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MANAGING RUTTING IN LOW VOLUME ROADS

Executive Summary

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PREFACE

The report that follows is an executive summary of the 2005 ROADEX II report on "Permanent Deformation". It aims to be a working manual, defining why rutting may take place in low volume pavements. Hence, it aims to provide advice for road owners and operators about means of overcoming rutting in newly constructed or reconstructed pavements by design and about assessing the likely future rutting in existing pavements.

The report is not intended to replace any text books or guidelines and specifications available on the subject but it is hoped that the material outlined will give the reader a greater understanding of the issues and solutions end especially the importance of this problem that is often not clearly understood.

The report was written by Andrew Dawson of the Nottingham Centre for Pavement Engineering at the University of Nottingham (UK) and by Pauli Kolisoja of the Tampere University of Technology, Finland. Ron Munro provided overall supervision as manager of the ROADEX III Project. Mika Pyhähuhta of Laboratorio Uleåborg designed the report layout.

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CONTENTS

1 Introduction

In the study areas of the Northern Periphery, unsealed or thinly-sealed road pavements are very common. Typically, these road structures are constructed from one, or more, layers of crushed stone aggregate laid on top of the subgrade (Figure 1.1). The surface of these pavements is either provided by the aggregate or by a thin bituminous seal into which stones of a uniform size are rolled. In both cases, the aggregate layers provide the major structural capability of the pavement.

Figure 1.1 Cross sectional view of a thinly sealed pavement. (Layer boundaries picked out by spray paint) (photo: courtesy S Erlingsson)

Compacted aggregate is a flexible material. If it is too weak, it tends to deform plastically, a little bit of plastic deformation occurring under each wheel loading. Little by little this accumulates and appears in the pavement as rutting. This type of behaviour is a feature of every layer. It is greatest if the applied stress level, under traffic wheels, is higher.

This report aims to explain why rutting occurs, the factors that influence it, and how it may be addressed by road owners and operators so that it becomes less significant.

2 Rutting

2.1 GENERAL

Rutting is highly undesirable in a pavement for several reasons (see Figure 2.1). Rutting gives problems to users by increasing the consumption of fuel and the risk of skidding (on water or on ice) – e.g. Figure 2.2. It also gives problems to the owner as ruts encourage water to soak into the pavement instead of draining off the surface; and this leads to rapid pavement deterioration. Water that enters the pavement in this way may collect in a 'buried' rut in the subgrade (see Figure 2.1) and/or reduce the load carrying capacity of the granular layers. The last of these is discussed further in this report.

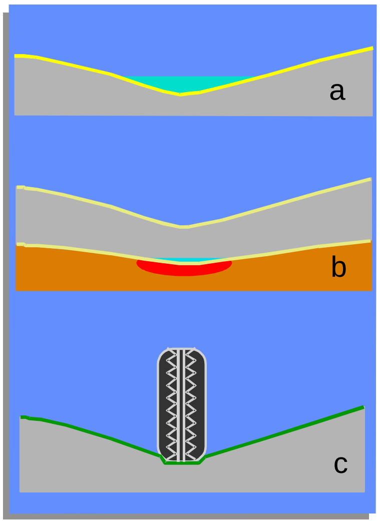


Figure 2.1. Reasons why rutting is undesirable:
(a=water in rut affecting trafficking;
b=water fed to lower pavement layers, weakening them;
c=increased tyre wear)

Furthermore, rutting of the aggregate and/or subgrade layers can lead to failure of the upper asphaltic layers (Figure 2.3). Less directly, rutting is usually not uniform along the length of the road so unevenness arises leading to user discomfort.

More friction is developed against the side of the tyre leading to higher rates of fuel consumption and tyre wear.

Figure 2.2. Water collecting in a wheel track of a thinly sealed pavement.

Figure 2.3. Rutting of a lower layers leads to distress in asphalt layers.

Rutting can occur for a number of reasons. Fundamentally there are four contributory mechanisms, which are here labeled as Modes 0, 1, 2 and 3. In practice, rutting is often due to a combination of modes at work. Each is now considered.

2.2 MODE 0

Compaction of non-saturated materials in the pavements can be a contributor to rutting (Figure 2.4). Normally compaction prior to trafficking is considered sufficient to prevent further compaction under trafficking. Furthermore this mode is self-stabilising - i.e. compaction under trafficking hinders further compaction (Figure 2.5). It also causes the material to stiffen and hence to spread load better. Better load spreading leads to a reduced stress on the subgrade, thereby reducing the amount and risk of rutting at that level.

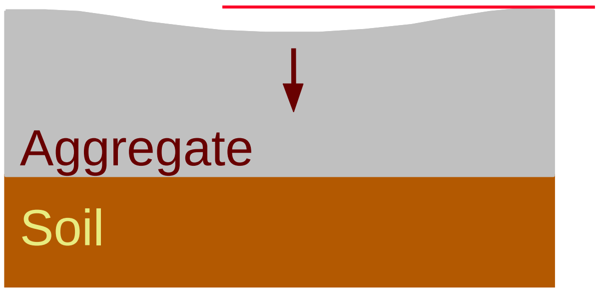


Figure 2.4. Mode 0 Rutting - compaction of

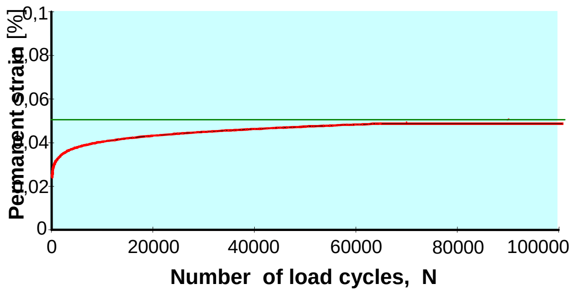


Figure 2.5. Permanent strain development for a crushed granodiorite

Rutting of this type is seen as a narrow depression relative to the original surface (Figure 2.4). The material affected is mostly near the wheel. Thus, for these reasons, a limited amount of rutting by this mode is beneficial. Good compaction minimises the amount of rutting observed.

In regions affected by frost penetration every winter, the frost, in combination with moisture, causes heaving. Latest results have revealed that, although usually observed in the subgrade, heave may also be seen in the aggregate layers, especially where water has earlier been absorbed by an unbound pavement structure. This heave leads to de-compaction of the aggregate layers. Thus, in the spring, when the frozen aggregate and subgrade thaws, compaction becomes possible allowing rutting of the Mode 0 type to develop. The natural variability of the subgrade leads to variable heave along the length of the pavement and, as a consequence, variable rutting.

Shear deformations (discussed below as Mode 1) may be associated with this Spring-thaw phenomenon as the loosened aggregate will be significantly weaker than in its compacted condition. This can lead to unacceptably large ruts after several years of Spring-thaw.

2.3 MODE 1

In weaker granular materials, local shear close to the wheel may occur. This gives rise to heave immediately adjacent to the wheel path (Figure 2.6). This rutting is mostly a consequence of inadequate shear strength in the aggregate relatively close to the pavement surface. Evidence from both trial pavements and from theory has demonstrated that the maximum shear movement occurs at a depth of approximately 1/3rd of the width of the wheel (or width of the wheel pair where twin tyres are used) – i.e. at a depth of ⊄15-20 cm. In pavements with significant traffic wander (wide lanes, roads with no markings, roads without existing ruts) the depth may be a little deeper. In pavements which have a significant asphalt layer the critical depth is likely to be rather deeper from the surface than a third of the wheel width due to the effects of the asphalt in changing the stress distribution within the pavement.

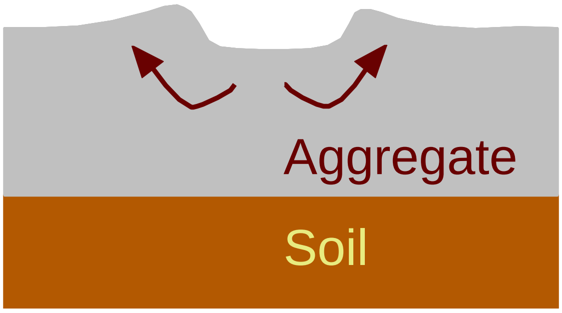


Figure 2.6. Mode 1 Rutting Shear deformation within the granular layers of the pavement, near the surface.

Figure 2.7. Scottish forest road exhibiting Mode 1 rutting. (photo: courtesy W Tyrrell)

Figures 2.7 and 2.8 show a Scottish pavement which exhibits this type of distress. Note the characteristic shoulder heave evident in the pictures. Internally such a pavement may look as in Figure 2.9. Here the local shear causing the 'shoulder' is clearly visible. There is no subgrade deformation evident (the yellow lines have been sprayed on to clarify the boundaries in

Figure 2.8. Close up of rut in Scottish forest pavement. (photo: courtesy W Tyrrell)

the picture).

In this mode, ideally, there would be no deformation at the subgrade surface. This type of rutting is frequently observed in the Nordic area that is affected by seasonal frost. There, in many cases, it is likely to be the main contributor to the accumulation of rutting when an aggregate of inadequate quality is loosing its load carrying capacity, for a short time, as it thaws in the Spring and contains excess moisture. For the rest of the year the same material, re-compacted (see Mode 0 above) and drained, is likely to have an entirely adequate performance.

Figure 2.9. The pavement of Figures 2.7 & 2.8 seen in cross-section. (Layer boundaries picked out by spray-paint) (photo: courtesy W Tyrrell)

The only remedy for such rutting is to improve the aggregate or by reducing the tyre imposed stresses. Subgrade treatment will have no effect on this mode of rutting. The granular material may be improved by compaction (within limits), by stabilisation, by the use of a geosynthetic reinforcement or by improving the conditions which control its behaviour – e.g. by drainage. The parent report of which this document is an executive summary has more details [see Dawson & Kolisoja, 2005]. If none of these approaches is effective, the aggregate may have to be replaced. Alternatively, tyre pressures can be lowered.

2.4 MODE 2

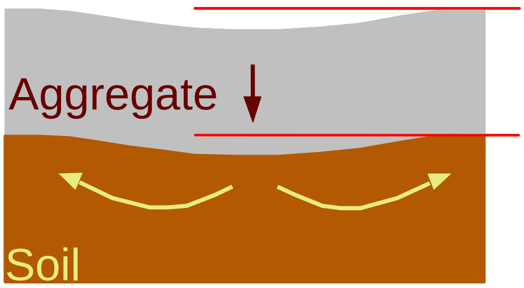


Figure 2.10. Mode 2 rutting - Shear deformation within the subgrade with the granular layer following the subgrade.

Figure 2.11. An advanced case of Mode 2 rutting seen in an exhumed pavement with a very weak subgrade. (photo: courtesy W Tyrrell)

When aggregate quality is better, then the pavement as a whole may rut. Figure 2.10 shows an idealised view of the subgrade deforming, while the granular layer(s) deflect bodily on it (i.e. without any thinning). The surface deflection pattern is of a broad rut with slight heave remote from the wheel (as it is the displacement of the soil which causes this). An extreme example of this type of failure can be seen in Figure 2.11. In this case the surface rut has been repeatedly infilled, but rutting at the subgrade surface has continued with aggregate following this. The subgrade has had to squeeze upwards between the wheel tracks and in the margin – a very advanced example of the rotational shear within the subgrade, which is shown by the arrows in Figure 2.10.

In regions affected by deep seasonal frost, the Spring thaw problem discussed above can lead to Mode 2 rutting of the subgrade. In such situations excess Mode 2 rutting may be seen only in the Spring when subgrades are softened for a few weeks by excess moisture consequent upon thawing.

The solution to this type of rutting is to improve or thicken the aggregate so that the wheel loads are spread better. Then the stress on the subgrade will be less. Another method is to restrict high axle loads (not tyre stresses) as these are the principal influences on stress at depth.

2.5 MODE 3

Particle damage (e.g. attrition or abrasion, perhaps by studded tyres) can be a contributor to the same surface manifestation as seen in Mode 0 rutting (Figure 2.4) though, of course, the mechanism is very different. If excess fines are generated the pore spaces in the aggregate may clog and then the aggregate will become more moisture susceptible.

2.6 COMBINED MODES

In practice rutting will be a combination of the above mechanisms. Data from some trial pavements in Scotland showed, on exhumation, both the thinning of the granular layer (Mode 1) and depression of the subgrade (Mode 2) – see Figure 2.12. The localised heave (or ‘shoulder’) close to the wheel path is clearly visible as is a reduced

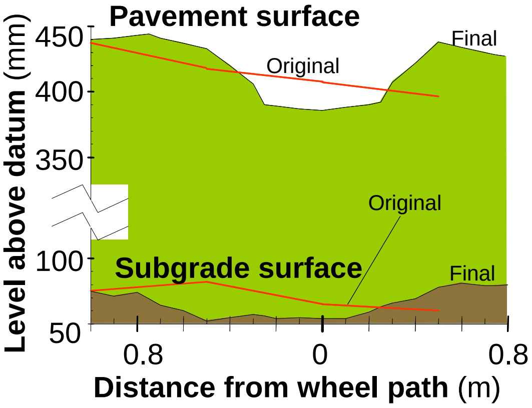


Figure 2.12. Rut observed on exhumation

deformation of the subgrade compared to the surface depression.

It is expected, and to some extent observed, that Mode 1 will be more evident with canalised trafficking (e.g. as is the case with many forest roads) where wheel wander is not available to displace-back, and generally compact, aggregate (Mode 0). Conversely, Mode 2 is expected to be more evident under wandering traffic with Mode 0 more likely to make a contribution in this case as the "kneading action" of a wandering tyre is more effective in achieving compaction.

3 Granular Pavement Layers

The structural layers of the pavements addressed by this report are almost invariably formed of compacted, granular material. This will have been sourced either from alluvial or glacial sand and gravel deposits or from rock quarries (Figs 3.1 – 3.4) and then fully or partially crushed. In either event the long distances to established, commercial, aggregate production centres will often mean that there is pressure to source aggregate locally in order to reduce costs. In such circumstances the material used may be less than ideal.

Figure 3.1. Glacial gravels being excavated from an esker deposit, Sweden.

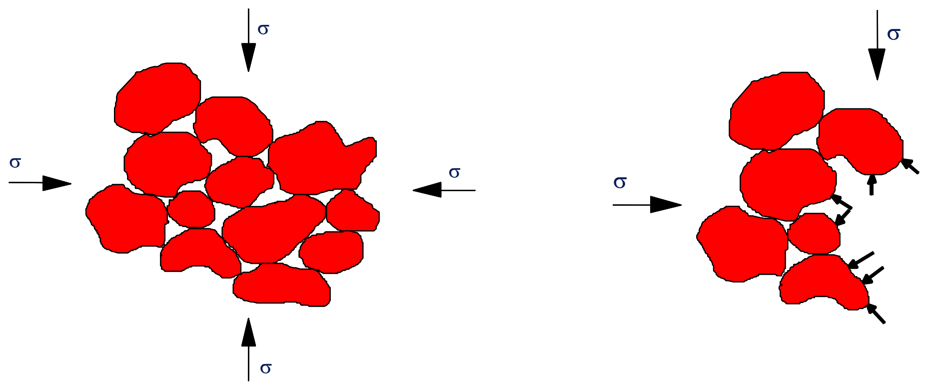
Figure 3.2. Metamorphic crushed rock quarry (greywacke-shale) at Balunton, Scotland. (photo: courtesy W Tyrrell).

Figure 3.3. Alluvial gravel after partial crushing.

Figure 3.4. Partially crushed alluvial gravel in an unsealed pavement.

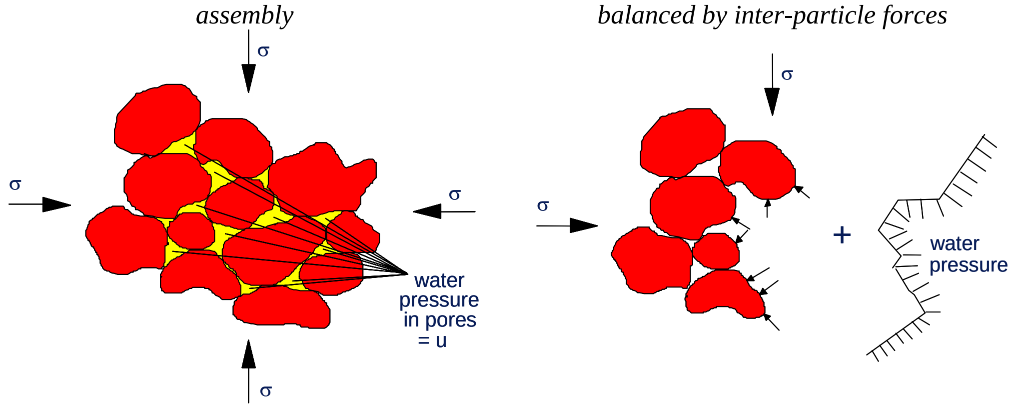
Because aggregate is a geotechnical material it suffers the same limitations as other soils – in particular it is weakened by excess water in the voids between the stone particles. Under traffic loading the water becomes pressurised and this pressure in the pores between aggregate pieces opposes the stress, which is pushing the stones together (Figure 3.5). Thus the contact stresses between particles are not as large as they might be. In turn, this means that inter-particle friction is less than desirable meaning that the frictional strength and resistance to deformation is reduced from appropriate levels. In effect, the water in the pores can turn a good quality granular material into a poor one.

A further concern comes from the size of particles, which make up the aggregate. If stones are large then the pores between them also tend to be large. Water drains easily in this case and, hence, the resistance to rutting, even in moderately wet conditions, will usually be quite good. On the other hand, fine-grained aggregates tend to hold water (even sucking water into their pores due to capillary effects) and, thus, are frequently poor performers in wet weather and, especially, during the thawing period after seasonal frost.



External stress applied to a granular assembly

The same assembly split and balanced by inter-particle forces



External stress applied to a granular assembly with water in pores

The same assembly split and balanced by internal water pressure and smaller inter-particle forces

Figure 3.5. The importance of low pore water pressure to ensure good inter-particle stresses and, hence, good frictional characteristics.

4 Climatic Effects

In the Northern Periphery area climate has a significant effect on most aspects of construction. Road pavements are no exception to this rule. There are two main effects of concern:

4.1 RAINFALL

Rain will tend to enter the pavement construction. In finer grained aggregates the capillary suction effects will help to draw water into the construction. The effect may be a little less pronounced when the surface is sealed with a bituminous layer, but these seals easily crack and let water in. It is impossible to avoid this problem entirely but coarse aggregate, good cross-falls (>4%) and a sealed surface (or an unsealed surface with a compacted fine aggregate to provide a partial seal) will all assist in limiting the ingress of rainwater. Operating drains are also important. Most pavements are built with some kind of drainage, perhaps in the form of a lateral ditch. However, limited budgets mean that maintenance may not take place so that, in time, drainage no longer takes place as intended. There is, almost certainly, an “out-of-sight, out-of-mind” aspect to this lack of ongoing attention. There is a separate Roadex II report [Berntsen et al, 2005] dealing with drainage which discusses these aspects in a lot more detail. There is also an executive summary in the same series as this summary [Aho & Saarenketo, 2006].

4.2 FROST

Cold weather will cause water in the pavement to freeze. As the frozen front moves downwards in the pavement due to a long, cold period, suctions are established which suck water towards the freezing front. By this means excess water collects in the pavement as ice. When thawing commences in the spring, this water tends to be trapped in the pores of the aggregate and cannot leave as the pavement’s drainage system remains frozen. Once again, a possible remedy is a coarser aggregate in which suction is less easily developed. In particular, a coarse aggregate layer at the bottom of the granular layers can act as a capillary break, cutting off the supply of water to the freezing front that exists higher up in those granular layers.

In both cases the problem is excess water causing frictional strength to decrease (Figure 3.5) and, hence, for rutting to occur more quickly and/or more severely.

Figure 4.1 shows temperature, rainfall and internally available moisture in a pavement construction. The effect of freezing and the high moisture immediately after thawing is apparent. The effect of heavy rainstorms can also be seen in some temporary increases in pavement moisture. The higher fines content of the sub-base can also be seen to lead to higher moisture content throughout and a greater 'reluctance' to drain after high moisture content occurs.

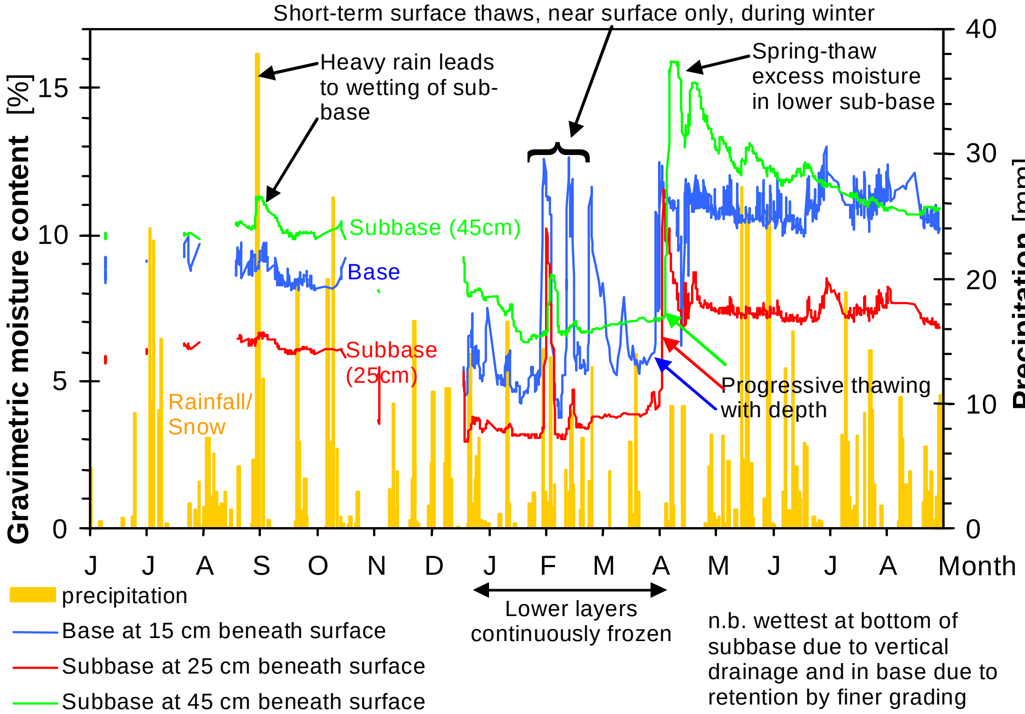


Figure 4.1.Environmental data for a pavement section over a period of 14 months showing free gravimetric moisture content, as indicated by TDR sensors, at three depths, together with the precipitation. [COURAGE, 1999]

Figure 4.1 indicates that, even in winter, there is some unfrozen water in the pavement, as much as 5%. This figure is almost certainly incorrect and is a consequence of limitations in the instrumentation and interpretation techniques. In fact unfrozen pore water probably accounts for less than 0.5% of the soil by volume.

5 Laboratory and Analytical Study

The aim of the study is to provide advice to road owners and operators on the maintenance and material selection practices which can give rise to poorly performing pavements and those which can give rise to better performance. A simple means of evaluating the likelihood of excessive permanent deformation is aimed for so that owners will have an approach for assessing existing pavements, for strengthening design, for dimensioning public low volume and private forest road pavements and a means of setting appropriate load limits when pavements are in poor condition.

To achieve this it was decided use data available from a variety of aggregates and many previous projects and to supplement this with specific testing of two aggregates that had been prepared at differing grain sizes and differing moisture conditions. The results were used to calculate the stress conditions in the pavement under typical truck traffic and this enabled an estimation of the likelihood of rutting.

5.1 STUDY METHODS

The principal study method involved:

- testing the aggregates to find out their responses to repeated stressing,
- use of the results obtained to calculate the stresses in pavements constructed of those aggregates,
- deducing those parts of the pavement structure which would be under stresses likely to cause plastic (irrecoverable) strains,
- calculating the amount of the pavement structure that would deform under these strains, thereby giving rise to rutting,
- relating the results from simple assessment methods to those from the tests used in the project to assess the aggregates. This was in order that there was a means of determining a road construction or subgrade soil material's potential for rutting without resorting to advanced laboratory tests,
- drawing general conclusions and advice from the study, in particular formulating a design and assessment procedure.

There is insufficient space in this summary report to present all the details of this work. Furthermore, including this information would be likely to detract from the aim of giving a clear overview. Therefore little detail is included in this report and readers are referred to the parent report [Dawson & Kolisoja, 2005] of which the present document is the executive summary if they wish to know about the details of the testing and analysis.

5.2 MATERIALS

Two aggregates were tested specifically for the purposes of this project. One was a moderate quality metamorphic aggregate from Scotland and other was a higher quality Norwegian crushed gravel aggregate. In addition the authors have drawn on data from several other aggregates from several countries including those used at the site of the environmental pavement condition station (‘Percostation’) in Northern Finland. Together, the data covers a wide range of geological origins, grain size, stone quality, shape, etc. The majority of materials from which the conclusions of this report derive have a crushed rock origin, but some sand and gravel type aggregate has also been studied. The aggregates were tested at a range of moisture contents and particles sizes while some were tested after freezing and thawing.

5.3 TEST METHODS

The most common test used was the repeated load triaxial test which measures the development of permanent deformation. This is a laboratory device capable of simulating the effect of repeated trafficking of an aggregate by many thousands of vehicles. It can achieve this simulation in only a few hours. The aggregate can be kept at stress and moisture conditions similar to those experienced in the road. Tests were performed on the various aggregates at various moisture conditions, some after freezing and thawing, and at various levels of stress – each stress pulse being repeatedly applied many times. Several other types of test were performed including strength and modulus (stiffness) tests, grading tests, compaction studies and dielectric assessments (by the Tube suction apparatus).

5.4 TEST RESULTS

From these tests it was shown that dielectric value can give an indirect indication of mechanical performance. From the study it is proposed that dielectric values are set (Saarenketo, et al. 1998) so as to exclude the poorest granular aggregates from being considered in detail for road construction. Values >9 are probably associated with a somewhat poor resistance to permanent deformation. This is likely to lead to unacceptable behaviour in areas with freeze-thaw cycles in Winter. A value >16 is definitely associated with unacceptably poor resistance to permanent deformation in all climatic conditions.

Stiffness Behaviour

The testing showed a very clear change in mechanical behaviour with added fine particles and extra moisture. It was found that the aggregates with more fine particles reached much higher water contents because the finer pores between the particles were able to hold more water than is possible in coarser mixtures.

As more water is put into a specimen, the material's stiffness reduces. In practice this means that finer aggregates will tend to be wetter aggregates and that layers in the pavement comprised of such aggregate won't spread the load so well. In turn, this means that the stresses on the subgrade will be greater. Larger stresses on the subgrade will lead to increased subgrade rutting (Mode 2 failure described in Section 2).

Plastic Behaviour

Under many cycles of repeated loading, as experienced by a pavement during trafficking, plastic deformation accumulates incrementally. Figure 5.1 shows the types of response seen. Range A behaviour is the desirable one because deformation (seen in the pavement as rutting) takes place initially but finally stops. The amount of deformation (rutting) to which Range A type behaviour finally stabilises is very dependent on the amount of water in the aggregate.

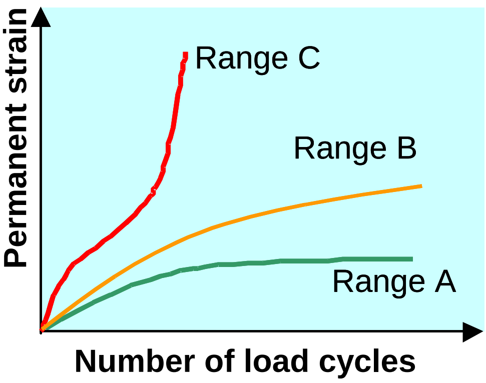


Figure 5.1. Indicative permanent strain behaviour

Analysis and experience of granular pavements shows that few, if any, aggregates can provide Range A behaviour directly under trafficking. Instead, Range B behaviour is likely for a well-behaved unsealed or thinly sealed pavement. Range A behaviour may be achieved under a thicker asphalt (e.g. > 80mm). The aim of the engineer with an unsealed or thinly sealed pavement should be, therefore, to obtain Range B type behaviour, not Range C which leads to rapid collapse of the pavement. Furthermore the engineer needs to keep the slope of the Range B line as shallow as possible, thereby prolonging the pavement's life.

It was found that proximity (close-ness) to static failure is very important in the development of plastic deformation. When a certain stress was repeatedly applied to a specimen of aggregate the specimen suffered some plastic strain. When a specimen at the same moisture and grading state was subjected to a higher repeatedly applied stress level, the plastic strain level was higher. The rate at which plastic strain accumulates was found to relate quite well to the proximity of the applied stress state to the stress conditions which are needed to cause failure under a single load.

In summary, it has been found from both materials studied in detail in this investigation, and drawing on information available from other sources, that the amount of plastic strain in an aggregate increases:

- When the aggregate gets wetter,
- When the aggregate has been frozen and then is thawed.
- When the stress applied gets closer to the static failure stress condition.

For design purposes, taking into account the various findings given above, it would be sensible to ensure that the stress experienced by any zone of aggregate in the pavement doesn't exceed a certain fraction of the failure stress. Previous researchers have suggested that the applied "deviatoric" (or shear) stress applied is limited to 70% of that needed to induce static failure under, in other respects, the same conditions. The data obtained in this study suggests that this may, indeed, be a sensible determination. However, the materials tested in this project suggest that this limit should be set at only 50-55% when the aggregate is very wet and fines prevent rapid drainage, or during Spring thaw conditions, if the amount of rutting is to be kept small. The Tube Suction results are also useful in determining whether the aggregate can be considered 'wet/fine' or 'normal' (i.e. does the 50-55% stress limit apply or the 70% limit?). The results suggest that a dielectric value of <9 (often associated with a void ratio of >0.33) defines this boundary.

5.5 PAVEMENT ANALYSIS

The resilient data (modulus values) obtained from the laboratory testing were used in a computer model to predict the stress levels in different kinds and thicknesses of pavements. The analyses were performed with asphalt thicknesses varying from almost zero (1mm) to 200mm, but only the results from the thinner asphalt pavements are of real use in this project.

5.6 RESULTS OF PAVEMENT ANALYSIS

From the computer analysis of the pavements it is possible to calculate the stresses within them. The calculation is not very simple because the aggregate has a modulus (stiffness) which depends on the stress it experiences and the stress in turn depends, in part, on the modulus, so an iterative analysis is needed. Once a balanced set of stresses and moduli has been found, the likely rate of build up of plastic strain can be estimated at any point in the aggregate of the pavement using repeated load triaxial test data.

Observations on Rutting in the Aggregate Layer (Mode 1)

The calculations showed that an asphalt layer needs to be greater than a threshold thickness (perhaps >4cm) if it is going to achieve effective load spreading and significantly reduce stress on the lower aggregate base layers. Otherwise it acts as a seal but isn't effective in protecting the aggregate from high stresses due to traffic.

As explained in Section 5.4, proximity to static failure is closely related to the rate at which rutting develops. The analyses showed that the aggregate is closest to static failure at a depth of 10cm or 15cm into the pavement (around 9 and 14cm respectively into the aggregate). So, it is at this depth that the designer needs to lower the stress level, away from the failure line, in order to reduce the onset of rutting within the aggregate layer. This might be achieved by moving the failure line (e.g. by improving the granular material by, for example, drainage or stabilisation) or by placing a thicker asphalt layer to move the aggregate stress condition lower.

As an example, this approach was taken for a Scottish aggregate. When in a fairly dry state with a moderate amount of fine particles, the maximum stress was between approximately 65% (2cm asphalt) and 80% (1cm asphalt) of that needed to cause static failure. Site observations of the behaviour of this material reveal that it does tend to rut under traffic, particularly in wet weather. Given the in-situ experience, a criterion of 75-80% of static failure strength might be appropriate for this material to prevent rutting. This is in line with published ratio values from other sources.

Observations on Rutting in the Subgrade (Mode 2)

As the aggregate layer is thickened, so the stress on the subgrade reduces. Analyses were performed with varying thicknesses of the aggregate and the induced stress at the top of the subgrade was calculated for many of the different aggregates tested in the laboratory. The results show, very clearly, that a reduction in moisture and in the proportion of fine particles leads to aggregates that can spread the traffic load much better, reducing the stress on the subgrade. The calculations also tell us that the thickness of the aggregate layers must be increased by between 14% and 73% from the thickness needed of a reasonably dry, open-graded, aggregate. An increase in thickness of between 85% and 92% was calculated as necessary for an aggregate that had been frozen then thawed. Aggregates with a higher proportion of fines gave similar required thicknesses to those given for the wet aggregates. Therefore, cleaner and dryer materials can be used more thinly to gain the same performance as regards Mode 2 (subgrade) rutting. Sometimes the thickness could be almost halved and the same rutting performance achieved.

6 A Simplified Approach for Implementation

Building on the laboratory test results, the computer analyses, published data and the experience of the study team, a procedure has been developed to implement the findings. In effect, a simplified procedure has been developed that tries to bring together the fundamental understanding of material behaviour, rut development modes and stress analysis in a manner that is practical for engineers in the Northern Periphery to use. It is very unlikely that such engineers will have time, nor budget, nor expertise, nor access to equipment to undertake a study as performed in this project. So the proposed procedure relates the approach outlined in Section 5 with simplified techniques.

Figure 6.1 The Tube Suction Meter

The sensitivity to moisture should be determined using the Tube Suction Test (see Fig. 6.1) (although void ratio may be used as a first approximation to drainability). A specimen of aggregate is compacted, wetted and then allowed to drain. If the dielectric value from the Tube Suction Test is high after this action, then poor performance is to be expected. The extent of performance (good or bad) can be determined in the following manner.

To know what the stresses are in the aggregate layers of pavement, near the wheel, charts of stresses likely to be found in the pavement is provided to replace the Finite Element analysis (Fig 6.2). The use of theses charts is described in

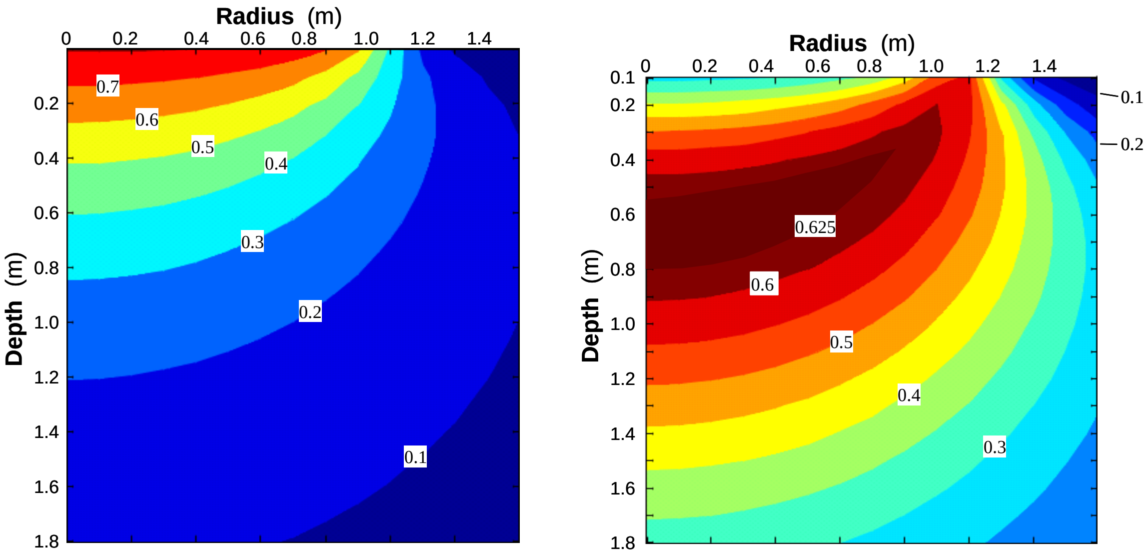


Figure 6.2. Stresses (expressed as a fraction of tyre pressure) beneath a loaded area 1m in radius. Left = average stress. Right = deviatoric stress

detail in more detail in the parent report of which this document is an executive summary [Dawson & Kolisoja, 2005] . Boussinesq's stress analysis is the basis of the charts as that analysis doesn't require the modulus (stiffness) values of the aggregate to be known. This method doesn't work if there is an asphalt layer as Boussinesq's approach assumes that there is only one layer in the pavement, but it does approximate the unsealed pavement's stresses which is a more critical case.

Figure 6.3 The Dynamic Cone Penetrometer (DCP)

To assess the strength of the aggregate the Dynamic Cone Penetrometer test (see Fig 6.3) is recommended as a simple, in-situ, method that gives a quick (although not very accurate) measure. The stress may then be compared to the available strength and aggregate adequacy for the pavement use can be determined.

These steps allow the aggregate to be assessed and, if necessary, improvement or stress-reduction (e.g. by asphalt surfacing) to be planned. For the subgrade the stress applied may be computed using a simple, publicly available stress analysis program for a PC. The strength of the subgrade may be measured by (e.g.) vane testing of clay soils. A comparison of the two values can then be used to thicken the aggregate layer until the stress on the subgrade is reduced to a tolerable level.

The overall procedure, using the methods just introduced, is summarised in a flow chart as Figure 6.4.

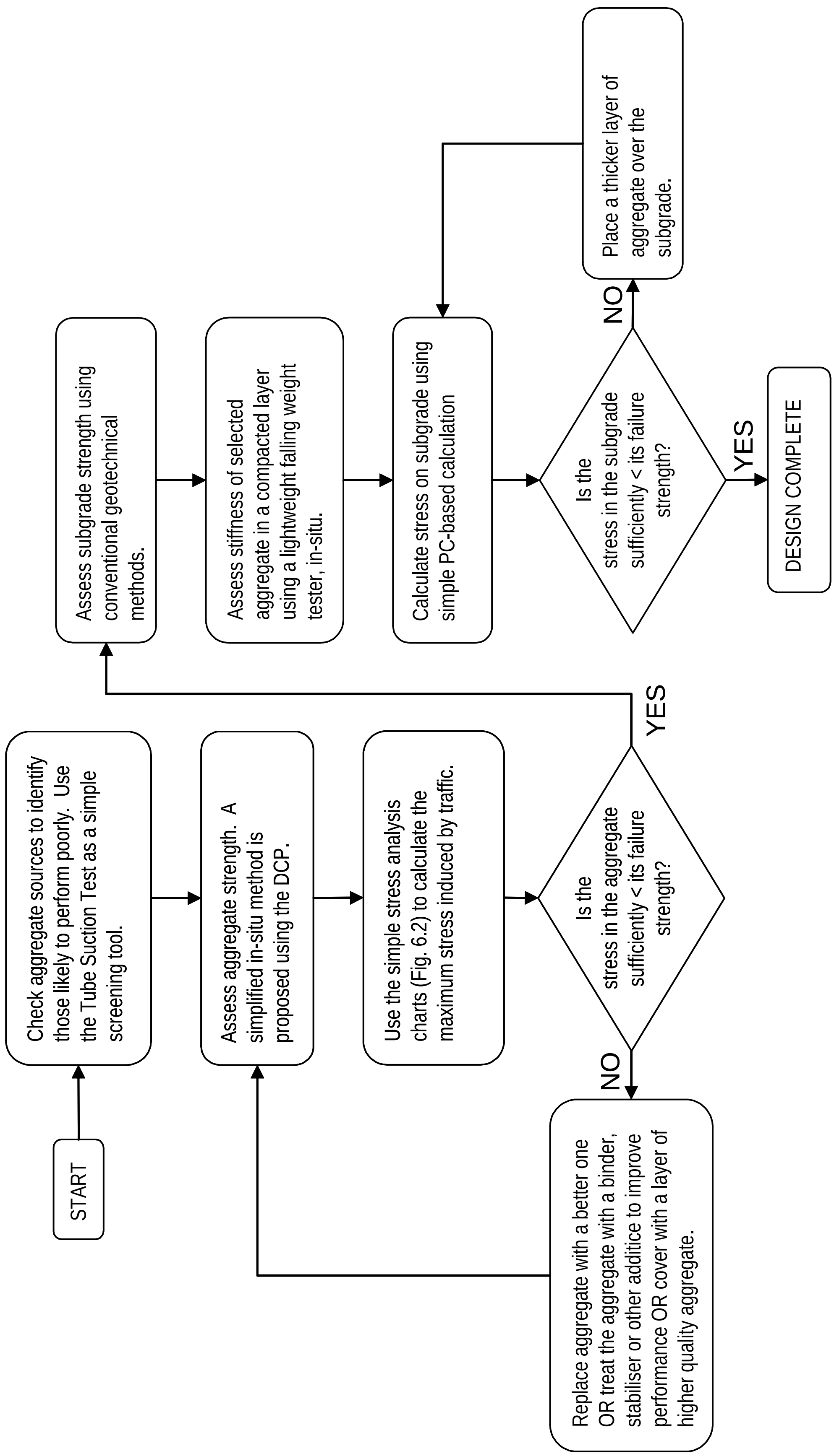


Figure 6.4 Summary flow chart showing design / assessment procedure

7 Pavement Rehabilitation

Many engineers will be more concerned with the maintenance and rehabilitation of their existing pavements than in new-build design. In principle, the same approach may be used - assessing pavements in-situ by DCP (aggregate) and vane testing (clay and silt subgrades) and predicting subsequent performance in the same manner as given. If the design thickness is too small and subgrade rutting is indicated, then overlaying to produce the required thickness will be indicated. If the quality of the aggregate is too low then extra thickness of aggregate can be placed on the surface and the method just introduced can be used to check that the stress placed on the old, buried, aggregate is acceptable.

Tube Suction testing of the aggregate materials can also be performed to check for moisture sensitivity.

In general, it will be necessary for the engineer to ensure that a representative material is sampled from the road. This will not necessarily be an easy task as segregation of unsealed pavement aggregate due to trafficking and re-profiling will often give a-typical gradings across the pavement whilst frost, pumping and rutting disturbance may all cause uneven distribution of fines through the depth of the pavement.

8 Conclusion

The investigation, laboratory testing, computer analysis and interpretation presented here aim to provide a simplified method of pavement design for low-volume road pavements in the Northern Periphery that derives from a sound theoretical understanding. Empirical approaches have much value, but do not help to generate understanding of the key concepts, influences and responses. Therefore, by combining the best of theory and empiricism the approach outlined seeks to provide a practical advance for engineering staff responsible low-volume roads such as those found in northern Europe.

There remains further work to be done in tuning the parameter values suggested here and in the parent report to real sites. Nevertheless, it is hoped that the data presented here will provide encouragement to assess materials in the ways described and to match predicted performance to real performance. In this way longer term benefit should arise if marginal materials can be incorporated into highway constructions with a greater degree of assurance that they are at positions or under loads and conditions that they can tolerate without undergoing significant rutting themselves. Similarly, longer term benefit should arise if these materials can be used in a manner that will help to prevent rutting of the underlying subgrade.