrade are the same as for conventional construction. If the insitu material or imported aggregate is too wet or too dry, effective compaction will not be achieved.

Traditionally, stabilisation of material which will not be sealed has been undertaken as late as May and June, providing the temperature is above 3 ° C - however, present studies indicate that the ionic and chemical reactions are suppressed or put into suspended animation if the ground temperature is below 7 ° C, and that the strength development does not occur when the ground temperatures rise in the following spring.

The advantage between stabilising the existing pavement or subgrade, and building a new road or putting a thicker layer of metal on an existing road, is that by using a stabilising agent in the existing material you develop a pavement of comparable performance and strength without having to import additional aggregates.

Similarly, stabilisation generally enables materials which are substandard in conventional unbound pavements to be enhanced/improved to be used as substitutes for premium grade aggregates.

There are many examples where insitu materials such as clays have been stabilised and used as roads etc., without the addition of conventional aggregates. In these cases the stabilisation transforms a quagmire into a 365 day a year access.

Stabilisation can be used as a rehabilitation or rejuvenation of existing pavements which have failed or fatigued beyond their service life. The end product is a recycled product with a much extended life.

Design Considerations:

The motivation in designing a stabilisation sub-base, or stabilisation pavement is to achieve one or all of the following:-

a Cost saving by enhancing the pavement with a small quantity of stabiliser agent, thereby eliminating the need to import additional aggregate.

b Rejuvenation of a pavement whose failure is because it has fatigued.

c Converting materials which unconventional roading use are sub-standard or highly variable in strength performance when subjected to varying ground and/or weather conditions into a stable impermeable platform.

In designing a load bearing surface, the two criteria which must be mastered in a pavement are the vertical deformation in the underlying and supporting subgrade (seen as deflection) called vertical compressive strain; and control of the horizontal strain at the base of the top pavement layer (seen as cracks in the surface).

CBR results are a calibration of the vertical compression. In-field and laboratory tests have developed empircal guidelines stating that, for given combinations of loads, frequency of the loads and total number of loads, a road will complete its design life, providing at various depths below the surface the insitu material exceeds the CBR value calculated.

Simplistically conventional pavement design states that the lower zone of the pavement masters the vertical compressive strain (vertical deflection) and the upper zone deals with the horizontal stresses generated by the activities at the surface.

In New Zealand Transit's State Highway Pavement Design and Rehabilitation Manual and it's predecessor TR2 in the days of the National Road's Board is used as the reference for pavement design. It projects a pavement's life for normal road conditions in terms of Equivalent Design Axle loadings and develops tables showing what CBR values should be at designated depths, and more importantly, minimum depth of granular material to control the horizontal strain in the top layer of the pavement.

Some practitioners have evaluated that the condition of the uppermost surface needs to be pristine. Others have determined that the use of an area will be short and sharp and that the in-built conservatism, based on the design assumptions of a service life of 15 + years, can be modified with considerable reduction in the pavement depth.

There are many examples of where clays have been stabilised without any surface treatment for horizontal strain and have performed as heavy haulage access roads or loading areas.

The TNZ design charts are orientated towards achieving excellence with minimal or no allowance for non-compliance. The element of risk taking is very small. Not surprisingly, the TNZ design charts give excessive depths if applied to uses other than conventional roading, such as in the logging industry.

Forest Loading Supervisors, wittingly or unwittingly, have identified the parameters of risk assessment. When determining practical pavement depths, the following factor's influence the risk assessment.

- Forestry roads having only to last for a short period and need not be designed to withstand twenty years harsh environment.

- Forestry traffic can accept less than pristine surface conditions such as large ruts, attrition of the surface, degradation of the uppermost layer (sacrificial crust).

- Forestry roads need not be designed for 365 days per year usage. Lesser pavement depths can be effective if the road utilisation is programmed to periods where ground conditions are not unfavourable.

- Forest Roads can incorporate a higher "non-compliance"/"failure-in-service" risk factor into the design depth determination, (the economic return principle of why build perfection when 70 % {say} perfection costs less than half {say} and does not interfere with production).

- The application of the fourth power rule when transposed from the On-Highway 8 tonne/axle loading assumptions to the 6 tonne/axle loads of the off highway trucks used in Forestry, appears to give conservative and excessive pavement depths.

Practitioners in the Forestry Industry can justify questioning the TNZ Design Charts when they can illustrate cases of 200 mm thick pavements meeting the industries' needs.

The 'success stories' generally feature the following common factors:-

(i) Effective drainage of the road platform and the underlying base.

(ii) Good cross fall and diligent road maintenance.

(iii) Judicious identification of localised soft foundations and over-excavation or use of fascines and/or geo-grid or filter cloth materials.

(iv) Construction during favourable ground conditions.

(v) Realistic and perceptive evaluation of the risk factors; and the subsequent road usage within those risk factors.

I would suggest that stabilisation will generate further reduction in pavement depths, and corresponding cost savings.

The following conclusions from roading could be transposed into the off-road applications.

Stabilisation of an existing pavement can eliminate the need to import an additional 50 mm of metal.

As a rule of thumb, 1 tonne of stabiliser can substitute up to twenty tonnes of aggregate.

Insitu material or local aggregates can, by modification with the stabilising agent, produce a pavement equivalent to a conventional unbound aggregate pavement, but at a significant cost saving.

Some practitioners are already using the TNZ Chart for Low Grade flexible pavements to determine the pavement depth and then reducing the depth by 50 mm to 75 mm if the pavement is stabilised. As a typical example: -

eg., Stabilisation of 150 mm of an existing pavement with 1.5 % of quicklime negated the requirement of an additional 50 mm of imported metal.

For a one kilometre length this equates to 36 tonnes of Quicklime replacing 400 m^3 of aggregate and a cost savings of over $15,000.00.

Recognising the Forest Industry can accommodate a greater tolerance of sub-grade and pavement failure savings greater than this example can confidently be achieved.

<u>Cost Considerations:</u>

An astute Forest Road Supervisor or Forest Asset Manager would pause at this stage without prompting and reflect that his in-field sampling showed Stabilising was a possibility and the follow-up low key laboratory tests had confirmed that stabilising was viable.

The next step is to assess the comparative Construction, Maintenance and Plant Operating Costs of a stabilised pavement versus an unstabilised.

An appropriate approach is the progressive economic advantage principal. It can be summarised if the cost advantage of the stabilised option at the construction stage isn't great enough, then add the discounted maintenance cost saving and if the saving isn't large enough, include the savings generated by the less wear on plant and the shorter turn-around times.

The Economics of stabilisation are:-

- Sub-grade CBR improvements = less pavement depth.

- Sub-base improvements = thinner upper layer.

-Lower grade/sub-standard material enhancement = saves the use of premium aggregates

-Rehabilitation of existing pavement = saving in material and transport costs.

Cost savings for a stabilised pavement accrue in the following areas: -

-Construction Cost comparison.

-Discounted Maintenance Cost comparison

-Operating Costs of Plant Comparison.

-Reduced turn-around cycle time costs.

The Construction Cost Comparison is straight forward. The type of construction plant used for stabilising are comparable to conventional construction. The Rotary Hoe/Stabilising Unit is the only additional unit. Accordingly the construction costs are comparable.

The cost to deliver materials on site usually determines the variability of stabilising.

If the cost of a small quantity of stabilising agent, multiplied by its cartage cost to site, is "less" than the cost of the greater quantity of the aggregate which it replaces, multiplied by its Cartage Costs, then stabilisation is a viable option.

If the Maintenance Costs of the stabilised pavement and the unstabilised pavement are costed out over the respective service lives of the pavement or work area and discounted to present value, then the accrued cost savings can be significant.

Generally a stabilised pavement wears better than an unstabilised pavement and requires considerably less maintenance during the pavement's service life. A stabilised pavement requires an annual maintenance allocation one third of the cost the same road required prior to the stabilisation.

As an example, over a ten year period one kilometre of a stabilised road will cost between $12,000.00 to $18,000.00 less to maintain than it would if it was left unstabilised.

There are also additional cost benefits in the area of plant operating cost and turn-around times.

The Transit/National Roads Board Project Evaluation Manual is a convenient cost/benefit methodology to follow when developing a feasible assessment.

Benefits of Stabilisation:

The benefits of stabilisation can be summarised as cost savings and conservation of premium aggregates.

The economics of a stabilised pavement encompass reduced transportation costs of materials to the site, reduced metal depth requirement and reduced maintenance costs. The savings are significant.

An existing pavement can be rejuvenated and recycled to produce an extended service life with either no or only minimal aggregate being imported.

Insitu materials or local quasi aggregates, previously rejected because of inferior performance or inadequate strength, can be modified to produce up to a tenfold increase in strength; and as a consequence form a working area which meets design loadings and traffic movements which needs no further strengthening.

In some cases stabilisation of a shallow depth eliminates the necessity to undercut and backfill with imported material.

In the past, aggregates have been readily and economically accessible. Existing premium aggregate sources are depleting or involve increasing over-burden removal. The Resource Management Act has constrained the development of new aggregate sources. Obviously an increase in aggregate prices will increase the viability of insitu stabilisation.

Even without the intervention of the Resource Management Act quantities of premium aggregate are limited. The Forestry and Roading Industry will continue the trend to utilise "lesser" materials which can be enhanced by stabilisation to produce a pavement which exceeds the design requirements as increasing pressure to conserve premium materials is experienced.

Stabilisation in 2005:

The Resource Management Act and the depletion of premium grade aggregates at variable prices will be the primary factors in the more use of stabilisation of insitu materials throughout all sectors of the Civil Engineering Industry.

Lime and cement stabilisation has been used prior to and since the Roman's built the Apian Way.

Construction techniques will not change significantly. It is unlikely that incremental improvements to construction techniques will produce any significant increases to the strength gains which stabilised pavements already achieve.

The industry will continue to amass laboratory tests and Quality Control Records.

Further cost savings will accrue if ongoing monitoring of the successful stabilised pavements where practitioners have progressively reduced pavement depth or reduced the quantity of added stabilising agent. In such cases the recording of the risk assessment assumptions and what design parameters were relaxed are essential.

Further cost savings to the Forest Industry will accrue if permanent depths can be reduced still further than advocated in this paper. Monitoring the success of pavements where the risk assessment assumptions are less conservative will define the limits to the design parameters. In reality the industry will learn more from roads whose design assumptions and construction were designed to just-about fail and did fail right at the end of it's service life. Such designing to the limit practises will generate more cost savings than continuing with conservative designs which give no indication of how much they exceeded what was required.

Conclusions:

Stabilisation has widespread implications throughout New Zealand. In most cases it is a viable engineering option.

Using the stabilisation option to construct a new pavement or strengthen an existing pavement can generate savings at the construction stage and accrue considerable savings in maintenance costs during the pavement's 'in-service' lifetime.

The method enables materials which otherwise would be rejected, or discarded, to be enhanced to replace premium aggregates.

Most design tables which predict pavement depths are conservative for Forestry, use and stabilisation. Stabilisation can reduce pavement depths further than practitioners are currently achieving. Pavement depth reductions of 50 mm to 75 mm have been achieved where the pavement has been stabilised.

Practitioners can determine from site tests whether stabilisation is 'engineeringly' feasible at low cost. These initial assessments can be corroborated by simple laboratory tests.

Quick Cost/Benefits Analyses are available, which will give good indications of the economic returns which a stabilisation option will generate.

Any realistic proposal for a new pavement, or rehabilitation of an existing pavement will have included an assessment of the stabilisation option.

Stabilisation is a competitive construction option which has lower ongoing maintenance costs (between a third and a half the maintenance cost for its comparable unsealed unstabilised counter-part).

Stabilisation will still be in use in 2005 and 2015 - because of it's use motivation by cost savings and conservation of premium aggregates.