Title: INTELLIGENT PAVEMENTS

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ABSTRACT

Pavement design and construction methodology is most often office based and reliant on critical input data and computer programs. However to design and construct a pavement intelligently and responsibly, other factors need to be brought into consideration to ensure cost efficiencies, best resource usage and least environmental impact. All important factors in today's economic and environmentally driven climate.

This presentation promotes stabilised pavement layers as intelligent and responsible pavement components and discusses criteria to be taken into consideration when designing a pavement. It is divided into subgrade and basecourse sections which have unique and different criteria and benefits.

Subgrade stabilising is a well recognised component in pavement construction but is not always specified. This can result in either contract variations with associated project cost escalations or construction complications and likely premature pavement failures.

Basecourse stabilisation or aggregate modification is also a recognised pavement construction technique. It is generally used in pavement construction as an alternative to the use of premium quality basecourse aggregates. Yet despite its proven benefits it is not widely specified by pavement designers and roading authorities.

The criteria discussed in this paper for both subgrade and basecourse stabilisation options covers issues such as site location, soil types, local practice, quarry location and quality, transport routes, construction program, demands on resources and project scale. All these issues should be taken into consideration during the design and construction phases of a pavement to ensure that the most appropriate pavement construction methods are incorporated.

Benefits of stabilisation such as reduced pavement costs, increased engineering performance, speed and ease of construction, reduced reliance on premium quarry resources and reduced transport requirements are out lined in this paper.

1. FOREWORD

While the title infers we have developed a pavement that has intelligence, the intention is to advocate stabilised subgrade and basecourse pavement layers as intelligent pavement components. Components worth consideration when designing and constructing a pavement to ensure the most cost effective, appropriate, responsible and practical pavement construction methodologies are adopted.

1.1 DESIGN APPROACH

Different roading authorities and engineers tend to have differing philosophies with regard to pavement design and construction methods. These methods are often based on local knowledge and accepted practice, but not always.

For example the debate still continues on the overall impact of moisture within a pavement. Overall it appears that research and innovative practice focuses on the upper pavement layer whereas the critical subgrade pavement layers are often overlooked, lack detailed investigation, aren't fully understood and are subjected to gross assumptions with often disastrous consequences.

The following pavement design scenario is not an uncommon occurrence:

- Basecourse layer: 150mm M4 AP40 aggregate.
- Subbase layer: 450mm high specification GAP65 aggregate.
- Subgrade: Silty clay soil with design CBR of 3%.
- Premium metal source: 60km from the job site.
- Transportation route: Through an extremely busy section of highway and a renowned bottleneck.

The actual pavement design is not an issue as it will no doubt provide the required pavement design life and performance. In contrast the other factors raise issues that require some consideration, for example:

- Aggregate production and supply costs make up a large component of the total cost of a pavement. Therefore by reducing aggregate depths and quantities significant cost savings would be achieved.
- The CBR strength is a subjective estimation and in reality may vary in strength throughout a relatively short time. The silty clay subgrade with a CBR of 3% would be easily improved by stabilisiation offering reductions in aggregate depths and a stronger, less plastic, more stable and durable subgrade.
- Aggregate production and transportation costs will be high and could be reduced by utilizing a locally produced lower quality aggregate and stabilizing it.
- Aggregate supply could be hampered during long periods of the day causing supply and production delays.

Consideration of these and other factors during the pavement design phase will avoid potential construction difficulties and the client will be provided with the most cost effective and appropriate pavement that will also have the added benefit of limited impact on the environment and other road users.

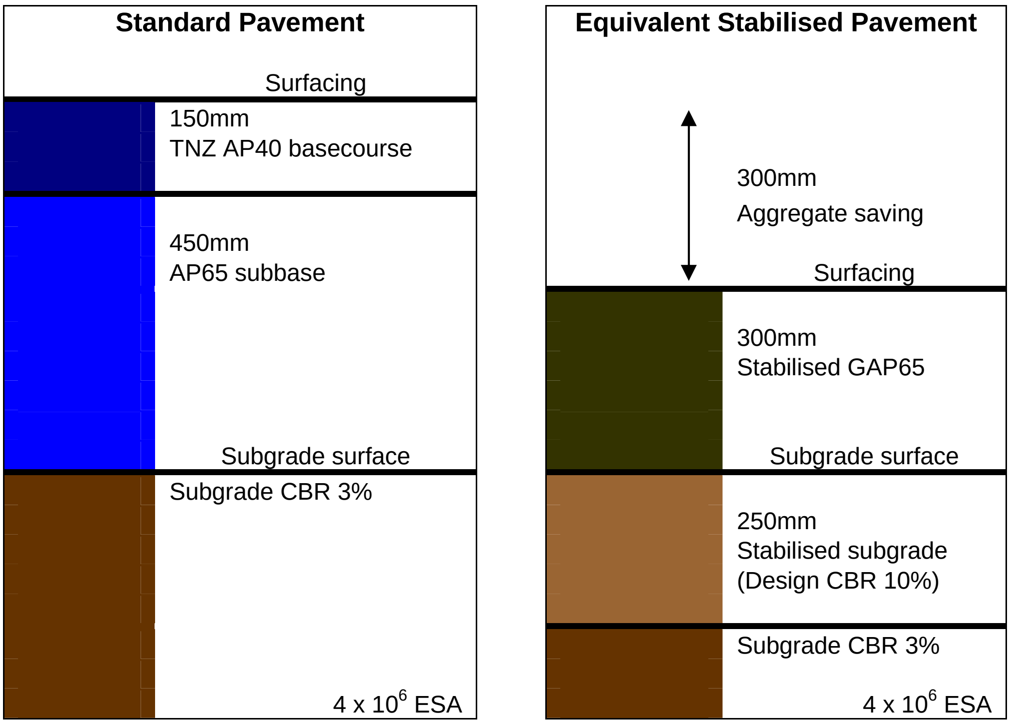
1.2 DESIGN THEORY

By utilising the Transit NZ, industry recognised and now widely used Circly Pavement Design software package, pavements can be modelled quickly and effectively but possibly dangerously in the hands of an inexperienced designer. Pavements with different design philosophies can be designed for equivalent performance and their varying methodologies and components compared to determine the most appropriate pavement design.

For example a traditional pavement comprising unmodified subgade, subbase and basecourse is modelled to determine the aggregate layer depths required to produce the necessary pavement design life. Using the same design input data, a pavement with stabilised sugrade, subbase (if necessary) and stabilised basecourse can then be modelled and the required layer depths determined to produce the same pavement design life.

Cost analysis can then be undertaken on the two equivalent performing pavements and together with consideration to other factors outlined in this presentation the most appropriate, responsible and intelligent pavement can then be constructed.

The following table shows an example of two pavement designs have been run through Circly using the same design input data. They have been designed based on two different philosophies but will provide equivalent design life and performance.



The table shows a standard pavement with 600mm combined depth of subbase and basecourse aggregate. The equivalent stabilised pavement has only 300mm of basecourse aggregate which will provide significant cost savings often in the magnitude of 30% of pavement construction costs.

2. PAVEMENT DESIGN CRITERIA

The following list of criteria is suggested for consideration when designing a pavement with regard to whether a stabilised subgrade or basecourse would prove beneficial.

- Cost
- Local soil types and characteristics.
- Standard local practice (not necessarily a confining factor).
- Location of the job site in regard to various aggregate sources.
- Alternative aggregates.
- Transportation routes for aggregate supply.
- Likely construction program, e.g. winter or summer.
- Scale of the project.
- What other projects are occurring at the same time and what are their likely demands on aggregate and transport resources.

2.1 COST

Following design of various equivalent pavements based on different design philosophies, cost estimates can be prepared and compared to determine the most cost effective pavement design. The other criteria in this section should then be applied to determine if the most cost effective pavement will be the most appropriate and practical pavement to construct.

2.2 SOIL TYPE

Having an understanding of the local soil types and characteristics is important. Characteristics such as natural strength, volume stability, plasticity, reactivity and classification should be considered when deciding whether to or how to stabilise the subgrade.

Generally cohesive, silty, clayey soils will react well with lime and sandy soils will react well with cement. Some soils will be a combination of silt, sand and clay and could require stabilising with both lime and cement. Reactivity testing as mentioned is important to ensure the right stabilisation treatment is carried out.

2.3 LOCAL PRACTICE

Having knowledge of standard local practice can save time and effort but understanding why such standard practice has been adopted is also important. For example lime stabilisation is generally used in Northland and cement stabilisation is favoured on the East Coast. Why?

If the general rule of thumb in the local area is to stabilise one or more pavement layers, then stabilisation should be seriously considered but understanding why certain binders are used is important as further cost and performance advantages may be realised.

On the other hand if local pavements are constructed out of premium quality aggregates on unstabilised subgrades then understanding why and considering the other criteria out lined in this section could determine that a stabilised subgrade and/or basecourse will provide significant benefits.

2.4 LOCATION

The location and quality of available aggregate sources needs to be taken into consideration.

For example, how close is the nearest premium (AP) aggregate source and how close is the nearest marginal (GAP) aggregate source? If there is a significant difference between the delivered premium aggregate and marginal aggregate prices, then a stabilised marginal aggregate should provide cost savings and transport costs and logistics will have a far lesser impact on the project.

Reactivity testing will determine the most appropriate stabilisation treatment for a particular marginal aggregate and will determine what binder application is required to produce equivalent performance to a premium aggregate.

A stabilised subgrade will reduce the volume of aggregate required and therefore transport costs and logistics will also have a far lesser impact on the project.

2.5 ALTERNATIVE AGGREGATES

In association with aggregate source locations, the type of available aggregate needs to be understood. Most “local” quarries, while not able to produce a high spec AP aggregate, will produce a GAP aggregate suitable for stabilising. Reactivity will determine the most appropriate stabilisation treatment for a particular aggregate.

With Transit NZ’s shift towards performance based contracts and the introduction of the TNZ M22 and B3 specifications the door has been opened for alternative pavement construction techniques and their associated advantages to become more common place. However there is still a lack of uptake from within the industry towards modifying aggregate for use as basecourse due to perceived or real contractual liability and risk. The industry needs to address this issue to promote innovation so that the intention of Transits objectives are realised.

2.6 TRANSPORT ROUTES

Though this is probably only an issue in a few areas of the country it could have a major impact on the construction program of the project. Certain transport routes are renowned bottlenecks with significant delays during long peak traffic periods. Relying on an aggregate source supplied by such a transport route will result in delivery delays, increased transport costs, reduced productivities and delays in the overall project completion. Utilising a locally produced aggregate will negate these supply issues.

2.7 CONSTRUCTION PROGRAM

Whether a pavement is constructed during the summer or winter months can have an impact on the quality of the finished product and the effort required in finishing and maintaining each pavement layer surface.

Many soil types are susceptible to increases in moisture content and volume and decreases in strength during wet weather and over periods of wet and dry weather will suffer ongoing deterioration. A stabilised subgrade will provide a high degree of moisture, volume and strength stability and should be considered especially if a winter construction program is likely.

A stabilised basecourse will require less finishing effort and is more resistant to wet weather requiring less maintenance prior to sealing and should also be considered if a winter construction program is likely.

A further application of stabilising in winter or wet conditions is the fill conditioning process. This process chemically conditions wet soils to increase strength and workability so that they are able to be placed as structural fill.

2.8 PROJECT SCALE

Small areas of subgrade or basecourse can be trimmed to grade, tested and covered by either aggregate or surfacing in a relatively short period of time which reduces the risk of the potentially costly effects of a wet weather episode.

Large areas of subgrade or basecourse tend to be left open to the elements for long time periods while trimming, testing, metal placement or surfacing is undertaken. This poses a substantial risk of wet weather occurring during this period causing subgrade deterioration or basecourse surface abrasion, with associated additional works such as undercutting, hardfilling or re-working and re-preparing of the surfaces as well as construction program delays.

A stabilised subgrade or basecourse is weather resistant and more durable and stable and will significantly reduce the effects of inclement weather during this critical construction period on large scale projects.

2.9 RESOURCE DEMANDS

Knowledge of the total demand for aggregate on a project is critical. The Auckland region is about to see an unprecedented road construction program valued at around $7 billion over the next 10 years. With the relatively recent closure of Winstones Lunn Ave Quarry pressure on existing premium aggregate supplies has been compounded.

Intelligent pavements which incorporate stabilisation, reduced overall aggregate volumes and alternative aggregate sources provide a positive impact on resource demand. Furthermore benefits such as reduced cartage traffic, better utilisation of aggregate resources, speed of construction and less environmental impact can all be realised.

3. STABILISED SUBGRADES

3.1 OVERVIEW

All subgrades should be stabilised. That is a bold statement that is arguable, but in most cases the benefits are significant.

The Romans undertook lime stabilisation of pavement soils some 2000 years ago. The process has since been highly mechanised and reformed but the principles remain the same.

All too often we see pavements which have prematurely failed due to low subgrade strengths. There is essentially only one chance to stabilise a subgrade during a new road construction. This will enable long term maintenance practices for the upper pavement layer to be implemented.

A well constructed stabilised subgrade can provide almost indefinite pavement design life provided that the upper pavement layer is designed as the limiting design life. This upper layer can be designed and programmed for maintenance or rehabilitation relatively easily as opposed to a full pavement reconstruction should an unstabilised subgrade fail.

3.2 GENERAL PRACTICE

Subgrades are generally stabilised with lime or cement binder or a combination of the two. Depending on the reactiveness of the soil, strength gains of up to 20 times are achievable. However, section 8.2.6.1 of the New Zealand Supplement to Austroads Pavement Design Guide states that a strength gain of no more than three times should be used for design purposes. Appropriate binder selection is often misunderstood or overlooked.

This strength increase is one of a number of benefits out lined in the following sections and enables a pavement to be designed with reduced depths of subbase and basecourse aggregate for an equivalent pavement design life and traffic loading.

To determine the reactivity of a soil, testing, which generally involves laboratory CBR tests on the natural soil and with binders added, is undertaken. The results are compared and the reactiveness and CBR strength increases are gauged.

This testing procedure can be approached from two angles. The first being simply to undertake a CBR with the proposed binder to confirm the reactivity of the soil. The other is to undertake a whole series of CBR's with different binder(s) and application rates to determine the most effective and appropriate stabilisation treatment.

The testing and interpretation of results must be undertaken with care. The effects of a laboratory controlled or unrepresentative test must be considered against real field conditions. For example how many roller passes on site produces the equivalent of 62 drops per layer of a standard compaction hammer within a "confined" CBR mould on a concrete anvil and what effect does constant temperature curing have as opposed to curing in the field?

3.3 STABILISED SUBGRADE BENEFITS

Some of the benefits of a stabilised subgrade were touched on in the previous section. Those and others are outlined in this section.

3.3.1 Engineering Performance

A stabilised subgrade provides a much more stable subgrade with increased strength and stiffness that is resistant to volume and strength changes caused by moisture and temperature variations.

The initial reaction following lime stabilising is an immediate strength gain caused by the exchange of calcium cations in the lime with sodium and hydrogen cations in the soil. This causes the soil particles to attract to each other (flocculate) and reduces their ability to bind with water.

The secondary reaction occurs between the lime and the aluminate and silicate minerals found in almost all clayey soils. The resulting calcium silicate and calcium aluminate hydrates are very similar to those produced by the hydration of Portland cement and produce often significant increases in soil strength over a relatively short time period.

3.3.2 Compaction Anvil

Stabilising will produce a subgrade layer with an increased and consistent strength that will act as an anvil when compacting subsequent aggregate layers, thereby enabling much higher densities to be achieved in the aggregate layers, realising their full potential.

The strength of the stabilised subgrade can be determined with a high degree of confidence and quality control thereby mitigating against the risks and effects of a variable strength subgrade.

3.3.3 Reduced Pavement Depth

By stabilising a subgrade, an increased design CBR strength can be achieved with resulting reduced aggregate layer depths for an equivalent pavement design life and traffic loading. Reduced aggregate layer depths result in reduced aggregate volumes, associated costs savings and conservation of aggregate resources.

3.3.4 Stable Platform

Aside from the previous items, increasing the strength and stiffness of a subgrade will provide a much more stable platform that is resistant to deformation and failure caused by construction traffic and requires less effort to trim to final levels. The consistent strength and depth of a stabilised subgrade layer is a huge construction advantage and risk mitigation measure.

3.3.5 Reduced Plasticity

Clayey soils have a high plasticity index which is the range of water contents that the soil maintains a plastic state. Lime stabilising reduces the liquid limit and increases the plastic limit thus reducing the plasticity index and increasing the workability of the soil and its ability to maintain its desired profile under loading.

3.3.6 Moisture Barrier

A stabilised subgrade will form a moisture barrier that will protect the overlying aggregate layers from capillary action and the underlying soils from gravity action. Subsoil and water table drains provide an important component in all types of pavements and are critical in removing water trapped by the stabilised layer.

3.3.7 Particle Migration

A stabilised subgrade reduces or eliminates the migration of soil particles into the overlying aggregate which causes aggregate contamination and acts as a lubricant between the aggregate particles. Also aggregate particles will not punch into the subgrade and effectively become lost to the integrity of the pavement.

3.3.8 Other Benefits of Stabilised Subgrades

- Provides design confidence and predicts pavement performance.
- Is a quality controlled and proven process.
- Reduces the risk of costly subgrade pavement failures.
- Creates a uniform pavement layer with consistent depth and strength.
- Reduces the soils moisture content and increases its workability.
- Can reduce or even eliminate the necessity for undercutting and the associated cost and environmental impact that transportation and disposal of unsuitable material involves.
- Is a proven, cost effective and durable pavement component.
- Reduces transport demands on existing roading infrastructure by reducing aggregate and undercutting to waste requirements.

Photo 1: Subgrade stabilising - Tandem hoes, particle sizer, padfoot roller and smooth drum roller.

4. STABILISED (MODIFIED) BASECOURSE

4.1 OVERVIEW

Traditional pavements generally incorporate a high specification AP40 basecourse aggregate where purely mechanical particle interlock provides compressive and shear strength.

In some parts of the country this type of aggregate is relatively cheap to produce, for example, good quality river run South Island Greywackes. In contrast in other areas it is extracted from specific sources, requiring extensive quarry operations incurring significantly higher production costs and higher transportation costs as a result of longer haul distances. The result is an expensive aggregate from a limited aggregate resource.

Stabilisation, or correctly termed modification, of basecourse aggregates was introduced a number of years ago as a cost saving alternative to premium aggregate use. Modification utilises a cheap, local aggregate which is modified by stabilisation providing a performance comparable to, or better than a high specification AP40 aggregate.

The desired effect is to achieve a "modified" granular pavement with an elastic modulus of 500 to 1,500 MPa in accordance with the New Zealand Supplement to the Austroads Pavement Design Guide: May 2000.

The modified aggregate achieves pavement performance from both mechanical and chemical interlock either through cementitious strength or chemical modification of the fine particle fraction within the aggregate.

In the 1970's cement stabilisation was commonly utilised using high cement contents that produced a high strength, rigid "heavily bound" pavement layer. As these rigid pavement layers were generally constructed over much lower strength, flexible layers cracks began to appear and the pavements began to fail prematurely.

Today the stabilisation process is a lot more researched and better understood than in the 1970's. New specifically designed binders are available as well as the traditional ones and the degree of modification can be specifically designed for and controlled through advanced construction techniques.

Photo 2: Basecourse stabilising – Komatsu GS 360 Hoe.

4.2 GENERAL PRACTICE

Modification has been adopted as accepted or common practice by some roading authorities and engineers who have realised the cost benefits and the success of this pavement construction technique is now well documented.

The Rodney District Council is one roading authority that has adopted stabilised basecourse as standard practice. Marginal quality Flat Top Quarry, and Waitakere Quarry aggregate is the only cost effective aggregate available for large sections of this district. These aggregates do not conform to TNZ M4 specification and have low sand equivalents of around 25 and low natural CBR's of around 50. They are much cheaper to produce and incur much lower cartage costs than premium M4 aggregate which would need to be imported from outside the area, usually from South Auckland.

Low sand equivalent is conducive to stabilising as the excess fine material within the aggregate will react with the stabilising binder to bond the larger particles together and increase the CBR strength. Stabilised Flat Top or Waitakere aggregate achieves CBR strengths in excess of the specified M4 requirement of 80 and have been used successfully in the Rodney district for many years. This has provided the council and rate payers with a much reduced cost per kilometre for seal extensions, pavement rehabilitations and new construction and an overall much improved roading network.

Different aggregate sources have different properties that will react differently to the various stabilising binders available. It is therefore imperative to undertake reactivity testing incorporating a series of CBR tests with the various available binders at various application rates to determine the most effective and appropriate stabilisation treatment.

Current binders available are lime, cement, KOBM Binder™ and Durabind™. These binders are used separately or in combination depending on the aggregate type and pavement requirements. KOBM Binder™ is a slag based by product of the Glenbrook Steel Mill which is generally used in conjunction with a very low cement application to act as an initiator. Durabind™ is manufactured from the same steel mill slag and contains various initiators to enhance and optimise its performance.

Care should be taken to only add sufficient binder to "modify" the aggregate. Excessive applications will cause cementation and a very stiff, bound pavement layer that could be susceptible to fatigue cracking.

GAP65 aggregate is the commonly preferred aggregate grading for stabilising as once pulverised by a stabilising hoe its grading will generally fall with in the grading envelope of a GAP40 aggregate.

4.3 STABILISED BASECOURSE BENEFITS

Some of the benefits of a stabilised basecourse were touched on in the previous section. Those and others are itemised in this section.

4.3.1 Cost Savings

The cost of supplying an expensive, premium quality aggregate transported over a long haul distance can be far out weighed by supplying a cheaper, locally produced aggregate and stabilising it.

4.3.2 Engineering Performance

A stabilised marginal quality aggregate can provide elastic modulus and durability characteristics that often exceed those of a premium quality aggregate, while maintaining pavement flexibility. This can provide the additional benefit of being able to design a pavement with a reduced aggregate depth.

By adopting Austroads Pavement Design Guidelines and relevant TNZ specifications and by undertaking a comprehensive program of pre-testing, field QA testing and performance monitoring, engineering performance can be confidently designed for and constructed.

4.3.3 Reduced Construction Time

Stabilisation results in reduced basecourse construction time when compared with conventional basecourse construction. Placement of the aggregate can be carried out full depth with less compactive effort and less moisture and segregation control required. Large areas will not require staged construction as they can be stabilised and finished in one operation. The stabilised surface requires less finishing effort and will hold together for a longer period resulting in the reduced likelihood of maintenance prior to sealing.

4.3.4 Quarry Resource Conservation and Pavement Recycling

Two basecourse stabilisation scenarios will conserve often limited aggregate resources. The first being that by utilising a marginal quality aggregate, premium aggregates sources will be conserved for more appropriate uses such as sealing chip and concrete aggregate production. The second being that a stabilised pavement can often be designed thinner than an unstabilised pavement as engineering properties can be increased.

Further aggregate resource conservation can be realised through the implementation of stabilisation to recycle failed road pavements thereby eliminating the need to cut to waste and import virgin quarry aggregate. This recycling process is a proven technique for carrying out pavement maintenance and rehabilitation and provides significant cost and time savings as well as having a far lesser impact on the environment.

4.3.5 Reduced Transport Requirements

Reduced aggregate quantities results in reduced transport requirements and utilising local aggregates results in reduced haul distances. These factors reduce demands on existing roading networks as well as reducing the environmental impact such transportation incurs.

4.3.6 Reduced Plasticity

Stabilisation will neutralise swelling clay minerals within the aggregate which can be highly plastic and act as lubrication between the aggregate particles. This is especially beneficial in aggregates with a low sand equivalent, high clay index or high plasticity index.

Photo3: Spreading KOBM followed by water cart for basecourse stabilising.

Photo 4: Twin smooth drum rollers following basecourse stabilising.

5. CONCLUSION

Constructing a stabilised pavement can often offer economic, engineering, logistical and environmental benefits. When designing or constructing an "Intelligent Pavement" stabilised pavement components should always be considered.

The various benefits and criteria outlined are offered as an aid to road controlling authorities, pavement designers and contractors for determining whether construction of a stabilised subgrade or basecourse layer will be beneficial.

Consideration and application of these stabilisation benefits and criteria will ensure that an "Intelligent Pavement" is constructed as it will be the most appropriate, cost effective and efficient with the least impact on the environment, the road user and existing road infrastructure.

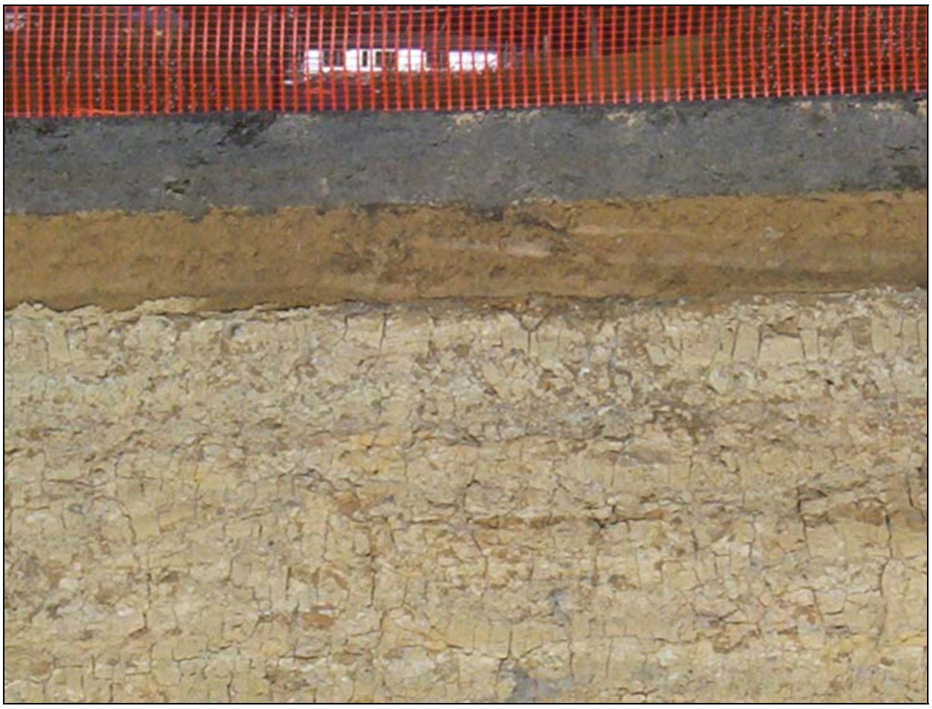


Photo 5: Cutting through an existing pavement on an arterial road showing single layer stabilised aggregate construction over stabilised subgrade and engineered fill.

6. REFERENCES

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  An Australian guide to the structural design of road pavements based on traffic loading distress modes and pavement layer and material analysis.

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  An overview of lime stabilisation principles, design, applications and techniques.

- **Ingles O.G. & Metcalf J.B. Soil Stabilisation – Principles and Practice (Australia 1972).**

  A comprehensive book covering technical and practical aspects of stabilising base on Australian research and experience.