SOME ASPECTS OF PAVEMENT DESIGN AND PERFORMANCE FOR LOW VOLUME ROADS IN NEW ZEALAND

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In defining the role of a pavement, this paper discusses the essential features, methods of design and performance with respect to flexible unsealed and thin surfaced New Zealand roads. The materials which are normally used in these pavements are identified and assessments made on material characteristics for design. By defining the two main modes of pavement deformation, namely shallow shear and deep seated (subgrade) deformation, it has been shown that stabilisation methods can be used to reduce the rate of deformation in both chip sealed and unsealed pavements.
In order to limit the rate of deformation, a Modified Design Approach, which essentially incorporates both a modified subgrade and base layer into the structural pavement, has been recommended and then confirmed as far as practicable using field performance data.
It is concluded that low volume roads can be constructed successfully using thin total pavement depth provided think time and stabilisation techniques are employed with the aid of appropriate design skills.

Roading in NZ

New Zealand is a small country (266 917 sq km in area), has a low population density (3 million), and has a roading network of 92 600 km. As stated by Langbein et. al. (1) New Zealand's economy is based on the export of primary produce, and therefore the transport system must cover the country with a reasonably close network, but with only a moderate density of traffic away from the three main centres of population.

The Roading Network

At present the national network of state highways has of 10 785 km sealed and 770 km unsealed while the local county and municipality roads and streets consist of 35 615 km sealed and 45 432 km unsealed.

The present network is divided into two classes, Class I limits a twin tyred spaced axle to 8.2 tonnes while for Class II the limit is 7.3 tonnes. Traffic flows on many roads are light (less than 100 vehicles per day) and the vehicle type varies considerably from area to area depending on land utilisation and port outlets.

Estimating design loadings is sometimes difficult as a change in use will turn a satisfactory road into one which rapidly deforms under the new traffic conditions.

Climate

Generally the climate in New Zealand can be regarded as temperate, with air temperatures reaching 30ºC plus in the summer down to below zero in the winter. Rainfall varies from 300 mm in the Central South Island region to 7000 mm on the southern parts of the West Coast. Frost penetration of pavement layers is confined to central regions of both North and South Islands with a maximum recorded penetration of 400 mm in areas serviced by roads.

Soil Types

Naturally occurring soils vary widely throughout the country and in fact can change over a 10 m length of road. In Canterbury thick layers of gravel form the subgrade while in the Central North Island, volcanic ashes and pumice are the predominant soils. Further north large areas of swamp and very weak clayey soils predominate.

Geologically the South Island is much more mature than the North and consequently soil types are more stable in the South Island.

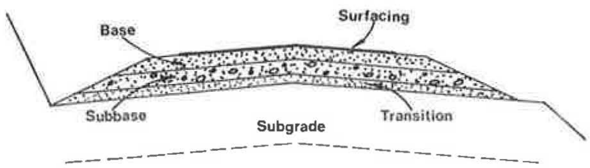
General Roading Type

Roads in New Zealand vary from just tracks suitable for four wheel drive vehicles, to modern motorways.

The unsealed road has generally been developed from cart tracks by grading and the application of maintenance aggregate. Of the sealed roads, 95% are surfaced with chip seals. The typical construction being subgrade, transition layer, subbase, base and surfacing (Figure 1). Many of these pavements so constructed were designed, but in the forties and fifties a "seal as is" policy was implemented in New Zealand to increase the total percentage of sealed roads.

A few concrete roads were built in the late twenties while in the late fifties to early sixties a number of pavement layers were cement stabilised.

Figure 1. A typical New Zealand pavement cross-section.



Surfacing - Thin bituminous chip seal.
Base - Quality unbound granular basecourse.
Subbase - Unbound granular material.
Transition - Graded layer to prevent fines from the subgrade migrating into the overlying layers.
Subgrade - That portion of the road formation, from formation level down one metre.
Basecourse - Unbound aggregate used as a base layer.

The Requirements of a Pavement

For the purposes of this paper, only thin surfaced or unsealed pavements incorporating unbound or bound layers will be considered.

For a pavement to be considered adequately designed it must be capable of retaining an acceptable (to the motorist) surface shape before the design life expires. In New Zealand basically three modes of pavement distress cause loss of shape in a thin surfaced flexible pavement, namely:

1. Failure of the surface allowing water infiltration (eg, by cracking);
2. Shallow shear within the pavement layers;
3. Deep seated (subgrade) deformation.

Assuming an adequate reseal cycle, pavements should be designed to resist the last two deformations for the vehicle loadings appropriate to the road.

The Purposes of Pavement Design

Design is not only an attempt to predict the performance of a system before it is constructed, but includes the best utilisation of available resources to yield an adequate structure. Even though pavements are different from most civil engineering structures in that they deform until the surface ride is no longer acceptable, some attempt at design is essential if premature surface deformation or shape change is to be avoided. In the past, pavement design has concentrated on the determination of thickness, based either on observation of local area performance, or design methods utilising limited laboratory testing of subgrade soils.

Pavement design is best approached by the selection of materials and structure thickness which will resist the modes of deformation. Whether new pavement is being constructed or an existing one upgraded, the design must recognise that deformation will occur. It is the control of the rate at which this occurs that is of prime concern.

Present Pavement Design and Material Use

Because of the limited funds available in New Zealand per kilometre of road, the practice has been to use local materials and minimal structural depths.

Unsealed Roads

Unsealed roads in New Zealand are seldom formally designed, but are maintained regularly by grader and maintenance aggregate added twice yearly at an average annual rate of 0.50 m^3 per kilometre per vehicle per day. Regular grading is essential to limit wheel path rutting, potholing and corrugation formation.

The quality of the running aggregate varies throughout the country such that some road controlling authorities are forced to use material which rapidly breaks down under traffic and the fines so formed are blown away. In other areas good aggregate is used, but it is pushed down into the subgrade over the winter period and lost.

Sealed Roads

Most existing thin surfaced roads have been designed on the basis of subgrade CBR values. Guidelines on pavement design are at present provided by the National Roads Board (2), while specifications provide for the quality control of materials to be used in a pavement. These specifications have been developed to allow the use of local materials especially in subbase layers.

Most pavements built in the last ten years have been designed as flexible using unbound materials. Acceptance of all but the basecourse has been predominantly on the soaked CBR value. The basecourse is accepted on grading control, sand equivalent, 10% fines limit and weathering resistance. In the last two years stabilisation of many local materials has changed the mode of pavement performance. The use of the CBR test as the acceptable criterion is now common for all cement or lime modified materials. This test may not appear the most appropriate but it at least provides some measure of shear resistance of the modified material.

General Pavement Performance

Most thin surfaced pavements have performed adequately to the end of their design life. Many road controlling authorities maintain a reasonable reseal cycle so that surfacing integrity is retained.

From trenching of deformed pavements it has been confirmed that the two main modes of distress are shallow shear in the basecourse and deep seated deformation with the predominant mode being found to be the former. Shallow shear appeared to be associated with low shear strength. This is confirmed by one hundred basecourses sampled from out-of-shape pavements in a local central North Island region where the soaked CBR's ranged from 3 to 30, thus clearly indicating the reason for loss of pavement shape. All the basecourses tested contained appreciable quantities of clay, which was probably produced by hydrothermal and hydrochemical degradation.

The Use of Stabilised Layers

For approximately 20 years, stabilised materials have been used in New Zealand road pavements (3). In the late 1950's and early 1960's considerable lengths of pavement were constructed using cement stabilised bases and subbases. Stabilisation declined in the late 1960's and early 1970's largely because of the lack of a clear concept of mode of action leading to concern at the development of reflective cracking. This decline continued until two years ago when renewed interest was shown especially in lime stabilisation. At the present time stabilisation is playing a developing role in New Zealand's roading construction and rehabilitation programme, and its use is expected to increase.

A stabilised layer can be located at any level in the pavement, or indeed the whole pavement above the natural subgrade may be treated.

Subgrade Treatment

1. By modifying the subgrade soil with small quantities of lime or cement, the sensitivity to ingress of water is reduced.

2. The addition of a stabiliser to the subgrade will increase the modulus (stiffness) of this top layer so formed which, although thin, will greatly reduce the rate of deformation in the untreated subgrade.

Subbase and Base Treatment

1. Both lime and cement improve the load spreading ability of an otherwise unbound material by increasing its modulus and tensile strength. With high lime contents and moderate cement contents, slab action can be developed, resulting in greater load spreadability of the pavement layer, provided intensive internal cracking can be avoided.

2. The addition of a stabiliser will also increase the shear strength of a material sufficiently to enable it to be used at a higher level in the pavement than that for the untreated material.

3. It would appear that lime and probably cement inhibit hydrochemical and hydrothermal degradation of aggregates. This means that presently unusable aggregates, after treatment, can be used in subbases and bases.

In designing any pavement with one or more stabilised layers it is essential that the original purpose of using a stabiliser is understood. It is not necessarily a process which will automatically bring about a pavement thickness reduction when compared with conventional unbound pavements, but is a system by which locally available material of otherwise unacceptable quality can be used in place of a higher grade and consequently more expensive unbound aggregate.

Likewise, it is not economic to over-stabilise a material. For this reason, Dunlop, (4) defined two distinct stabilisation phases namely; modified-soil and cemented-soil.

A modified-soil is one in which small amounts of stabiliser (.5-3.0 percent by mass) are used to correct a grading deficiency, reduce or eliminate plasticity, or provide a weak construction platform. In this definition, for a soil to be termed modified, the tensile strength of a lime treated soil after 14 days curing at 20°C must be less than 80 kPa. The same criterion applies to a cement modified-soil but the curing time should be seven days.

A cemented-soil has a tensile strength of greater than 80 kPa using the same curing conditions specified for the modified-soil.

Identifying Reactive Soils

Before attempting any stabilisation work it is essential to check that the soil is reactive to the proposed stabiliser. Most soils can be stabilised with either lime or cement, but soils containing organic matter do not usually react.

In New Zealand laboratory testing is undertaken before any soil is stabilised. If reactivity only is required a quick response test is specified (5), while for more accurate results detailed testing is required. For modified soils the CBR values are obtained on the untreated and then treated soil after a specified number of days curing and soaking. Increase in bearing of at least 100% indicates reactivity. If cemented soils are required then tensile testing with respect to time is carried out to check strength development.

Selection of Materials for Light Duty Pavements

Wide ranges of material types and design methods are available for thin surfaced flexible pavements. With limited cross-section and hence limited volume of materials per unit length, importation of materials from a significant distance incurs not only a transportation cost penalty, but the cartage of roading materials will often cause a substantial proportion of total pavement wear on the low volume road network. Therefore for overall economy a road controlling authority should aim to use local materials, either untreated or treated.

Untreated, modified and cemented materials each have their advantages and disadvantages. Examination of the disadvantages of each, in the local situation, is a suitable way of deciding on local policy. The principal disadvantages to be considered for each material are:

Totally unbound materials.

1. All subgrade variability must be dealt with by the superimposed pavement layers.

2. Nearly all unbound materials have substantial moisture sensitivity.

3. Easily won local materials can suffer substantial breakdown by hydrothermal and hydrochemical alteration (6).

4. Most naturally occurring materials when being won from a source (eg quarry) contain pockets of contaminants or low grade materials.

Modified-soil.

1. Require specific mixing/blending equipment and techniques needing change in job skills and management.

2. Design method needs modification to effect maximum available economies.

Cemented-soil.

1. All cemented-soil layers are affected by shrinkage and thermal strain changes.

2. The layers are subject to fatigue failure and are vulnerable to over-stressing caused by overloads (7).

3. Crack initiating defects are events which will usually have to be designed for, (8) and will cause up to 40% increase in the tensile strain at the bottom of a cemented layer. When such a defect progresses to full crack development, the vertical strain in the top of the subgrade is increased by a factor of up to 14 in the area immediately adjacent. If water filters down the

crack into the subgrade a concentrated soft spot develops with consequent loss of bearing.

4. Construction variability on the bottom of a cemented-soil layer (the critical zone for tensile based performance) must be carefully appraised and controlled. Both mixing and compaction are difficult at the bottom of an in situ mixed layer; Otte (9) indicates that a reduction of 30% in assigned strength should be used for design purposes.

5. Cemented soils increase in stiffness with time, accentuating the load attracting characteristics and hence likelihood of crack formation unless strength improvement matches the stiffness change.

6. Design method requires substantial sophistication, and sufficient testing and construction control to assure expected properties, if full economy of the process is to be realised.

7. Construction technique adaption is required as for modified-soils.

It can be concluded that both unbound and cemented-soil layers have problems which are not always easy to overcome. Take for instance the development of the up-side down pavement in which a cemented-soil layer is used as a subbase. It appears to be one more of accident than real design in that it was found that cemented bases produced large reflective cracks on the road surface. Therefore to overcome both thermal and shrinkage effects and the danger of reflective cracking the cemented layer has been buried under a granular base.

The writer would question the thousands of dollars which are now being, and have been spent on trying to accommodate an introduced problem layer. Hence the recommended use of a modified-soil with its superior shear strength, modulus and durability when compared to untreated unbound aggregate yet it is unlikely to cause reflective cracking even when used in the base.

Recommended Design for Flexible Pavements

Pavement design is developed in this section as a concept approach utilising locally available materials and its consistency with inservice performance is discussed in the following section.

Design for Unsurfaced Roads

An unsealed road must withstand environmental changes, traffic abrasion, and vehicle loadings. The motorist expects the road to remain free of potholes and corrugations, to be dust free and never become impassable.

The presently accepted New Zealand technique of applying maintenance aggregate once or twice yearly and regularly grading falls well short of the motorist's requirements of an acceptable ride, little dust and in some cases a passable road. Some roading authorities have now decided that an initial outlay of three times the annual maintenance bill per kilometre can stabilise the existing unsealed pavement to a depth of 200 mm with either lime or cement and produce overall savings within four years. This treatment also provides a much better service to the motorist.

For this type of treatment, design requirements are minimal, but the following steps need to be considered:

1. If the road is likely to be subjected to freeze-thaw cycles then stabilised layers should be used with caution. This problem can be overcome by overlaying the stabilised material with a depth of non-frost susceptible either unbound, or lime modified aggregate to a depth equivalent to the maximum frost penetration expected.

2. Check if the soil is reactive to lime; if not use cement.

3. Decide on stabiliser content on the basis that the top surface should not act as a slab. Normally 2-4% stabiliser is required.

4. Plan to construct late spring early summer to allow the stabilised layer time to develop strength before the winter.

5. Ensure that adequate water tables are formed before commencing construction.

6. Shape and compact the surface to a tight finish.

7. After one day roll into the surface a thin layer of clean large-sized running aggregate.

This procedure is applicable for roads carrying less than 500 vehicles per day.

In the first summer deformation in the wheel paths will occur and the dust problem will be similar to that experienced on an unbound unsealed road. Over the first winter lime stabilised material in particular can be re-shaped once the pavement becomes saturated. From this time on dust problems will be minimal and potholes and corrugations are very unlikely to develop.

Design for a Thin Surfaced Road

This section outlines the minimum input data required and then describes with the aid of Figure 3 the use of modified materials (defined by tensile strength not exceeding 80 kPa), in a Modified Design Approach for thin surfaced pavements.

Traffic Analysis. In determining the pavement loading prior to determining the required thickness it is desirable to obtain information on the present traffic volumes, the loading of the vehicles using the road, the expected growth rate and the desired design life. If a completely new road is being constructed then forecasts of traffic volumes need to be made.

Because of convenience and lack of evidence to the contrary, the AASHO road test data for axle load equivalencies should be used, in which all loads are related to an equivalent design axle (EDA) of 8200 kg.

Stage Construction. In obtaining pavement loadings it is desirable to consider the economics of stage construction. Normally a new flexible pavement would be designed for 15-20 years but a shorter design life should be evaluated. Many roading authorities are now considering stage construction in which the design life is reduced for the initial construction stage, and an overlay is programmed to be constructed after approximately ten years depending on traffic loadings.

The design life for a stage should take into account pavement deformation rate, surfacing life and residual life so that the next stage will become necessary only when full economic benefit has been obtained from the initial investment.

Environment. Variations in ambient temperatures do not appreciably change material properties of unbound material except in the upper 100 mm of the base. In this top layer temperature gradients can become quite high thus moving moisture through the unbound layer and changing its shear strength. Another factor which needs to be considered is the possible accumulation of water on the underside of the seal. It would appear from New Zealand experience this only becomes a problem when the basecourse layer is topped with fines whose high surface area available for water retention promotes seal lifting.

Increasing water contents has a detrimental effect on the subgrade whereas freezing and thawing can affect any pavement layer constructed of frost susceptible soils. When designing a pavement the designer must allow for adequate subsurface and surface drainage.

Material Characterisation

Subgrade Soil. Many investigators have demonstrated on full scale test pavements that linear elastic theory can be used to describe the subgrade response provided the modulus of the soil is determined under appropriate conditions. It is preferable that modulus values be obtained from either in situ or repeated loading laboratory tests. If this information is not available then the empirical relationship between modulus and CBR can be used.

$$E = 10 \times CBR \text{ MPa}$$

The other factor which needs defining is the permanent deformation in the subgrade. Claessen et al (10) have suggested the use of the following relationship:

$$e = 2.8 \times 10^2 \times N^{-0.25}$$

e = permissable compressive strain in subgrade

N = number of strain repetitions.

It must be remembered that strains developed in cohesive soils under repeated loadings depend on soil history, saturation and density. Therefore if a pavement is being placed on a dense over-consolidated soil subgrade then the permissible strain is increased.

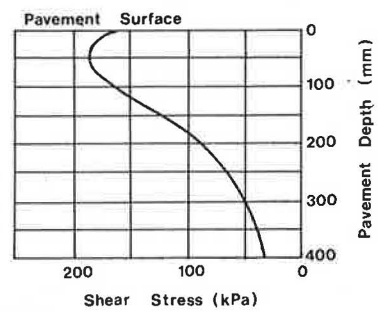
Normally a subgrade soil is subjected to relatively low stresses due to wheel loads, compared with overlying materials, so that shear failure is not possible. In thin pavements with cover thickness of less than 200 mm it is recommended that shear strength of the soil be checked.

Untreated and Modified Granular Layers. From research recently carried out in New Zealand (11) unbound and modified aggregates, after initial traffic compaction, tend to develop interparticle interlock which remains intact indefinitely provided adequate durability and shear strength of the material are retained. Therefore these two factors, durability and shear strength characterise an unbound or modified material.

As degradation occurs by physical, hydrochemical and hydrothermal means, no present known test adequately ranks aggregates for long term durability. In an attempt to overcome this present lack of an adequate durability test it is proposed that any unbound or modified-soil be subjected to a 12 cycle wetting and drying test (5) followed by petrographical analysis of the clay size particles. Ranking of these fines can be aided by the "clay index" system developed by Sameshima et al (6). It is suggested that a clay index of > 4.5 should be regarded as satisfactory. Inservice performance indicates that aggregates modified with cement and lime appear to develop an immunity to degradation.

In determining the suitability of the soil which has been subject to the wetting and drying test a simple shear test will provide adequate results. The tested soil shear strength should be at least twice the expected shear strength obtained in the appropriate pavement layer (Viz Figure 2, developed using linear elastic layered theory).

Figure 2. Maximum Shear Stress versus Depth for a Typical Unbound Pavement



Modified-Soil Subgrade Design. The design which is outlined in Figure 3 (Step 1) assumes that any subgrade with a CBR of five or less should be modified with a stabiliser, fabric or granular fill to produce a working platform with more uniform performance with respect to bearing and to provide a transition layer between the subgrade and overlying layers. In adopting a modified subgrade it is difficult to assess the strengthened layer's full potential. If lime is being used to stabilise a cohesive subgrade soil it can fairly safely be assumed that some tensile strength will be developed in the modified layer. This factor should therefore be used in design together with the natural subgrade and stabilised subgrade CBR values.

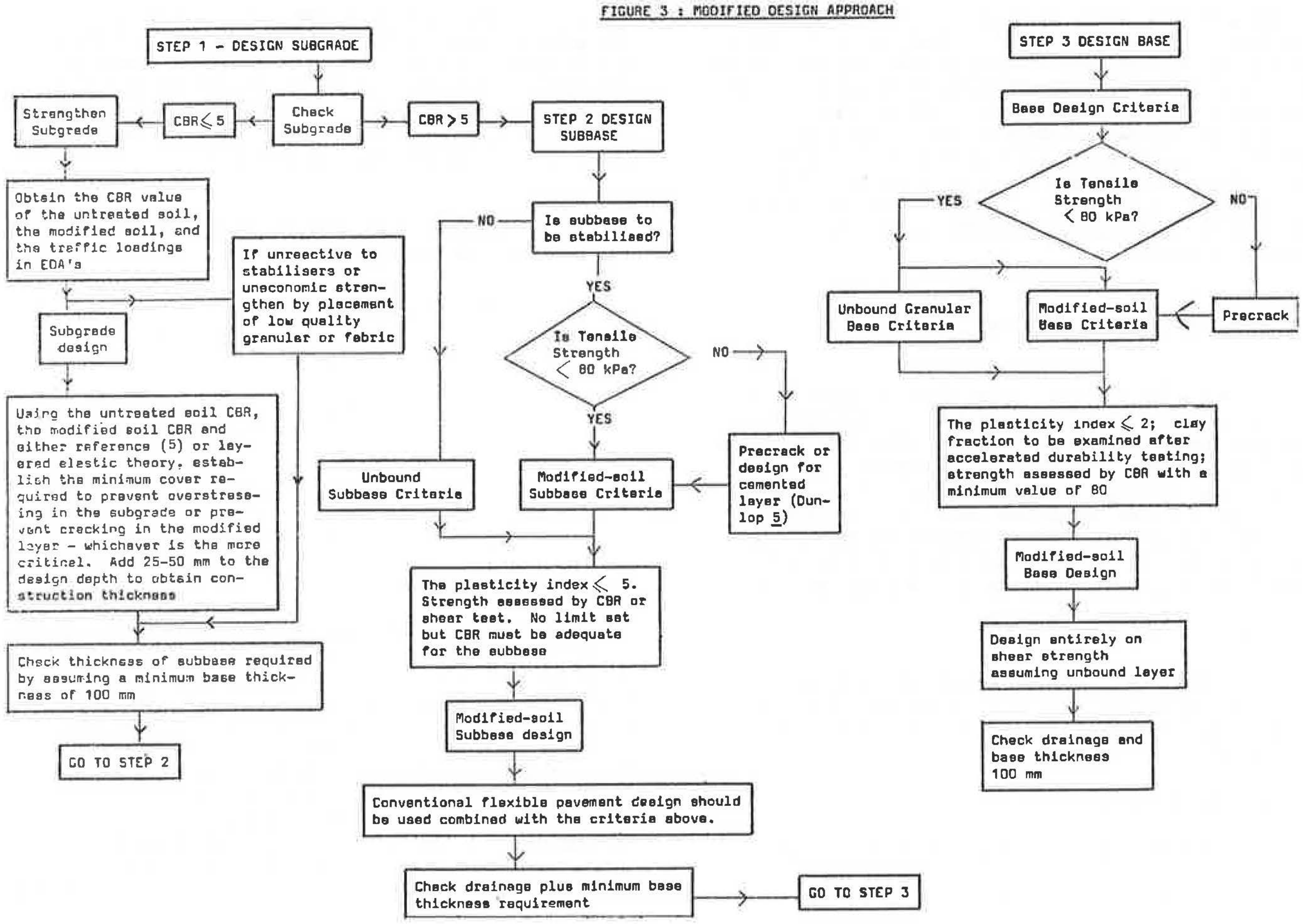
Reference (5) gives details of a simplified modified subgrade design approach, but a linear elastic multilayered program can be used in conjunction with limiting strain in the subgrade to obtain granular cover thickness. From this point it is essential to check that a subbase is required as some lightly trafficked roads need only a base layer.

Subbase Design. Step 2 on Figure 3 specifies the procedure for design of the subbase using unbound, modified-soil or cemented-soil pavement layers. Although unbound and cemented-soil layers are included, as suggested earlier in this paper a modified layer gives the best performance for capital outlay. An unbound subbase layer will be adequate provided durability and shear strength are maintained for the design life of the pavement. Both unbound and modified layers develop particle interlock which aids the load carrying ability of the layer yet does not produce undesirable reflective cracking.

Base Design. Design of the base follows down Step 3 of Figure 3 and is very similar to the subbase design. Again unbound and cemented-soil layers have been included, though the writer considers that precracking of the cemented base to form an essentially modified-soil layer is highly desirable. Precracking is the process by which a roller is used to deliberately crack a stabilised pavement layer into blocks of less than 100 mm square, thus preventing wide spaced reflective cracking.

In designing a base for a thin surfaced road it

FIGURE 3 : MODIFIED DESIGN APPROACH



is essential to determine long term durability and shear strength of the material being used. As suggested in the section on material characterisation, durability can be checked by an accelerated wetting and drying test and possibly limiting the plasticity index to less than 2. Unless large scale shear boxes are available it is suggested that a minimum CBR value of 80 be specified in conjunction with the durability requirements to ensure adequate shear strength in the base layer.

Drainage requirements of the whole pavement must also be checked to ensure that water which penetrates a cracked seal does not filter down into the subgrade and reduce bearing capacity. Also when stabilised subbase layers are used their low permeability with respect to the base may cause pore pressure dissipation problems which need to be overcome by attention to crossfalls, full construction widths and subsoil drainage.

Pavement Performance

The design concept introduced in the last section was based on many in-service observations of pavements and their performance. No design method is complete without feedback from observations of performance of constructed pavements with respect to loading and time.

Even though many "test sections" have in the past relied heavily on surface deflection and shape as performance criteria, a number of the more recent ones have been initiated with good start data. The use of "in-service" data is best demonstrated by examining the results of some test sections on a test track and on a number of roads in New Zealand.

Unsealed Pavements

In a number of recent trial sections on lightly trafficked county roads, attempts have been made to stabilise the top 150-200 mm with quicklime. After stabilising, the layer is compacted, cured and left unsealed.

One particular clay road in the Waipa County near Hamilton was treated this way with no aggregate being added to the under-designed pavement. After its second winter, its appearance is good with no potholing or corrugations. The road surface has cracked into approximately hexagonal paving block sizes and some wheel path rutting has occurred as predicted (Figure 4). While this road only carries 100 vehicles per day the savings in maintenance since completion has been approx. 60%.

In a number of other sections of road which have been lime stabilised, unbound aggregate layers of 50-100 mm have been placed over the stabilised layer to add pavement strength. Within a few months considerable potholing and corrugations developed in all sections indicating the deficiency of using an unbound base layer for an unsealed road.

The latest development has been to lime stabilise an existing unsealed road and one day after construction roll into the surface a one particle size layer of clean 37 mm aggregate. This aggregate provides resistance to traffic wheel abrasion and reduces dust loss in the summer.

Figure 4. Stabilised Unsealed Road Surface

Test Track Results

The circular test track at the University of Canterbury has been used to evaluate twelve different unbound basecourses under a standard 4.1 tonne dual wheel. The difficulty of laying basecourse and the extent of grading change with rolling was observed. It was found that refusal density could not be obtained by compaction plant, but was achieved before the pavement reached 10% of its design life (ie, traffic compaction plays an important role).

An interesting feature of this testing was the virtual lack of basecourse deformation which occurred after refusal density was obtained. This does not correspond with many studies carried out in the laboratory (12), in which samples have indicated considerable creep with accumulated traffic loading. It would appear that the densities achieved in laboratory samples are not as great as in the field, hence the continued recording of creep.

The other important point is the sensitivity of a basecourse to saturation. As the basecourse is compacted, the grading changes and more fines are produced. These fines will provide a large surface area for attraction of moisture hence dictating equilibrium moisture content. If traffic continues to compact an already dense partly saturated (by construction water) basecourse layer, instability has been shown to increase rapidly once saturation exceeds 80%.

On examination of the above results it is evident that there are many problems associated with constructing a basecourse with respect to minimising traffic densification and avoiding 80% saturation. These points tend to reinforce the modified-soil concept in which grading and moisture sensitivity are not important.

Quarry Road Test Sections

Bartley (13) in a report on 13 test sections at Quarry Road near Auckland, New Zealand, has outlined the problems associated with construction and performance of unbound, bitumen bound, foamed bitumen treated, asphaltic concrete and lime treated methods of overlay. It was apparent that materials which did not retain adequate shear strength, deformed by shallow shear. Likewise the low quality aggregates treated with 1% of hydrated lime have performed excellently in service and better than even the unbound high quality basecourses.

Bradley (14) in triaxial tests performed on both the good quality unbound and poor aggregate treated with lime found that the resilient moduli of saturated samples were 400 MPa and 1100 MPa respectively for a deviator stress of 250 kPa and a confining stress of 50 kPa. These laboratory results confirm field performance which indicates the advantages of using a material which can resist shear deformation under heavy wheel loadings.

East Coast Road Test Sections

In a series of eight test sections constructed (in 1969) and monitored in a co-operative project between Waitemata County Council and the Road Research Unit of the National Roads Board, New Zealand; bitumen treated basecourse, cement treated basecourse, local aggregates, lime stabilised subbases and conventional high quality unbound aggregates were used. From results presented in a report on this project by Malcolm et al (15) and subsequent information collected the following conclusions can be reached:

1. The bitumen treated conglomerate used as a base was found in post testing to have a soaked CBR value of 25. This treated material gave very poor performance as it deformed to an unacceptable level after 4 x 10^4 EDA.

2. The cement stabilised base cracked under imposed traffic loadings within the first six months.

At this stage a chip seal was applied and no further cracking has appeared on the surface. Performance has been excellent with very little visible rutting and no shallow shear failure. The 150 mm cement stabilised conglomerate layer over 50 mm of unbound conglomerate subbase on a measured CBR of 70 has carried 2.5 x 10^5 EDA without any signs of measurable deformation.

3. Of the unbound basecourses the performance appeared to be related to the layer thickness and the aggregate fines plasticity. Basecourse layers of 150 mm were found to be adequate while the 75 mm layer exhibited early shallow shear deformation. Likewise, the basecourse with a plasticity index of 11 also did not perform well to the extent that this section reached only one quarter of its expected design life.

4. The two sections containing lime stabilised subgrade (150 mm and 125 mm) performed well even with the minimal cover depths of 75 mm and 150 mm respectively. The most interesting point is that these two sections have carried a total of 2.3 x 10^5 EDA without showing any appreciable subgrade deformation even though water contents were high. These results substantiate the recommended design concept of modifying the subgrade to reduce sensitivity to water and improve load carrying ability.

General Comments on Pavement Performance

Many other case histories could be mentioned (4), but the following concluding comments will reflect the findings:

1. Unbound basecourses which produced soaked

CBR values of less than 50 when tested in the laboratory were providing unsatisfactory performance in service by exhibiting shallow shear deformations.

2. Many unbound aggregates which were apparently satisfactory before being placed in a pavement had deteriorated.

3. Neither lime nor cement stabilised aggregates have shown these changes in durability properties.

4. Stabilised shoulders appear to reduce incidence of edge breaks, shoulder wear and water infiltration under the sealed pavement.

Concluding Comments

This paper has attempted to outline the main deformation modes which cause loss of surface shape in unsealed and thin surfaced roads and then suggests design techniques which will limit the rate at which these deformations occur. In the development of stabilised surfacings it must be appreciated that their use should be confined to areas where frost penetration does not occur. Nevertheless many countries throughout the world do not have a freezing problem and therefore could benefit from the use of stabilised unsealed roads.

For a thin surfaced road the Modified Design Approach outlined in Figure 3 provides a designer with a simple method by which the typical low volume road can be designed. By improving the input data and design sophistication may be more predictable pavements could be built, but for roads carrying low traffic volumes it can be shown that very thin pavement depths are adequate.

Many of the analytical techniques employing high speed computers do not predict the performance of pavements built of unbound or modified materials. While the initial consolidation of a newly constructed subgrade (deep seated deformation) can be predicted the unique characteristics of unbound and modified materials appear to improve the pavement's overall performance over that predicted analytically. This could be attributed to particle interlock which tends to develop within a pavement layer to form a weak slab. Provided physical and chemical degradation do not occur the unbound or modified layer should last indefinitely.

In concluding that deep seated deformation will always occur the Modified Design Approach has suggested that every weak subgrade should be modified before being overlaid with the remaining pavement layers. By modifying the subgrade with lime, the rate at which deep seated deformation develops is reduced. The lime will improve the soil's sensitivity to water infiltration, even out bearing capacities in the subgrade, and prevent clay infiltration into upper unbound pavement layers.

To conclude, it should be emphasised that pavement design can be reduced to fundamental considerations providing the designer thinks about the structural design and then follows a method similar to that described in this paper. Observation of pavement performance is still and will be for many years to come one of the most valuable means by which the local practitioner can gain the necessary design skills. No designer with the aid of the most powerful computer, yet no appreciation of pavement mode of action and its likely performance in service, will produce an adequate pavement design at an economic level.

Also it must be emphasised that correct construction techniques, adequate quality control and good design are equally important as neglect of any phase will cause the performance of the pavement to suffer. Stabilised layers can play a major role in providing cost savings and longer pavement life when compared with conventional unbound construction. With the limited availability of high quality aggregates and the increasing cost of moving them to the construction site, use of modified local materials in the pavement structure must continue to increase.

Acknowledgement

The author acknowledges the permission of the Commissioner of Works to present this paper. It does not necessarily represent the policy or opinions of the National Roads Board or its servicing agency, the New Zealand Ministry of Works and Development.

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