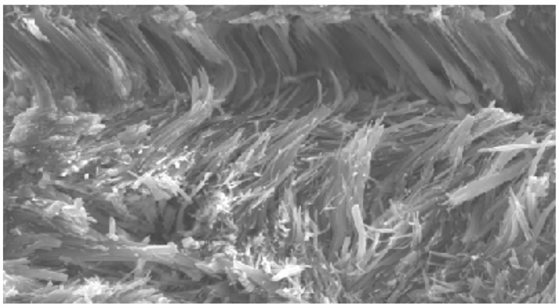
The Road to the Future

Manual for working with RoadCem



www.powercem.com

PowerCem Technologies
Innovations for better solutions!

Postbus 6039 - 4780 LA Moerdijk
Plaza 24 - 4782 SK Moerdijk
Telefoon +31(0)168 409440
Fax +31(0)168 358600
info@powercem.com

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Authors: P. Marjanovic, C.E.G. Egyed, P. de La Roij, R. de La Roij
NUR-code: 956
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Editor: R. de La Roij
Plaza 24
4782 SK Moerdijk
The Netherlands

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“My country was never so rich that it could afford poor roads”

William the Conqueror 1066

Foreword

"JUST AS ENERGY IS THE BASIS OF LIFE ITSELF, AND IDEAS THE SOURCE OF INNOVATION, SO IS INNOVATION THE VITAL SPARK OF ALL HUMAN CHANGE, IMPROVEMENT AND PROGRESS",
"INNOVATION IS THE ABILITY TO SEE CHANGE AS AN OPPORTUNITY NOT A THREAT"

In their search for a better life people are always looking for better products and services. It is a lifelong pastime for everyone.

In the shop we look for the best product that we can find to meet our needs. On the road we look for a faster or shorter route or both. We choose the restaurant where we go for dinner by the quality of the waiter service and the atmosphere in the restaurant more often than by the quality and quantity of food in the portion served. Our life is a permanent search for improvement of some kind. In this we are often influenced by the advertisements and marketing that a producer of a product or a service has invested in. In principle, we make the choices we do on the basis of information we have, and our understanding and interpretation of that information. In effect, our choices and subsequently the success of a product and/or service is to a large extent determined by the quality of information the user has about it and also by the inherent characteristics of the product/service that this information is trying to convene.

In practice we often buy a product or a service without knowing that there is a better one available, purely because we do not have the necessary information. In our private life as a customer, we let ourselves be tempted and maybe even mislead when buying food, soft drinks, electrical goods, cars, houses, etc. In our professional life as client, we may choose one product where another might have been more suitable. Being under pressure for time or not wanting to take a risk with an unknown product we base our choice on what we know, on the information we have and our ability to interpret it adequately.

In line with the above it may be concluded that the biggest barrier for the success of new and innovative products and/or services is in fact the information about these products and/or services and its quality.

As professor of Environmental Engineering at the University of the Witwatersrand in Johannesburg, South Africa, I have always looked at innovation as a critical aspect of a sustainable society and solutions for the future. In line with this I have, for years, searched for new approaches and new solutions to the principal problems of environmental degradation, pollution and climate change that we as a civilization encounter.

In this permanent search I often came across new methods, new materials and new technologies which were associated with claims of success in their contribution to sustainable future of human societies.

Most of the times such claims did not stand the rigor of scientific proof and more often than not the claims made were a marketing tool rather than a substantiated fact.

I then came across a company called PowerCem Technologies in Moerdijk, The Netherlands, that has developed a range of products that make it possible to turn previously unusable materials into useful building materials or to immobilize broad range of pollutants in the environment while at the same time turning the polluted resources in a useful and beneficial products and/or services to society.

Their products are used in combination with traditional cement and pozzolanic binders to render previously useless materials and resources into a useful “structural” product while at the same time reducing our environmental (ecological) footprint. The products have an inherent ability to convert a highly contaminated secondary materials and byproducts of society into a useful material/product/service and do so with ecological as well as financial gains. In doing this their products also transform the way we look at resources as well as the methodology of building and designing some of our infrastructure systems.

PowerCem Technologies has come up with an innovation of a huge potential impact that they themselves were not able to grasp the importance of their innovation, nor were many of their initial clients. The ability to prevent and reduce continual mining of natural basic materials and the use of methods of construction that will eventually swallow up the natural materials, for example in road construction, was unfortunately not enough to make PowerCem Technologies an immediate “talk of the town” and an instant success.

Caught in the paradigm of Hermann Hesse that:

> **“Theory is knowledge that doesn’t work and practice is when everything works and you don’t always know why”**

PowerCem Technology embarked on an uncertain journey to convince potential users and clients, governments and private sector, scientists and skeptics that here is an innovation that is real and that will deliver on the claims.

But like every new product, method or application, taking the first step is always the greatest challenge, especially in the multi-disciplined world of civil engineering where different specialist are working in geotechnical, hydraulic, environmental and road engineering and construction, etc.

This Manual represents the first step from innovation to transformation to a sustainable future for PowerCem Technologies as a company and it is written in such a way that it is accessible for everyone needing a clear view of what the innovative PowerCem Technology and its products are all about, how to work with them and what the broad range of application possibilities for the technology and the product are.

The manual has been compiled together with Christophe Egyed from ARCADIS, Robin de La Roij, Guido de La Roij and Pascal de La Roij from PowerCem Technologies. We have written down our findings about the knowledge at present with regards to the possibilities for the use of PowerCem Products in road engineering and for applying and designing roads with RoadCem. This is the second edition and new editions will come out as new knowledge and practice becomes available.

Come and take the most important first step with us:

The Manual contains results from research and co-operation of our partners, clients and collaborators and we acknowledge their respective roles and contributions.

ARCADIS Infrastructure, environment, buildings

PowerCem Technologies Innovations for better solutions!

TNO

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KOAC • NPC fundament onder mobiliteit

University of the Witwatersrand Johannesburg

Prof.dr.ir. Prvoslav Marjanovic

Summary

This manual is in fact a guide for the use of RoadCem in road construction supplemented with other relevant information.

RoadCem is a PowerCem based Technology product. RoadCem is an additive to cement, that makes it possible to use cementitous binders on all suitable natural materials and even sludge and other waste materials and make a product that can be used in Road engineering.

RoadCem modifies the chemical and mineral structure of the materials that it is used with. The mechanism of how RoadCem works is explained in this manual.

A part of the manual is also a description of decision making processes used by people in choosing a particular product and how these can be used together with the information on the benefits of using RoadCem to help one convince the client that the RoadCem is the product of choice.

The use of RoadCem requires proper mix design and an appropriate pavement structure design. This requires basic criteria to be and the suitable construction process to be applied. The manual also deals with these issues in detail and presents a step by step guide to mix and pavement design and construction using RoadCem.

The manual contains most important knowledge and experience on working with RoadCem currently available. As new knowledge and experience is gained new versions of the manual will be published.

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Introduction

Via-e-Vita

1.1 General

PowerCem Technologies, The Netherlands, is a company that produces a range of products which are used as additives and improvers of Cement for different applications. One of the products is known as RoadCem and is a product primarily used in road construction. RoadCem is an additive and cement improver, used in soil and other material stabilization typically for road construction. It can also be used in all kinds of other soil stabilization works such as dike construction or landfill lining and similar applications. RoadCem and other PowerCem Technologies products have been used on demonstration and full scale projects in many countries on 4 continents.

This Manual is aimed at all our distributors and other users of our RoadCem product. The builders, contractors, governments, scientists and other interested parties are all welcome to use the Manual.

The Manual is based on experience gathered from different work and research projects we have carried out throughout the world and it explains WHAT RoadCem is, HOW a RoadCem design can be made and how RoadCem is (and can be) applied in practice.

Special consideration has been given to the fact that throughout the world there are different requirements and demands for roads and the approaches and methods used for their design. We have taken cognizance of these different requirements and try to cater for a generic, non location specific approach. This approach can fit within the particular requirements of any given location and or country and standard system.

Traditional road design and construction has proven to be very material and energy intensive. It demands also import and export of enormous quantities of virgin material in order to be completed successfully. This is especially true in situations where the load bearing capacity of base soils is low or when other geotechnical conditions along the route of the road are not suitable.

As a result there are multilayered designs and structures based on imported gravel and/or other acceptable material often exceeding 100 cm in thickness. The traditional designs typically consist of different layers such as the Surface course, Base course and Sub base course (Figure 1.1). These layers are all typically made of imported materials.

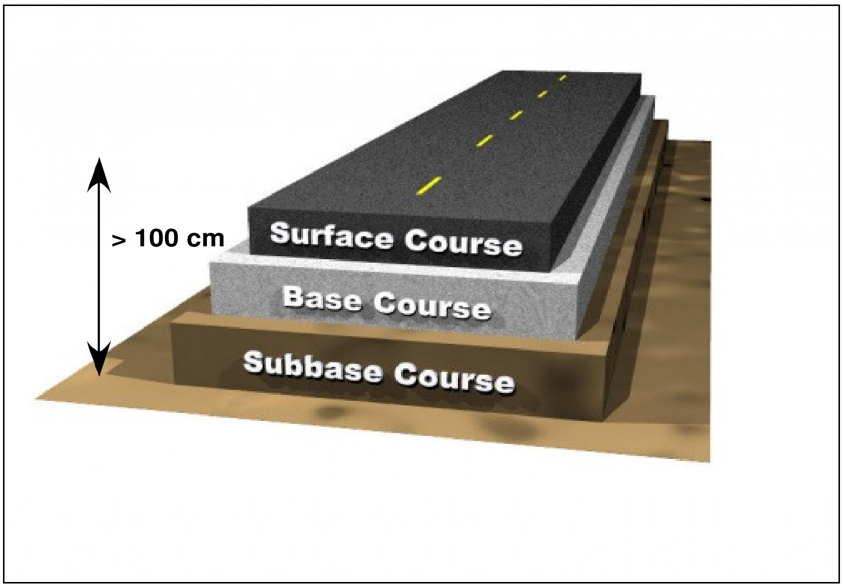


Figure 1.1 Typical Road Design and Structure.

Imported material requires transport and environmental and other costs increase with the distance to the source of the material. Often there is the shortage of the material in the country and import from other countries is needed. The reliance on imported material for conventional road construction is a factor that often contributes most to the cost of the road project and its environmental footprint. In fact, the reliance on imported material is the main problem, from a sustainability and efficiency point of view, of the traditional road and pavement design and construction. It is also the main reason for our search for a more rational road design and construction approach aimed at reducing the dependence on imported material while improving the quality and durability of the roads we design and build.

Modern societies produce large quantities of waste materials often disposed off in landfills and considered not to have any value.. The possibility to use many of these waste material as a replacement for the imported virgin material in road construction has been recognized as an option for many years. Up to now only a limited portion of the waste stream could be brought to use in road construction due to pollution problems associated with reuse of waste materials in road construction (leaching, immobilization etc.). The use of RoadCem removes many of these obstacles allowing the use of more waste materials in road construction and making possible the solution of two problems simultaneously:

1. Control of waste streams and pollution.
2. Providing cheaper and more environmentally friendly source of materials for road construction.

With RoadCem the road design and construction also allows for the use of in situ material (any soil type) for road construction. This results in the reduction of the required thickness of the pavement structure and contributes to the solution of the problem of declining resource base for imported materials.

In summary, RoadCem is a product that makes possible:

- Use of waste materials in road construction.
- Use of In-Situ materials for road construction independent of their quality.
- Reduction of the thickness of the pavement structure for the equivalent road performance.
- Avoidance of material import for road construction.
- Immobilization of pollutants in waste materials.
- Reduction of the waste stream management costs.
- Reduction of energy inputs needed for road construction and associated reduction of environmental and ecological footprints of road construction.

1.2 Objectives Of The Manual

When compiling this manual various goals have been put forward.

The central objective is to ensure that RoadCem is used in an appropriate manner, following appropriate design and construction process and procedure.

The second goal is to promote the use of RoadCem as a product of choice in road design and construction.

The third goal is to provide sufficient technical support to the distributors of RoadCem and their clients to be able to write appropriate specifications and provide technical support to road designers and contractors.

1.3 Setting the Stage

In order to maximize the benefits of using RoadCem in road construction it is necessary that a structured, thorough and efficient procedures in design and application are used.

To achieve the desired results and maximize the benefits of RoadCem the first precondition is to have a clear understanding of the client/user requirements. This is reflected in the specification of road performance requirements with respect to a number of different criteria which in essence is determined by the properties and characteristics of the finished product, the road, and the materials used to make the finished product. For example: breaking strain, fatigue, deformation behaviour, shattering, bearing strength, water permeability and associated environmental impact requirements such as substance and pollutant leaching, resistance to de-icing agents such as salts, corrosion resistance, resistance to acids and basis etc. In addition to this operational considerations also impose certain requirements such as workability, durability and a given set of physical properties.

Figure 1.2 shows the relationship between the user/client requirements and the choice of materials for the construction of any given road. The availability of RoadCem affects the elements of the relationship in the Pyramid in figure 1.2 in a profound way and establishes a need for a non-conventional approach and methodology to design, construction and material choice elements of the pyramid. This is shown in Figure 1.3.

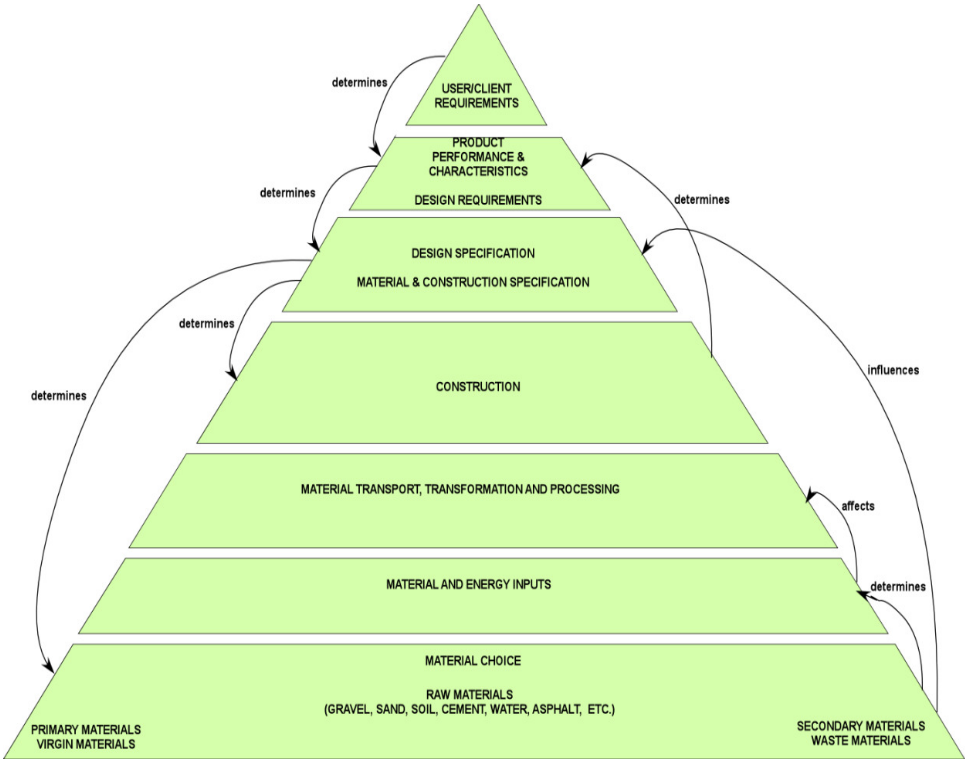


Figure 1.2 From USER/CLIENT Requirements to Material Choice - The Process Pyramid.

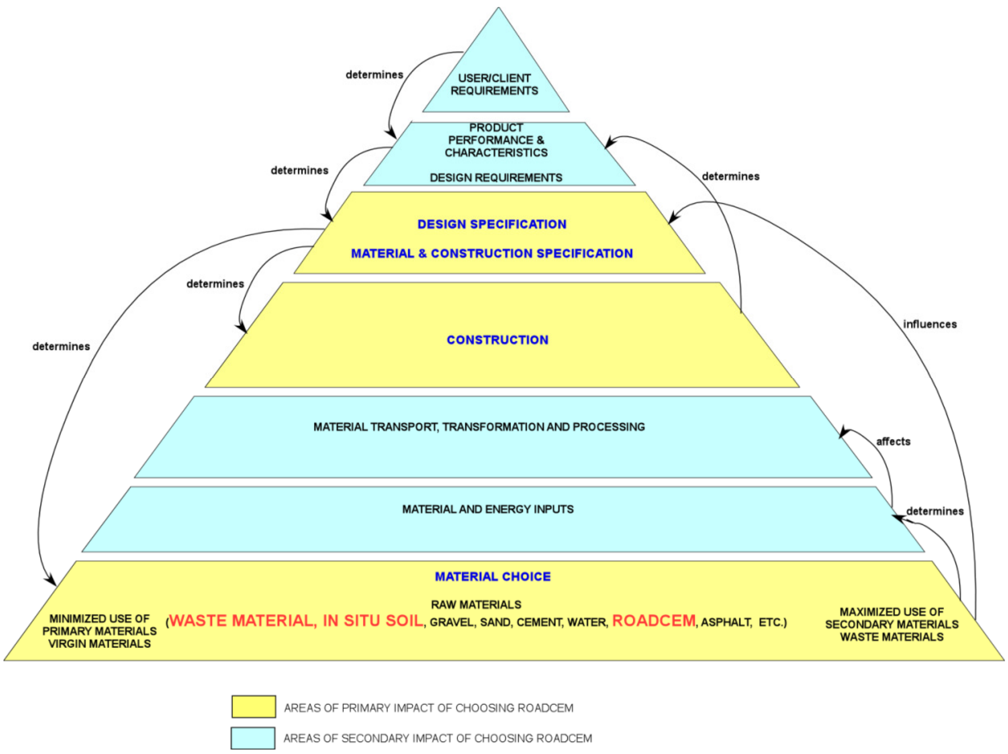


Figure 1.3 Changes to the Process Pyramid by use of RoadCem.

Designers of traditional pavement structures are familiar with the properties of materials and construction methods. They are familiar with secondary materials such as mixing granulate, concrete granulate, furnace slag, asphalt granulate, etc. and materials like gravel, sand, clay, peat. These designers are also often familiar with properties of different types of sludge and other waste and polluted materials but not necessarily of the new methods and technologies available to modify the properties of all materials. This fact has eliminated and/or limited the use of many materials in road construction and has established a state of practice where only certain materials can be used for road construction.

The use of RoadCem changes a situation as materials which in a traditional approach had a negative value and needed to be removed and/or disposed of at a significant cost, now suddenly become materials which have a positive value and which can be used in road construction. At the same time these non traditional materials can achieve the same performance requirements such as resistance to deformation and cracking at thicknesses lower than the layer thicknesses needed with traditional; materials. The net effect is that road construction with RoadCem often results in a 30% to70% reduction in the cost of building a road. Other factors such as reduced or eliminated environmental/ecological footprint make the advantage that much more important.

To achieve these benefits both the design and construction phases of the project need to be modified (See Figure 1.3). The design fraternity needs to be familiarized with modified material properties resulting from the use of RoadCem. This is no easy task and requires a lot of research data and experimentation before the use of RoadCem can be classified as a mainstream (traditional) method of road construction.

The diagram in Figure 1.4. shows step-by-step procedure for working with RoadCem.

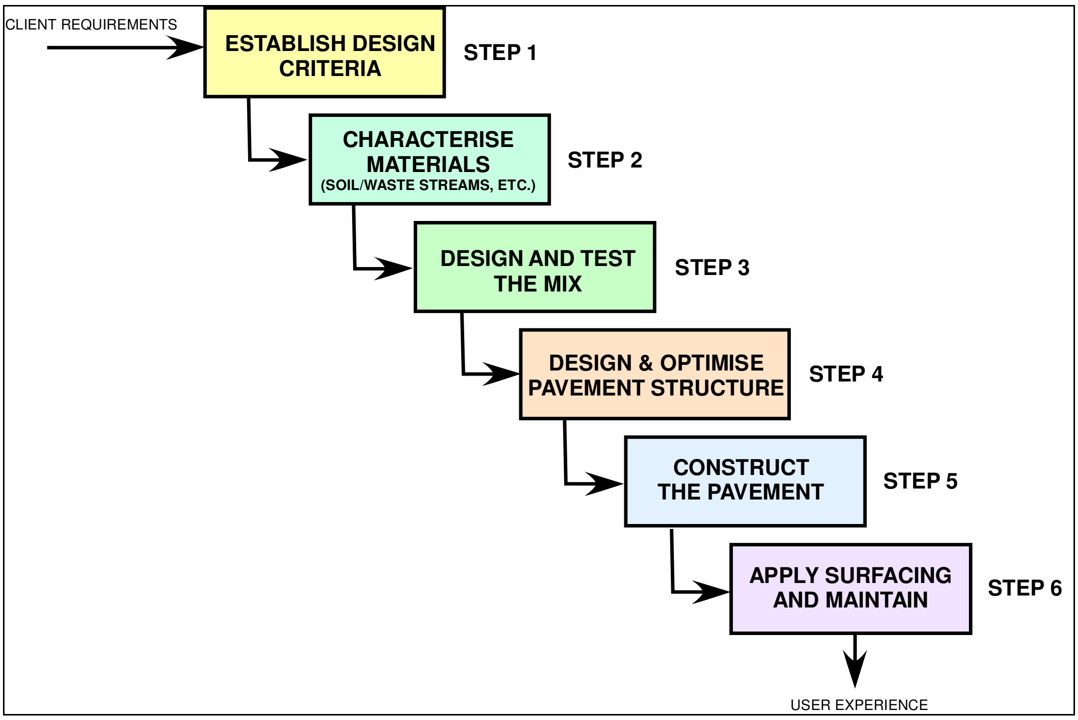


Figure 1.4 Step-by-step plan – "working with RoadCem".

PowerCem Technologies as a company will continue to focus on building a data base with the necessary information. The Design and Construction fraternity on the other side needs to begin to use RoadCem so that a track record can be established and advantages of using RoadCem further demonstrated and confirmed.

1.4 The structure of the Manual

For a good road construction with RoadCem it is important to work systematically in accordance with an acceptable procedure. This manual has been developed keeping this in mind and can be used in all the countries of the world.

Chapter 1 is the Introduction.

Chapter 2 is devoted to a basic explanation of the mechanism of material modification and improvement by RoadCem.

Chapter 3 is a summary of the initial stages of the project and an extended discussion of the Pyramid in Figures 1.2 and 1.3.

Chapter 4 is devoted to basic data collection about the in-situ and waste materials that can be used for road construction and the minimum data requirements needed for proper design using RoadCem.

Chapter 5 focuses on principles of material modification based on RoadCem, the actual pavement structure design and optimization process needed when using RoadCem.

Chapter 6 addresses the issues related to the construction in the field when RoadCem is used and road surfacing and drainage.

Chapter 7 is the concluding Chapter summarizing the Manual and giving a final Guideline – The Epilogue.

The Manual ends with a set of supporting appendices.

2.RoadCem
The Way From Chemistry To Road Engineering

2.1 RoadCem and Sister Products

While this Manual is focused on RoadCem, PowerCem Technology also manufactures and markets a set of sister products which are based on the same technology as RoadCem. The sister products are:

1. ImmoCem – used for the immobilization of pollutants. Even the most contaminated sludge can be treated and make the treated material meet the requirements needed for a Category 1 building material. The specific properties of ImmoCem are mentioned in the manual "Working with ImmoCem".
2. ConcreCem – used to improve concrete properties. The main improvement, compared to traditional concrete is higher pressure strength in less time and an improvement of the shrinkage properties of concrete. The specific properties of ConcreCem are mentioned in the manual "Working with ConcreCem".
3. NucliCem – is a product from PowerCem Technologies that makes it possible to immobilize low level radioactive waste.

In highly specific applications blending of different PowerCem products with RoadCem to achieve specific goals is possible but this is not the subject of this manual.

RoadCem is specifically designed for applications in road construction and stabilization. It is a fine grain sized additive based on alkali earth metals and synthetic zeolites complemented with complex activator, giving it unique properties.

Figure 2.1 RoadCem.

RoadCem enhances and increases the strength and flexibility of stabilized road layers and improves the overall performance of cement bound materials used in road construction. RoadCem modifies and extends the chemistry of the cement hydration process and extends the crystallization process by forming long needle crystalline structure. It is able to delay or to speed up the hydration process of cement and can thus be used as a tool to custom designs the mixes of required performance. Any type of material that can be bound with RoadCem and gives strength to the construction can be used in a road pavement. This eliminates the need for material import and export and in so doing significantly reduces the cost of road construction and the environmental impacts thereof. Its unique characteristics enable cost effective and rapid construction of high quality roads of different categories and rapid and effective stabilization of soil for different purposes (embankments, dikes, supporting structures etc.).

RoadCem is a product that is always used in combination with cement and/or other pozzolanic materials. In order to understand how RoadCem works we first have to briefly explain how Cement and pozzolanic materials act as binders of different materials.

2.2 Portland Cement

Cement needs moisture to hydrate and cure (harden) and become an effective binder of other materials such as aggregate, sand etc. When the binder (Cement) dries, it actually stops getting stronger. Cement with too little water may be dry and it will not fully react. The properties of such paste would be inferior to those of a wet paste. The reaction of water with the cement is extremely important to cement properties as a binder and these reactions may continue for many years.

Portland cement consists of five major compounds and a few minor compounds. The composition of a typical Portland cement is listed by weight percentage in Table 2.1.

Table 2.1 Composition of Portland cement with chemical composition and weight percent.

Cement Compound	Weight Percentage	Chemical Formula
Tricalcium silicate	50 %	Ca_3SiO_5 or $3CaO{\cdot}SiO_2$
Dicalcium silicate	25 %	Ca_2SiO_4 or $2CaO{\cdot}SiO_2$
Tricalcium aluminate	10 %	$Ca_3Al_2O_6$ or $3CaO{\cdot}Al_2O_3$
Tetracalcium aluminoferrite	10 %	$Ca_4Al_2Fe_2O_{10}$ or $4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$
Gypsum	5 %	$CaSO_4{\cdot}2H_2O$

When water is added to cement, each of the compounds undergoes hydration and contributes to the final product. Only the calcium silicates contribute to strength. Tricalcium silicate is responsible for most of the early strength (first 7 days). Dicalcium silicate, which reacts more slowly, contributes only to the strength at later times.

The equation for the hydration of tricalcium silicate is given by:

Tricalcium silicate + Water ---> Calcium silicate hydrate+Calcium hydroxide + heat

$$2\ Ca_3SiO_5 + 7\ H_2O \longrightarrow 3\ CaO.2SiO_2.4H_2O + 3\ Ca(OH)_2 + 173.6kJ$$

Upon the addition of water, tricalcium silicate rapidly reacts to release calcium ions, hydroxide ions, and a large amount of heat. The pH quickly raises to over 12 because of the release of alkaline hydroxide (OH-) ions. This initial hydrolysis slows down quickly with a corresponding decrease in heat evolved.

The reaction slowly continues producing calcium and hydroxide ions until the system becomes saturated. Once this occurs, the calcium hydroxide starts to crystallize. Simultaneously, calcium silicate hydrate begins to form. Ions precipitate out of solution accelerating the reaction of tricalcium silicate to calcium and hydroxide ions. (Le Chatlier's principle). The evolution of heat is then dramatically increased again.

The formation of the calcium hydroxide and calcium silicate hydrate crystals provide "seeds" upon which more calcium silicate hydrate can form. The calcium silicate hydrate crystals grow thicker which makes it more difficult for water molecules to reach the anhydrate tricalcium silicate. The speed of the reaction is controlled by the rate at which water molecules diffuse through the calcium silicate hydrate coating. This coating thickens over time causing the production of calcium silicate hydrate to become slower and slower.

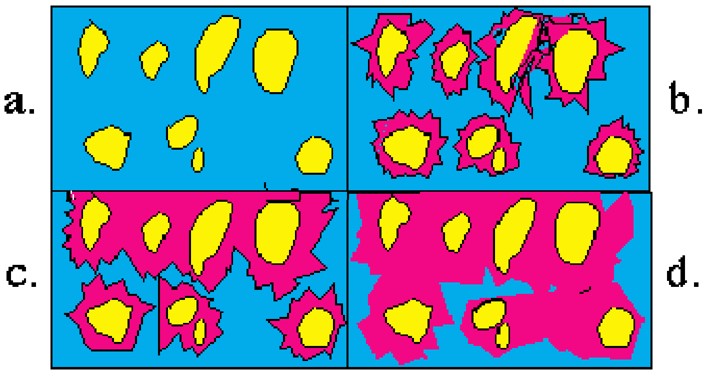


Figure 2.2 Schematic illustrations of the pores in calcium silicate through different stages of hydration.

The diagrams shown in figure 2.2 represent the formation of pores as calcium silicate hydrate is formed. Note in diagram (a) that hydration has not yet occurred and the pores (empty spaces between grains) are filled with water. Diagram (b) represents the beginning of hydration. In diagram (c), the hydration continues. Although empty spaces still exist, they are filled with water and calcium hydroxide. Diagram (d) shows nearly hardened cement paste. Note that the majority of space is filled with calcium silicate hydrate, what is not filled with the hardened hydrate is primarily calcium hydroxide solution. The hydration will continue as long as water is present and there are still anhydrate compounds in the cement paste.

Dicalcium silicate also affects the strength of concrete through its hydration. Dicalcium silicate reacts with water in a similar manner as tricalcium silicate, but much more slowly. The heat released is less than that by the hydration of tricalcium silicate because the dicalcium silicate is much less reactive. The products from the hydration of dicalcium silicate are the same as those for tricalcium silicate:

Dicalcium silicate + Water ---> Calcium silicate hydrate + Calcium hydroxide +heat

$$2\,Ca_2SiO_4 + 5\,H_2O \text{---}> 3\,CaO.2SiO_2.4H_2O + Ca(OH)_2 + 58.6\ kJ$$

The other major components of Portland cement, tricalcium aluminate and tetracalcium aluminoferrite also react with water. Their hydration chemistry is more complicated as they involve reactions with the gypsum as well. Because these reactions do not contribute significantly to strength, they will be neglected in this discussion. Although we have treated the hydration of each cement compound independently, this is not completely accurate. The rate of hydration of a compound may be affected by varying the concentration of another. In general, the rates of hydration during the first few days ranked from fastest to slowest are:

tricalcium aluminate > tricalcium silicate > tetracalcium aluminoferrite > dicalcium silicate.

Heat is evolved with cement hydration. This is due to the breaking and making of chemical bonds during hydration. The heat generated rate is shown in figure 2.3 as a function of time.

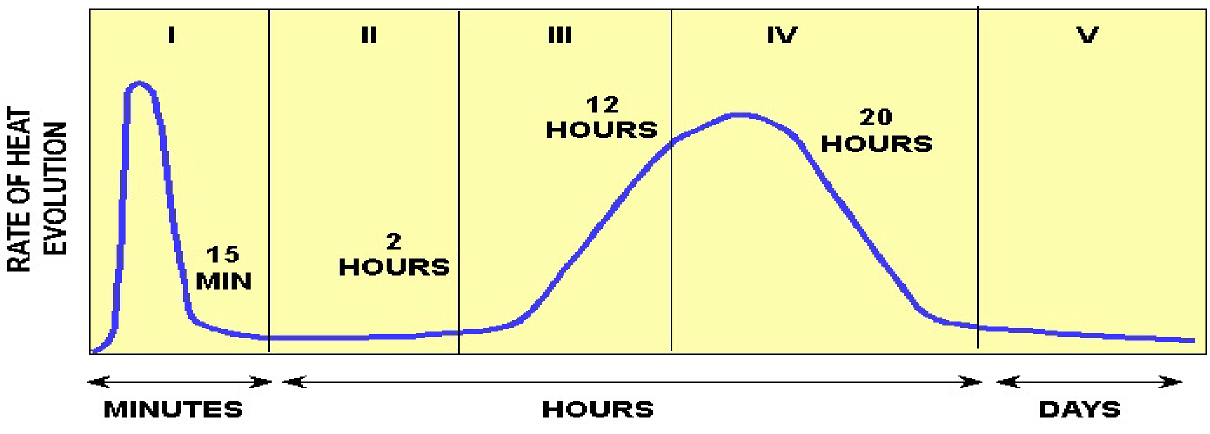


Figure 2.3 Rate of heat evolution during the hydration of Portland cement.

The stage I hydrolysis of the cement compounds occurs rapidly with a temperature increase of several degrees. Stage II is known as the dormancy period. The evolution of heat slows dramatically in this stage. The dormancy period can last from one to three hours. During this period, the concrete is in a plastic state which allows the concrete to be transported and placed without any major difficulty. This is particularly important for the construction trade who must transport concrete to the job site. It is at the end of this stage that initial setting begins. In stages III and IV, the concrete starts to harden and the heat evolution increases due primarily to the hydration of tricalcium silicate. Stage V is reached after 36 hours. The slow formation of hydrate products occurs and continues as long as water and anhydrate silicates are present.

The strength of cement bound products is very much dependent upon the hydration reaction just discussed. Water plays a critical role, particularly the amount used. The strength of the product increases, when a lower amount of water is used. The hydration reaction itself consumes a specific amount of water.

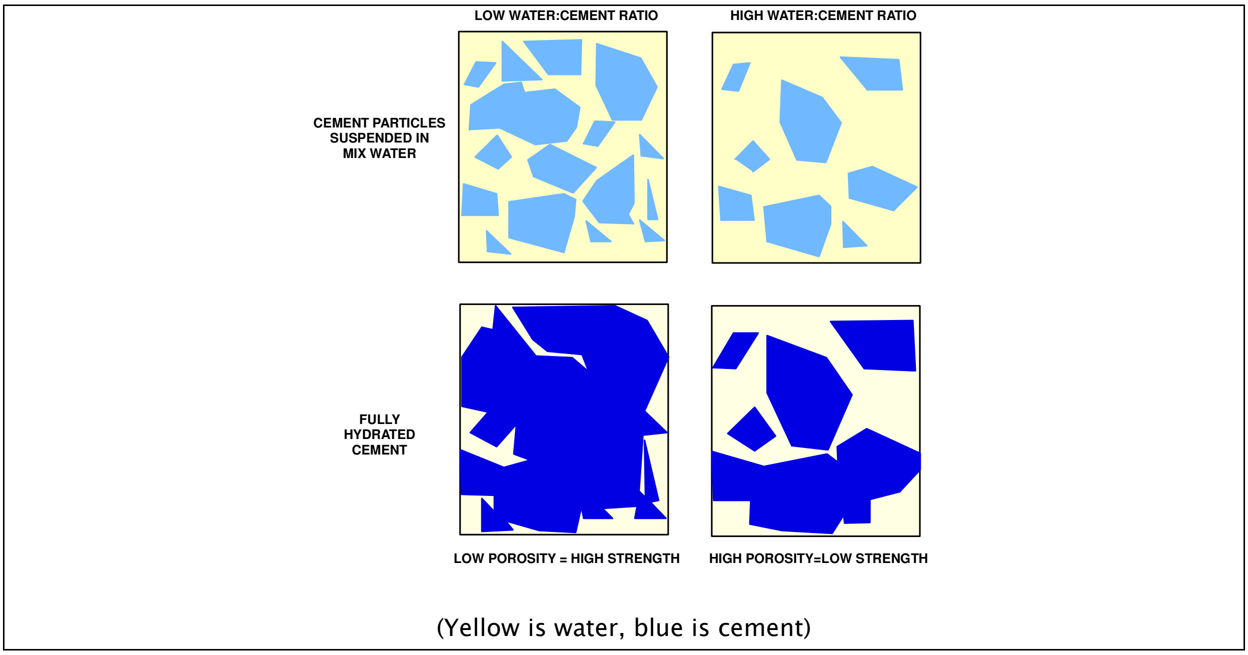


Figure 2.4 Schematic drawings to demonstrate the relationship between the water/cement ratio and porosity.

The empty space (porosity) is determined by the water to cement ratio. The relationship between the water to cement ratio and strength is shown in figure 2.5.

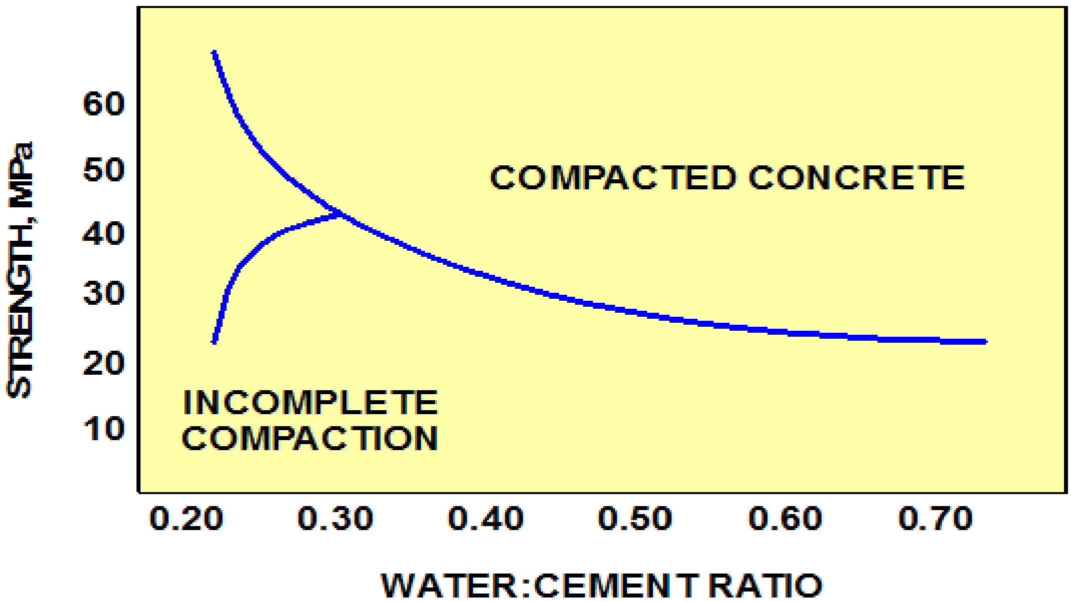


Figure 2.5 A plot of product strength as a function of the water to cement ratio.

Low water to cement ratio leads to high strength but low workability. High water to cement ratio leads to low strength, but good workability.

Time is also an important factor in determining product strength. The product hardens as time passes. The hydration reactions get slower and slower as the tricalcium silicate hydrate forms. It takes a great deal of time, even years for all of the bonds to form, which determines the product's strength.

2.2.1 Portland Cement with RoadCem as an additive

When RoadCem is used as an additive, moisture remains necessary for hydration and hardening.

The five major compounds of the hydration process of Cement still remain the most important hydration products but the minor products of hydration probably change. Furthermore, the rate at which important hydration reactions occur and the relative distribution of hydration products changes as a result of the addition of RoadCem. In addition, the crystallization of calcium hydroxide accordingly occurs at different rates and the reduction of heat generation from the hydration reactions occurs. There are more crystals formed during the reactions and the relevant crystalline matrix is much more extensive.

When adding RoadCem, the amount of water trapped as free water is reduced and the crystals grow into the empty void space. This makes the product less permeable to water and more resistant to all types of attack that are either water dependant or water influenced. A bigger fraction of the water is converted to crystalline water than is the case with the reactions in the absence of RoadCem. The reduced porosity and increased crystalline structural matrix increases compressive, flexural and breaking strength of the product and change the relative ratio between these strengths.

Heat evolved during hydration is reduced especially in phases III and IV in figure 2.3 indicating that some of the phase III and IV reactions might not be occurring or that different reactions are occurring.

Water continues to play a critical role, particularly the amount used. As before the strength of the product increases when less water is used to make a product. The hydration reaction itself now tends to consume a different amount of water. When adding RoadCem it is also possible to use salt water and achieve a good end result.

The empty space (porosity) is still determined by the water to cement ratio but is affected to a lesser extent as a result of the increased rate and extent of the crystallization process. The relationship between the water to cement ratio and strength remains similar to the one shown earlier but the slope of the relationship changes and does so differently for different segments of the graph.

The extended crystallization process changes significantly when using RoadCem. The binding mechanism changes from “glue” to “wrapping” as shown in figure 2.6.

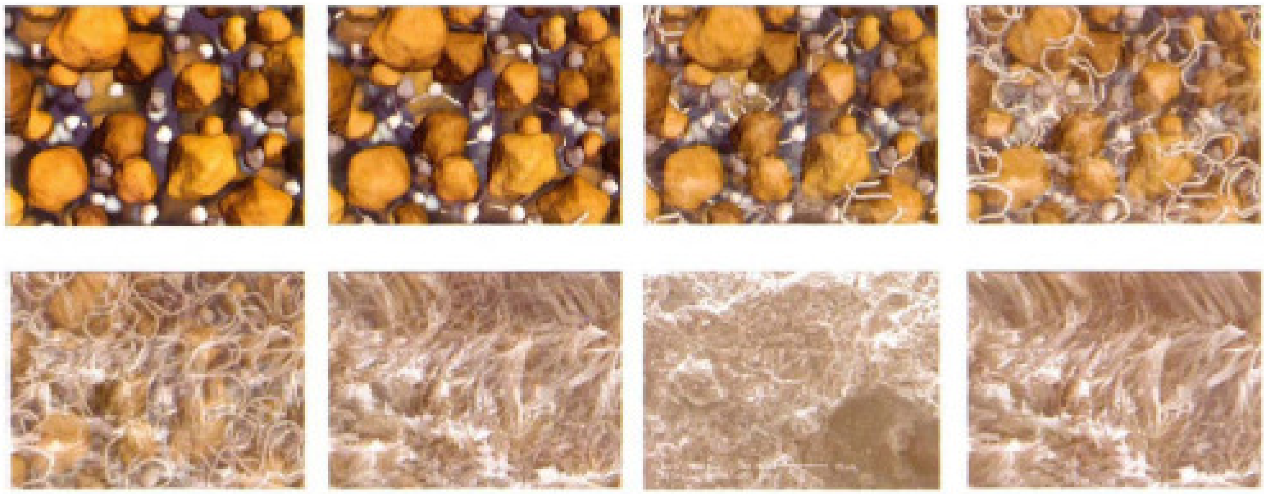


Figure 2.6 Simulated expressions of the hydration reactions and associated "wrapping" crystallization effect.

The "wrapping" effect associated with the crystalline products of the hydration reactions, which continue with time are in effect also responsible for the ability of RoadCem modified cement to bind even heavy clays. With cement alone this cannot be done successfully.

The same is true for the binding of other previously non bondable materials such as sludge and different waste streams. In addition to the above, due to the composition of RoadCem, other processes also occur simultaneously and especially with clays and similar materials mainly through cat ion and anion exchange and replacement and charge neutralization as indicated in figure 2.7.

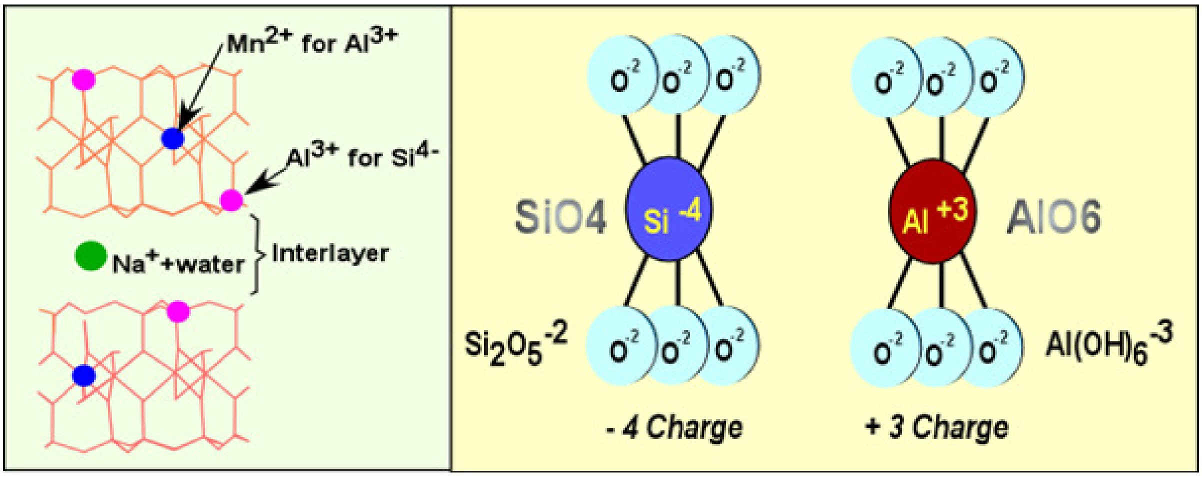


Figure 2.7 Replacement and charge neutralization.

Ion substitution and Charge modification for improved binding of charged particles and increased cat ion exchange capacity also result. Electrochemistry change is induced by addition of RoadCem. It makes it possible to bind different materials even in acidic environments and when combined with the "wrapping effect" this leads to a product which has superior characteristics and performance in accord with the requirements.

Using an electron microscope one can see the structure of the material once the physic chemical and mineralogical processes have completed. Figure 2.8 shows the structure of basic materials and a typical structure of end products with cement alone (figure 2.9A), and with cement and RoadCem added in (Figure 2.9B). It can be seen that the addition of RoadCem creates a different crystalline structure.

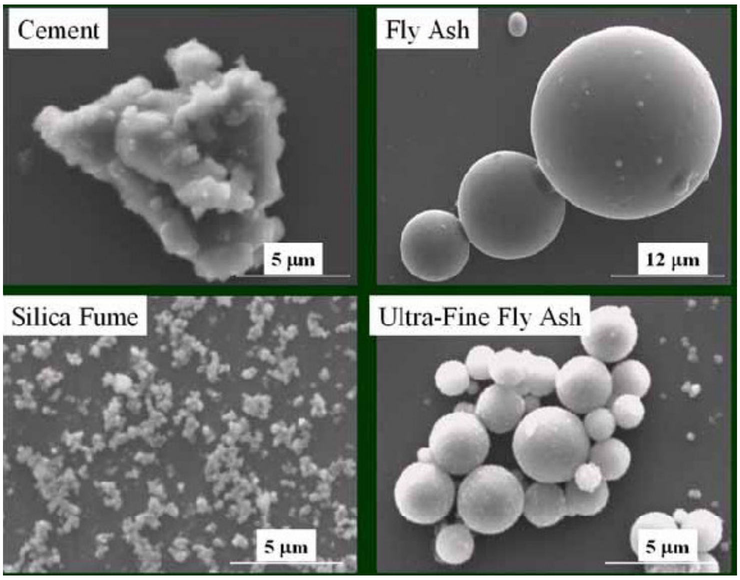
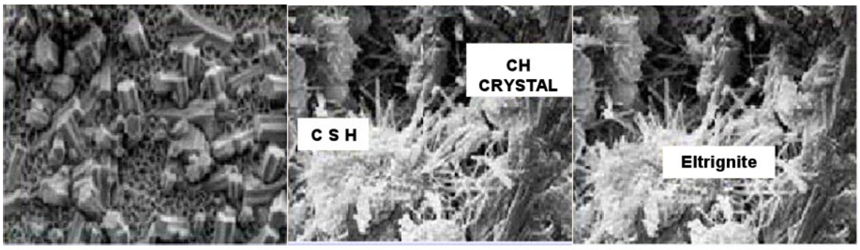
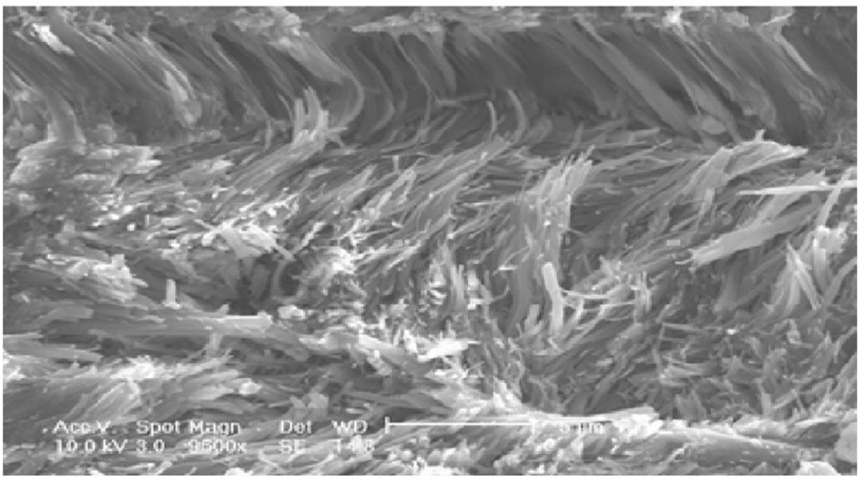


Figure 2.8 Electron Micrograph of different basic materials.



A. End Product of Cement Hydration Showing Elements of Crystalline Structure Formed



B. End Product of Cement + RoadCem Hydration Showing Extended and More Pronounced Crystalline Structure Formation and "Wrapping" Effect

Figure 2.9 End product of the hydration reaction for A. Normal Cement and B. RoadCem modified Cement situations.

2.2.2 Encapsulation or “Wrapping” and Auxiliary Effects

In daily life we use many materials which are made from bound, harmful substances. For instance, a lead crystal glass with high lead content.

When such a glass is used or when a glass breaks the lead is not released because the lead particles are enclosed in the crystalline structure – they are “wrapped” in the crystal fibers.

In a similar manner RoadCem and other PowerCem Technology products are capable of encapsulation of dangerous and toxic substances and keeping the contaminated substances out of the environment as well as preventing their release into the environment.

The “wrapping” and encapsulation of polluting substances into crystalline structure which is a product of hydration reactions of RoadCem improved cement creates a strong and stable material which has structural qualities that we desire in road construction, i.e., high compressive strength, high flexural strength and high breaking strength for example.

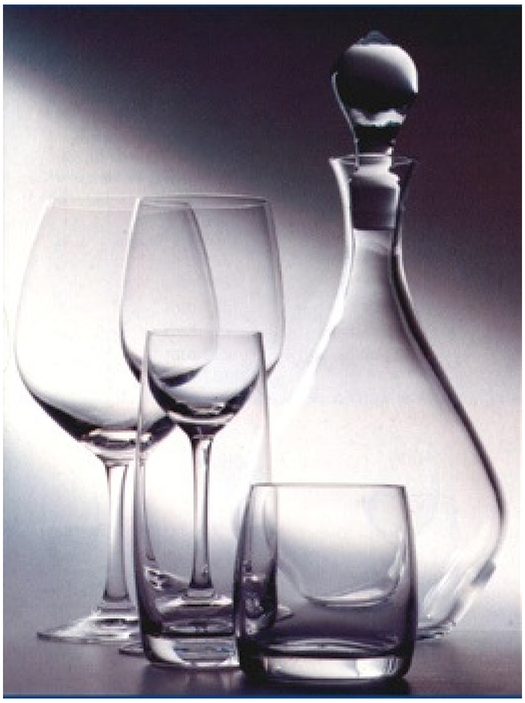


Figure 2.10 Why is Lead Crystal not harmful to human health when Lead is highly Toxic.

Figure 2.11 shows a slab that has been made from sludge using Cement and RoadCem. It does not break even under the weight of a hydraulic crane.

Figure 2.11 Sludge mixed with PowerCem based product.

The water in the material with sludge has been bound in such a way that even at 2000°C the water does not form a gas. With concrete (B25) at a temperature of 400°C the mixture forms gas and the concrete explodes.

Figure 2.12 Thermal lance on sludge mixed with PowerCem based product.

Figure 2.13 Impermeability of mixed soils together with PowerCem based product.

Figures 2.12 and 2.13 shows that adding RoadCem results in a higher resistance against external forces and temperatures and also against attack from de-icing salts, acids and bases. When the mixture is well compacted then it becomes water impermeable and no damage can occur from a freeze-thaw cycle for example.

3.Design criteria

When you know what you want, you get what you want

3.1 General

Road Design and Construction is a unique part of civil engineering. Every road serves two main groups of users:

1. People and the economy – the users
2. Proponent of the road – the client.

The client has demands that are articulated to represent the needs of the users. A good design for a road is therefore one that meets the needs of the two main groups: the client and the users, while at the same time meeting additional requirements that the other stakeholders might have. The requirements of the users and the client are typically reflected in the design and other criteria that the designer and the implementing agent (the contractor) have to meet. The designer and the implementing agent (the contractor) will consider the user and client requirements and the associated criteria and make sure that their design and the end product – the road – are in accordance with the requirements and the criteria previously defined.

In doing this the intention should always be to come up with the optimum (quality, economic factors, environmental factors, etc.) solution for any given road project. Defining the optimum will involve answering many and diverse questions:

1. What is the cheapest option for a given road?
2. What is the best option from the O&M point of view?
3. Which option is fastest to implement?
4. Which option has a smallest environmental footprint?
5. Which option will last longest?
6. Which option is acceptable to the people?
7. Which option is acceptable to the economy?
8. Which option is acceptable to the client?
9. Is the option technically feasible?
10. And many more…

In this Chapter we consider the basic user and client requirements before we begin with consideration of other technical and design aspects of road construction.

The basic user and client requirements and criteria must be defined before a design starts.

The first step in any road project is therefore to define user and client requirements and criteria. Only after this has been completed can the design be made.

Consider the following problem:

> *A river divides a particular community right down the middle. People need to cross the river to meet each other. The bakery needs to deliver bread to both parts of the community. The Major of the town promised that he will solve the problem of communication between the two parts of the community during last elections. The community is in recession and funds are limited. Nearby communities are growing fast and our community is beginning to follow the same pattern with more and more people moving in and complaining that the road infrastructure between the two parts of the community is limiting economic growth and opportunities, etc. All these forces have come together and resulted in a consensus that we need a solution to cross the river, safely, fast, daily, urgently and for a long period of time in the future.*

There are many different options we can use to solve the above problem: different types of bridges, a ferry, a tunnel, a helicopter etc. All of these will meet the basic requirement to cross the river but which option is the best? When the community has decided on a bridge does the consultant have enough information to determine which option is the best??

Figure 3.1 What do the users and the client requires??

In order to meet the user and client requirements and in order to prepare a good design it is important to know what the users and the client really want!

Knowledge of functional specifications and system engineering is a tool to give clarity. The objective must be that the users and the client are satisfied when the work is finished. The golden rule is:

Satisfaction = appreciation + expectation

Figure 3.2 Experiencing successes.

Together with the users and the client basic criteria must be defined and described to lead to their satisfaction. Sometimes this maybe feasible at others times not, the requirements will need to be re-specified.

The user and client requirements may indicate a solution which is not technically feasible (figure 3.3). At other times the designer and the implementing agent may favour the solution that the users and the client actually do not like. (Figure 3.4).

As our objective is to deliver a solution that meets the minimum user and client requirements whilst being technically feasible (optimum solution space in figure 3.5) it is essential that the users, the client, the designer and the implementing agent(contractor) communicate with each other about what is wanted and is actually attainable.

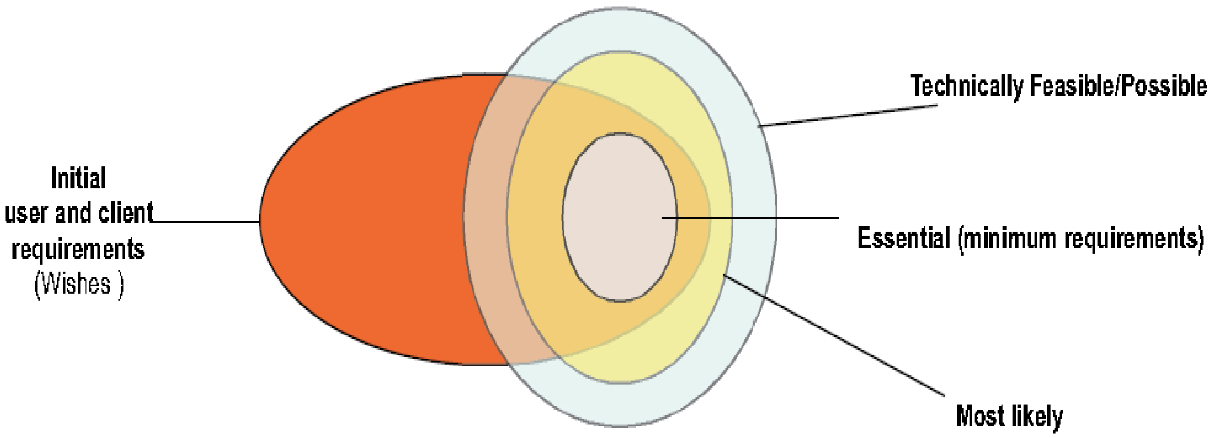


Figure 3.3 "Solution Space" and Initial user and client requirements.

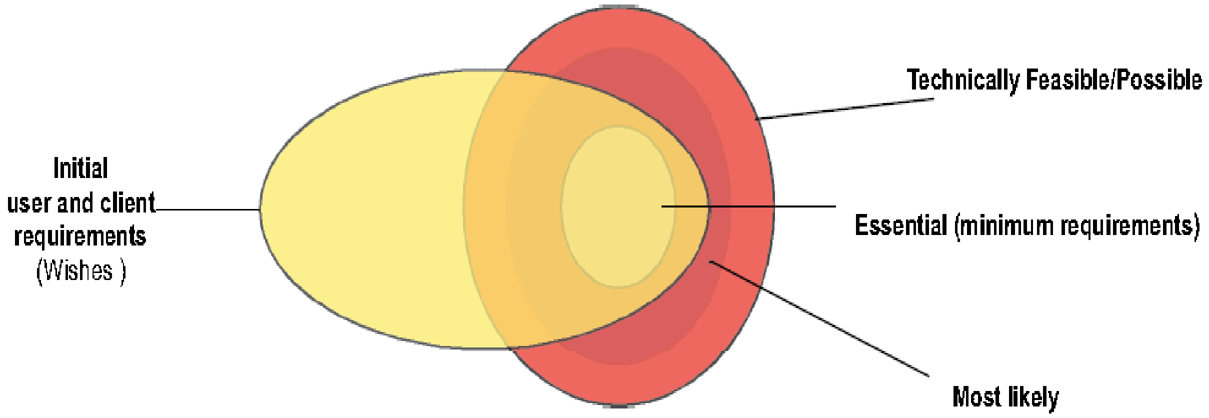


Figure 3.4 Designer and implementing agent's view of the "Solution Space".

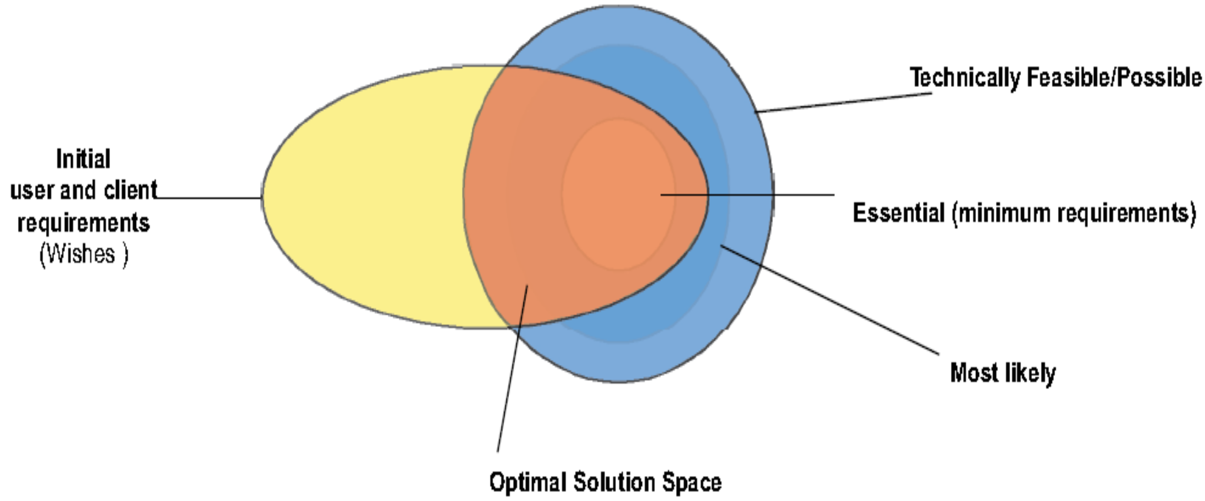


Figure 3.5 Optimal "Solution Space" that all must agree on before work starts – the actual solution must fall within the Optimum "Solution Space".

Traditionally, the users and the client do not like risks. They insist on a solution which has a proven track record – a solution that has already been used somewhere else, – and impose this upon designer and the implementing agent as a requirement. This is almost never the "Optimal" solution in figure 3.6. The users and the client didn't take too much risk and innovation was not the order of the day.

Faced with dwindling resources and more stringent regulatory requirements as well as the need to find solutions which have a smaller environmental footprint the users and clients of today have learned that there is room for improvement and that a better solution than the traditional one typically always exists. As a result modern users and clients have different ways for making a contract and now the functional properties that the construction needs to meet are specified and the designer and the implementing agent are given freedom to innovate and the possibility to work with new materials and methods to come up with the "OPTIMUM" solution (Figure 3.6). In this the risk is transferred to the designer and the implementing agent and the users and the client do not carry any risk what so ever.

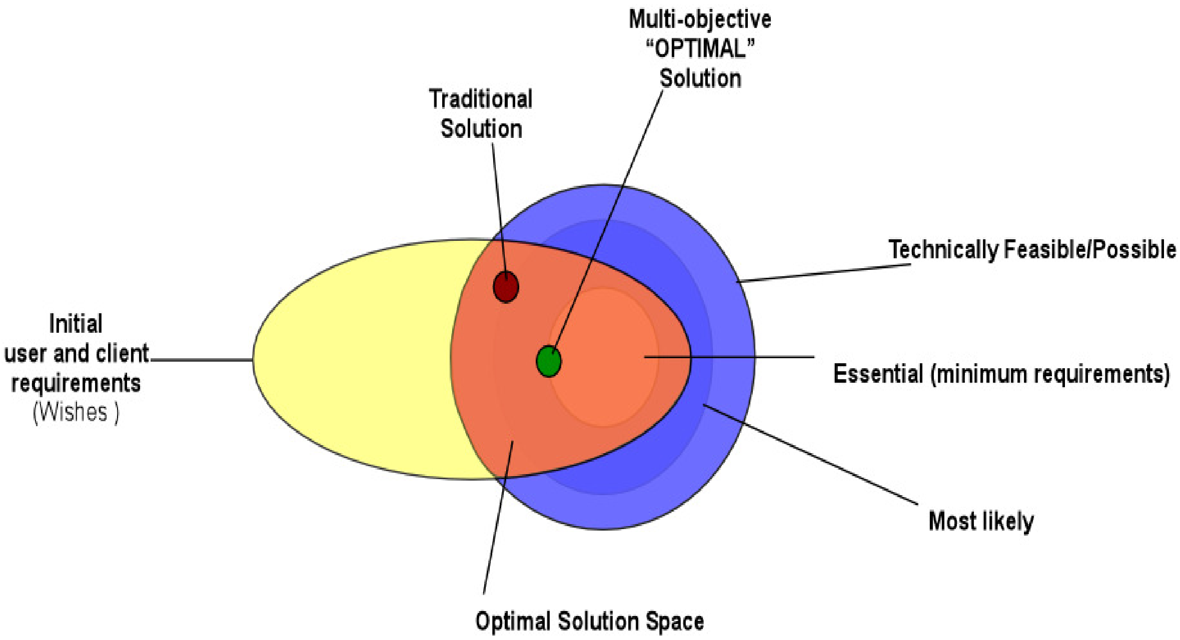


Figure 3.6 Traditional Solutions of the past and "Optimal" Solutions of the present.

While in the past the criteria for awarding the contract was typically the cheapest solution in a modern world this criteria is now more extensive and includes factors such as:

- Low construction costs;
- Low maintenance costs;
- Limited maintenance work, greater availability of the road;
- Quicker use of the road;
- Longer lifespan;
- Recycling of building materials;
- Containing adequate stiffness;
- etc.

In developing countries there may be additional criteria such as:

- Labour intensive construction methods;
- Use of locally available materials, etc.

This recent change in the approach to finding a solution to a particular problem and to contracting has resulted in a huge push for innovation on the side of designers and implementing agents. Innovation is driven by the opportunity to make more profit. The playing field has been levelled and new players come to the party.

This has also opened an opportunity for innovation in material use and this is where the niche for PowerCem Technologies as a company and its products, especially RoadCem has opened up.

In practice RoadCem will be applied when the designers and implementing agents(consultants, building-contractors, engineering companies) have enough trust in the product and when this can be proved to the users and clients (Government ministries, water authorities, private sector companies).

It is therefore fundamentally important that when a RoadCem based solution is recommended that:

1. User and client requirements are clearly understood.
2. Users and clients have a clear understanding of why a RoadCem solution is a better solution.

Point 2 is of special interest to PowerCem Technologies. The following pages are intended to provide enough information so that the distributors of RoadCem, designers and implementing agents can convince the users and the clients about the advantages of the RoadCem solution.

3.2 Basic Points

3.2.1 General

When making a road design, or better said pavement structure design, certain basic points must be known up front.

The information on these basics can be supplied by the client. If he does not have this information available then it can be found by making use of literature studies or by field measurement and research.

When designing proper road pavements, there is need for information about:

- Soil.
- Traffic load.
- Material properties.
- Construction and design.

Within each of these categories data and information needs are substantial and need to be met.

3.2.2 Soil

Information on the sub-base can be determined from the existing field research reports. These reports should contain information on the grain composition, the bearing strength (the dynamic elasticity module) and the groundwater level as a minimum.

When this information is not available then a tests must be carried out to collect this data and information. (tests are discussed in Chapter 4)

The information/data that is required and must be either extracted from existing reports or by doing field surveys and measurement refers to:

- Bearing strength of the sub-base, the dynamic elasticity modulus.
- Groundwater level.
- Grain composition of the soil (upper 0, 40 meters /surface-soil).

- Chemical composition of the soil.
- Ground structure (upper 2 meters).
- Capillarity of the ground and setting behaviour.
- Soil Behaviour during the frost/thaw cycle.

3.2.3 Traffic load

The required traffic load information can be divided into two components:

- the heaviest axle load expected on the pavement (breaking strength!), and
- the maximum amount of standard repeating axle loads (fatigue!).

Information about the traffic load is generally specified by the client but when he does not know what the expected loads are then traffic surveys need to be conducted or engineering judgement and experience can be utilized to make an of the expected traffic intensity and axle loads.

In addition to the above the following data and information is also needed to make a good pavement design:

- Kind of construction that is being placed (asphalt, concrete, elements, other).
- Function of the future construction.
- Maximum load expected on the pavement.
- Maximum axle load on the pavement.
- Axle loads configuration(s) of the different vehicles.
- Amount of axle load repetitions per load.
- Desired lifespan of the pavement.
- Tire pressure of the vehicles.

How to determine maximum axle load and amount of axle load repetitions is discussed below.

Maximum axle load

The maximum axle load is the highest axle load that can be expected at any one time on the pavement. This can come from heavy transport or bad weight distribution of a truck whereby the full load is placed on one wheel. When dimensioning the pavement there is need to determine that the breaking strength of material used in pavement structure is not exceeded.

Table 3.1 Typical wheel loads for different vehicle types

Kind of vehicle	Maximum standard Wheel load (kN)
Car	5
Heavy truck	50
Reach stacker (front wheels loaded)	206
Airplane A380 Take off Airplane A380 Arrival	280 194

In pavement design with the axle loads of the vehicles it is assumed that there are 2 wheels on each axle.

With heavy loaded vehicles (Reach stackers, airplanes) the amount can rise to 4 or 8 wheels per axle. The number of wheels depends on the maximum axle load.

Table 3.2 Maximum axle wheel loads for different vehicle types

Kind of vehicle	Maximum Axle Load (kN)
Car	10
Heavy truck	200
Reach stacker (front wheels loaded)	800
Airplane A380 Take off Airplane A380 Arrival	2.240 1.552

In practice a safety factor is used. The Maximum standard axle load is multiplied by a factor of 2. This means that with a Maximum standard axle load of 100 kN the Maximum axle load that is taken into account in the calculations is 200 kN and the wheel load 100kN.

Figure 3.7 Reach stacker. Figure 3.8 Antonov.

Figure 3.9 High axle load examples.

Maximum standard repeating axle load

For the dimensioning of pavements in most countries the maximum standard axle load is set at 100 kN per axle and in some countries this is 80kN. It is expected that the standard axle load shall increase in the future as there are more heavy vehicles on the road.

For the tire pressure there is a maximum of 1.000 kPa. When the tire pressure increases then the weight shall be distributed over a smaller surface and this leads to a higher pressure and strain on the pavement.

The damage to the pavement is created mainly by the high load. Cars compared to trucks hardly contribute to the damage. With viscous-elastic materials such as is the case when RoadCem is used the damage from cars is 4 orders of magnitude smaller than it is for trucks.

As an example, the comparison below explains what the damage effect is from a truck and a car.

Input data: Axle load car is 10kN

Axle load heavy loaded truck is 100 kN

The formula we use to determine the damage factor is

$$\text{Damage factor, } Ni = \left(\frac{\text{Axle Load}}{100}\right)^4$$

Therefore the result for the two different kinds of vehicles is:

$$\text{Personal Car, } Ni = \left(\frac{10}{100)}\right)^4 = 0{,}0001$$

$$\text{Heavey Loaded Truck, } Ni = \left(\frac{100}{100)}\right)^4 = 1$$

As can be seen the damage effect of 1 truck is comparable to 10.000 cars. Therefore, in road engineering the loads during the life span on the pavements are estimated by the number of trucks and not by the number of cars.

Calculating the axle load repetitions

To determine the amount of axle load repetitions it is important to know how much truck traffic can be expected driving in the lanes with the heaviest loads. How heavy the trucks are when loaded, the expected traffic growth over the design lifetime for the pavement and the expected lifespan of the pavement are all to be taken into consideration The following formula is used to determine the amount of standard maximum axle load repetitions:

$$N_{eq} = V \cdot W \cdot F_s \cdot F_s \cdot D_v \cdot F_v \cdot \frac{\left(1+\frac{G}{100}\right)^L - 1}{\frac{G}{100}}$$

Where

N_{eq}	=	Total amount standard axle load repetitions.
V	=	Number of trucks per 24 hours.
W	=	Number of work days per year.
F_s	=	Correction factor for the amount of driving lanes per year.
F_v	=	Correction factor for the driving lane width.
F_r	=	Speed of the heavy goods traffic.
D_v	=	Truck damage factor.
G	=	Growth.
L	=	Life span.

The different variables and typical design values are discussed below.

Trucks, number (V)

Generally the client has an indication of the number of trucks that are expected to use the road. In suburban areas typically there are limited numbers (e.g. refuse trucks, fire-engines, etc), 2 trucks per 24 hours is a good assumption. On the highway the number of trucks expected is much higher, varying from 500 to 20.000 per 24 hours.

Figure 3.10 Amount of trucks.

Working days-total (W)

There are 250 working days each year but lately more and more trucks are using the roads in the weekends and holidays. For example the authorities in the Netherlands registered that during weekend days on average 1/6 of the heavy goods traffic are present compared to a normal working day. Based on this information it is recommended to use 270 working days per year as a design criteria.

Truck traffic velocity (Fr)

If the traffic speed is slower than 80km/h (design driving speed for trucks) then the damage factor as a result of the slow traffic will increase. It is clear that congestion also has a negative effect on the lifespan of an asphalt pavement construction. Traffic speed has very little effect on a concrete pavement construction. Traffic jams on asphalt roads increase the load on the road surface by a factor 1, 76. The traffic speed is important basic information for design because a RoadCem pavement is also a viscous-elastic material like asphalt.

The choice of traffic speed for a design is strongly dependant on the route and the legally allowed speed on the road.

Table 3.3 Correction coefficient for the speed of the truck traffic.

Speed km/h	F_v
20	1,76
40	1,33
60	1,12
80	1,00

Driving lane width F_v

The position of the trucks across a driving lane depends on the width of the lane. With smaller lanes the distribution of the traffic load is reduced and more detrimental as the trucks will continually drive over the same area. In table 3.4 the correction coefficients are suggested as a function of the width of the lane.

Table 3.4 Correction co efficient for the driving lane width.

Lane width	F_s
< 3,00 m	1,14
3,00 m – 3,50 m	1,07
> 3,50 m	1,00

Figure 3.11 Is the Driving lane wide enough?

Total amount of driving lanes F_r

With more driving lanes available on the road the trucks shall spread over the different lanes. When there are more lanes in one driving direction then the trucks will use mainly the right hand lane with partial use of the other lanes. In table 3.5 the correction factors are given based on experiences in The Netherlands.

Table 3.5 Correction coefficient for the amount of driving lanes.

Number of lanes	F_r
One lane Special lane No overtaking	1,00
Two lanes	0,95
Three lanes or more	0,90

Figure 3.12 Special lane only for trucks and busses.

Truck damage factor D_v

To estimate the truck damage factor it is necessary to determine the kind of truck traffic on the road. There are 3 possible categories. In table 3.6 the relevant truck damage factors are given. This damage factors are used for viscous-elastic materials such as asphalt and RoadCem.

Table 3.6 Correction coefficient for the truck damage factor.

Kind of truck traffic	D_V
Light duty trucks	1,2
Middle duty trucks	1,6
Heavy duty trucks	2,0

Figure 3.13 Heavy transports.

Growth (G)

The growth expected on a road depends on the kind of road and the economical and spatial development. The growth can vary from 3-10% per year.

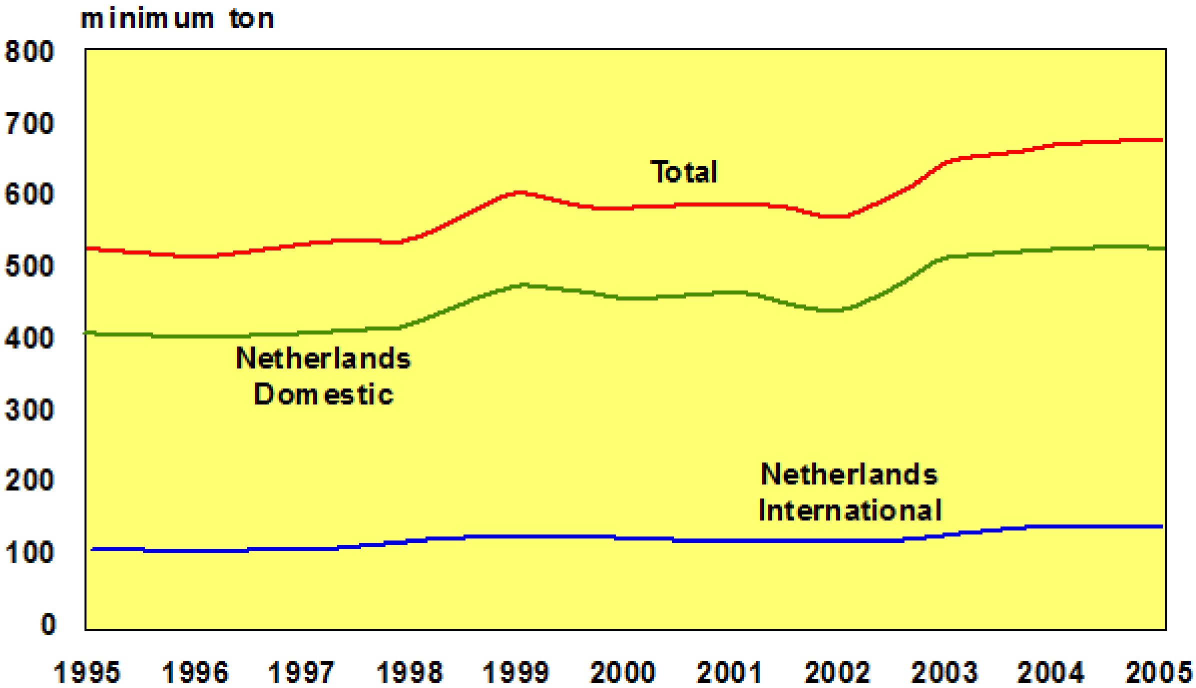


Figure 3.14 Increase truck traffic Netherlands and abroad.

Life span (L)

With respect to lifespan we differentiate between 4 different categories:

- Functional lifespan.
- Structural lifespan.
- Financial lifespan.
- Social lifespan.

The social life span of a pavement is specified by the client. He determines how long a road must be used for.

The Financial life span of a road construction depends on the period that the client needs to write off the costs for making and maintaining the road.

The financial and social life span determines **the structural life span**. This ends when cracks and large faults occur in the pavement.

The functional life span is related to keeping the function of the road at an appropriate level. The pavement can fail but not collapse and the traffic can continue. The failure of a road can result due to insufficient stiffness or insufficient noise absorption whereby a road no longer meets the demands other than being able to drive from A to B. The surface layer takes on the most functional properties that a road needs to meet.

3.2.4 Material properties

The physical properties of the different materials used for road construction need to be known in order to determine the layer thickness of each material. This applies also to the physical properties of the sub-base. All of these factors they need to be determined before every project.

The physical properties are:

- Dynamic elasticity module of the future foundation.
- Viscosity of the different materials.
- Pressure strength of the different materials.
- Breaking strength of the bound materials.
- Crushing value of the different materials.
- Stiffness value of the material to be used.
- Fatigue properties of the different materials.
- Water permeability of the different materials.

The value of these properties is used as the starting point when making the design. If the design values above are not known appropriate assumption must be made.

Surfacing layers

Road surfacing can be made in many different ways and using many different materials. Relevant options and material properties are presented in Appendix 5. It is noted that all traditional surfacing options can be used on a top of a RoadCem base:

- Asphalt;
- Concrete paving stones;
- Concrete slabs, etc.

It is noted that it is also possible to use RoadCem based layer as a surfacing option.

Foundation material

Different foundation materials are used in road construction and these can be separated into bound and un-bound foundation material. In appendix 5 the most important properties of foundation materials are given. It is possible to compare the traditional materials and a material with RoadCem based on these properties.

The properties of a material modified with a binder and RoadCem are dependent on the properties of the aggregate present and the amount of cement/fly-ash, RoadCem and water. These properties are discussed in chapter 5.

3.2.5 Construction and execution factors

In addition to the factors already discussed we also need to consider the prevailing conditions that are expected during the actual construction of the pavement. Factors of importance are:

- Weather expectations during construction of the product;
- Optimal moisture content of a material for achieving MPD (maximum proctor density)
- Equipment that is available;
- In-situ material characteristics and properties;
- Costs for the different materials;
- Costs for “installing/treating” the materials.

The weather has an influence on the execution of the task. For example when it is warm or it is too windy then more water needs to be added to the cement mixture as more evaporation would take place under these conditions and this needs to be compensated for. With temperatures higher than 20° Celsius and/or with strong winds approximately 1% extra water needs to be added in relation to the optimal water content to achieve MPD during compaction. This is essential for achieving the right binding for cement bound pavements.

Attention must be paid with freezing weather also. A concrete mixture cannot bind when it is colder than -4°C. Addition of RoadCem reduces the temperatures at which one can carry out the work up to -10 °C.

The availability of equipment is also important. A grader can mix the material but with a layer thicker than 25 cm it is advisable to use a recycler, soil stabilizer or cultivator.

Compacting the layers needs to be done securely using a static drum roller. If there is only a light weight roller available then compaction will be poor and strength performance will be compromised..

In some countries the costs of the different materials used in road construction, the concrete and the RoadCem will differ. This must be considered when making the design and with execution of the project.

It is recommended to discuss all these points with the client before the final designs are made, especially when these have been accepted by the potential contractor.

3.3 Conclusion

The data and information discussed in this Chapter is the minimum data and information needed for a good design. Other factors may be important in different project situations. In summary. the detailed specification of the following main factors needs to be prepared for a successful pavement design and for the identification of an "**OPTIMAL**" solution:

- User and Client Requirements.
- Traffic and Load intensity and dynamics.
- Material availability and specification.
- Equipment availability and specification.
- Economic and development specification.

When the first 2 of the above are known it is a matter of applying a structured design process to show what the advantages to using a RoadCem based solution are. To make RoadCem solution an acceptable solution it will usually be required that at least two comparative designs be prepared – one based on a conventional approach and one based on RoadCem technology. When this is done properly, the users and the client are typically convinced that the RoadCem approach is a better and more "OPTIMAL" solution than the conventional solution.

Until such time when RoadCem based solutions are considered main stream this design overhead is a necessity and will be necessary.

4. Design criteria

Weakest, Weaker, Weak, High, Higher, Highest

4.1 Introduction

To carry the traffic load and the weight of the pavement structure the sub-base must have a certain bearing strength. Traditionally, soil was not considered to be a valuable material for the construction of roads and aside from using it as a sub-base it was usually avoided in road construction. Instead what was considered to be an appropriate material was imported.

However we know that soil can also be used as a structural material, for example earth dams have been constructed for centuries throughout the world, houses have been constructed using soil as a main building block and different soils have been used in the manufacture of bricks and other structural materials for centuries. Why than is it that soil has not been considered as good road building material?

The answer to the above question partially lies in our tendency to follow the common practice and past solutions and partially in our failure to ask a question:

> **"How can we use any type of soil in road construction"??**

This question has now been asked and some answers have been provided. RoadCem is one of such answers as it allows us not only to improve soil as a sub-base but also to use soil for the construction of pavements proper. How this can be done will be discussed in the next chapter. In this chapter we focus on soil and its characteristics of importance to us from the road construction point of view. The main purpose of this chapter is therefore:

> **"Understanding important properties of soils as a road building material"**

4.2 Soil properties

4.2.1 General

Figure 4.1 Can we use soil for pavement structural layers?

The first thing one needs to do when characterizing the soil/sub base is to adopt a soil classification system.

The adoption of the principles of soil mechanics by the engineering profession has inspired numerous attempts to devise a simple classification system that will tell the engineer the properties of a given soil. As a consequence, many classifications have come into existence based on certain properties of soils such as texture, plasticity, strength, and other characteristics.

A few classification systems have gained fairly wide acceptance, but rarely has any system provided the complete information on a soil that the engineer needs. Nearly every engineer who practices soil mechanics will add judgment and personal experience as modifiers to whatever soil classification system he uses. Obviously, within a given agency (where designs and plans are reviewed by persons entirely removed from a project) a common basis of soil classification is necessary so that when an engineer classifies a soil as a certain type, this classification will convey the proper characteristics and behaviour of the material. Furthermore, the classification should reflect those behaviour characteristics of the soil that are pertinent to the project under consideration.

For our purposes we recommend that a Unified Soil Classification System (USCS) be used. When appropriate a reference to other Soil Classification Systems will also be given.

The USCS is based on identifying soils according to their textural and plasticity qualities and on their grouping with respect to behavior. Soils seldom exist in nature separately as sand, gravel, or any other single component. They are usually found as mixtures with varying proportions of particles of different sizes; each component contributes its characteristics to the soil mixture. The USCS is based on those characteristics of the soil that indicate how it will behave as an engineering construction material.

The following properties have been found most useful for this purpose and form the basis of soil identification:

- Percentages of gravel, sand, and fines (fraction passing the No. 200 sieve).
- Shape of the grain-size-distribution curve.
- Plasticity and compressibility characteristics. In the USCS, the soil is given a descriptive name and a letter symbol indicating its principal characteristics.

These properties can be determined by simple tests and, with experience, can be estimated with some accuracy.

USCS Procedure is summarized in Figure 4.2.

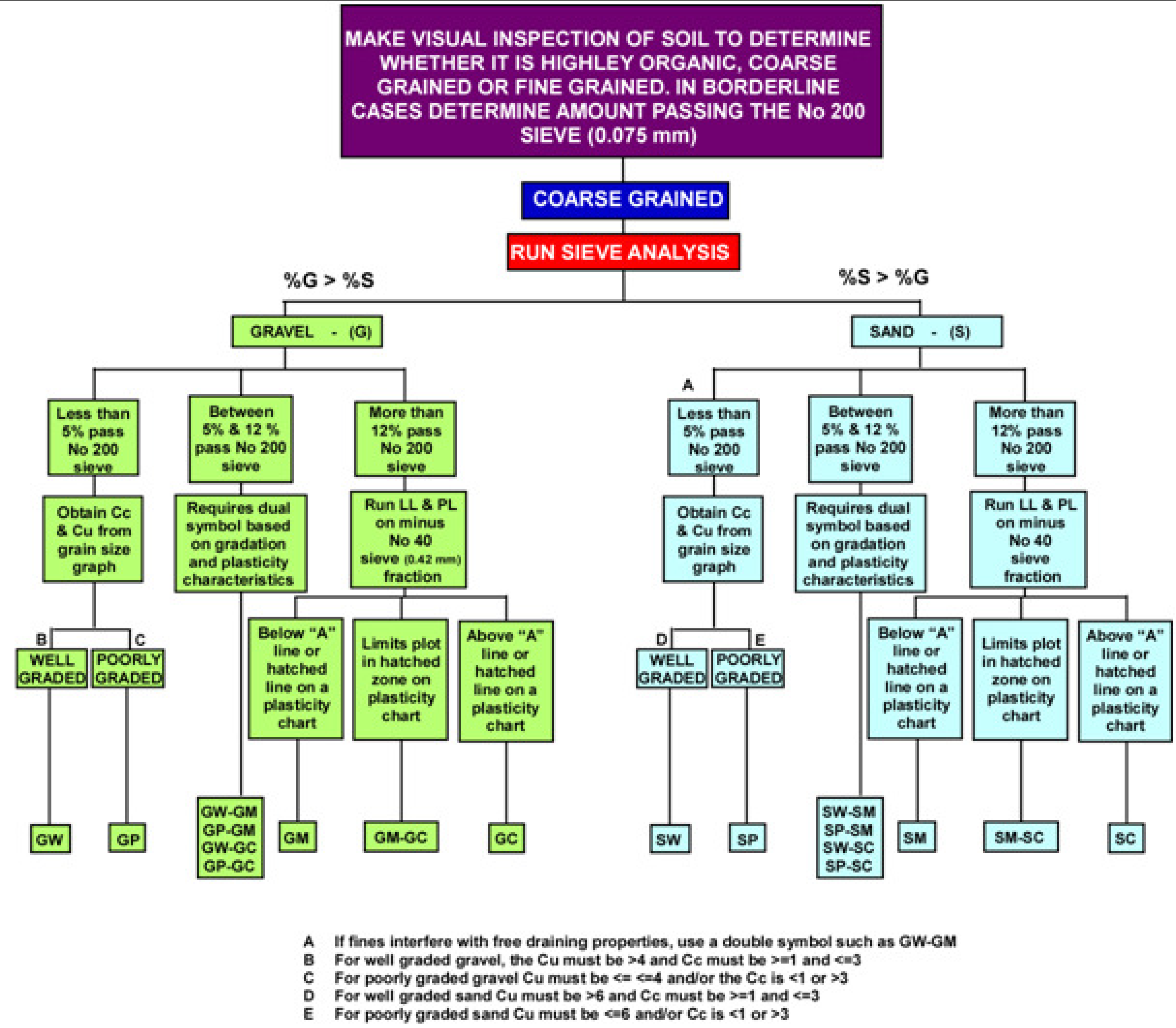
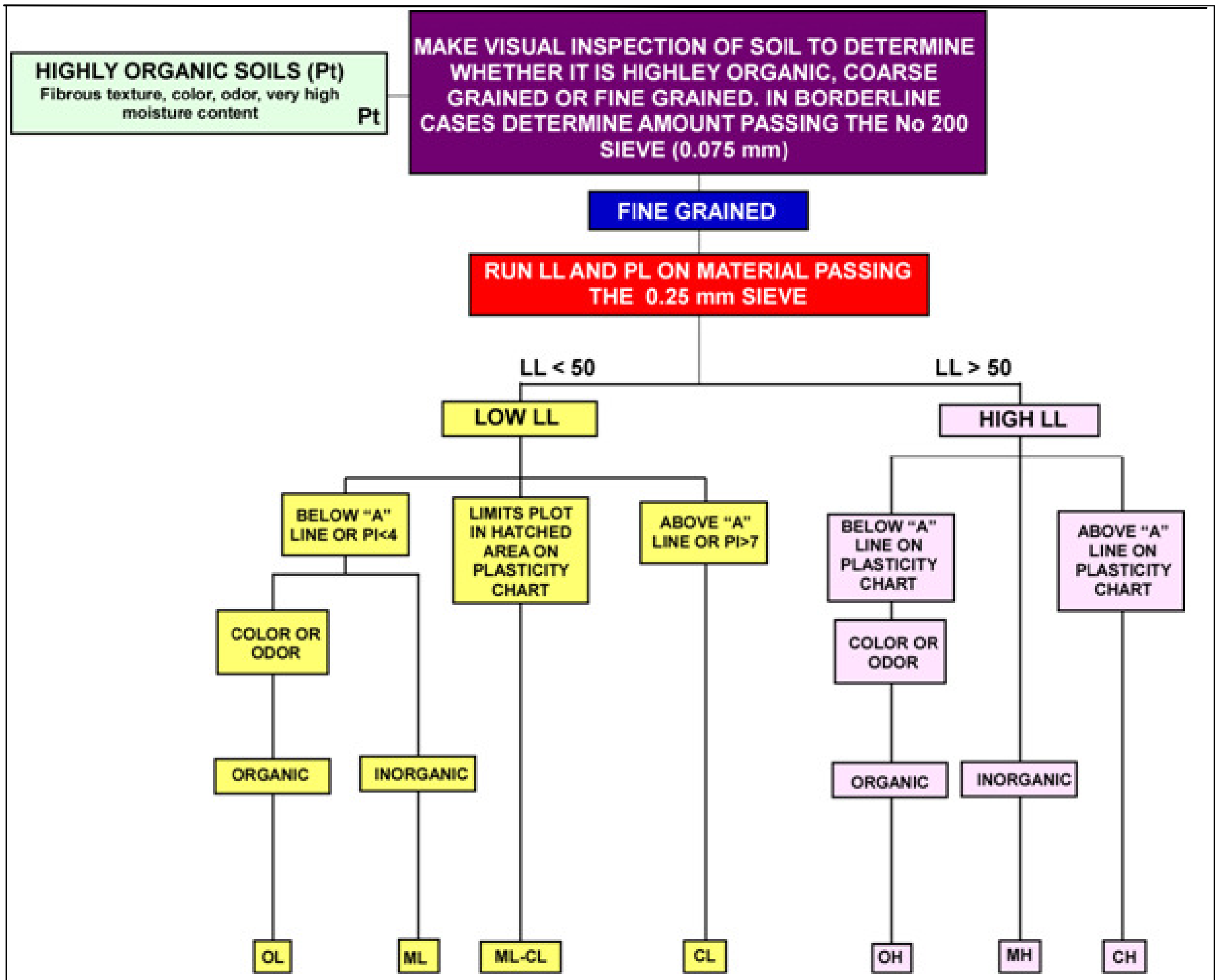


Figure 4.2a USCS Procedure Part A



F In cases where organic material can not be determined by color or odor, a LL and PL tests must be conducted on a sample of natural moisture content and a sample that has been oven dried. Organic soils will show a radical drop in plasticity for the oven dried sample compared to the retained moisture sample. Inorganic soils generally fall within +/- 1 or 2 % of each other.

Figure 4.2b USCS Procedure Part B

On the basis of the parameters used in the classification system the different soil categories have also been categorized with respect to their suitability for road construction. This traditional suitability classification is shown in figure 4.3.

MAJOR DIVISIONS		LETTER	COLOR	NAME	Value as a subgrade when not subject to frost action	Potential frost action	Compressability and expansion	Drainage Characteristics	Compaction Equipment	Dry Weight kg/m3	Typical Design Values	
											CBR	Subgrade Modulus k (kg/cm3)
Coarse Grained Soils	Gravel and Gravely Soils	GW	Red	Well graded gravels or gravel sand mixtures, little or no fines	Excellent	None to very slight	Almost none	Excellent	Crawler type tractor, rubber tiered roller, steel wheeled roller	1250-1400	40-80	50-90
		GP	Red	Poorly graded gravels or gravel sand mixtures, little or no fines	Good to Excellent	None to very slight	Almost none	Excellent	Crawler type tractor, rubber tiered roller, steel wheeled roller	1100-1400	30-60	50-90
		GM d	Yellow	Silty gravels, gravel-sand-silt mixtures	Good to Excellent	Slight to medium	Very slight	Fair to poor	Rubber tiered roler, sheeps foot roller, close control of moisture	1250-1450	40-60	50-90
		GM u	Yellow	Silty gravels, gravel-sand-silt mixtures	Good	Slight to medium	Slight	Poor to practically impervous	Rubber tiered roler, sheeps foot roller	1150-1350	20-30	35-90
		GC	Yellow	Clayey gravels, gravel-sand-silt mixtures	Good	Slight to medium	Slight	Poor to practically impervous	Crawler type tractor, rubber tiered roller, steel wheeled roller	1300-1450	20-40	35-90
	Sand and Sandy Soils	SW	Red	Well graded sands or gravely sand mixtures, little or no fines	Good	None to very slight	Almost none	Excellent	Crawler type tractor, rubber tiered roller, steel wheeled roller	1100-1300	20-40	35-70
		SP	Red	Poorly graded sands or gravely sand mixtures, little or no fines	Fair to Good	None to very slight	Almost none	Excellent	Crawler type tractor, rubber tiered roller, steel wheeled roller	1050-1350	10-40	25-70
		SM d	Yellow	Silty sands, sand-silt mixtures	Fair to Good	Slight to high	Very slight	Fair to poor	Rubber tiered roler, sheeps foot roller	1200-1350	15-40	25-70
		SM u	Yellow	Silty sands, sand-silt mixtures	Fair	Slight tohigh	Slight to medium	Poor to practically impervous	Rubber tiered roler, sheeps foot roller, close control of moisture	1000-1300	10-20	20-50
		SC	Yellow	Clayey sands, sand-silt mixtures	Poor to Fair	Slight to high	Slight to medium	Poor to practically impervous	Rubber tiered roler, sheeps foot roller,	1000-1350	5-20	20-50
Fine Grained Soils	Silt and Clays, LL<50	ML	Green	Inorganic silt and very fine sands, rock flour, silty or clayey fine sands or clayey	Poor toFair	Medium to very high	Slight to medium	Fair to poor	Rubber tiered roler, sheeps foot roller, close control of moisture	900-1300	15 or less	20-35
		CL	Green	Inorganic clays of low to medium plasticity, gravely clays, sandy clays, silty clays, lean clays	Poor to Fair	Medium to high	Medium	Practically impervous	Rubber tiered roler, sheeps foot roller	900-1300	15 or less	10-25
		OL	Green	Organic silts and organic silt clays of low plasticity	Poor	Medium to high	Medium to high	Poor to practically impervous	Rubber tiered roler, sheeps foot roller	900-1050	5 or less	10-20
	Silt and Clays, LL>50	MH	Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	Medium to very high	High	Fair to poor	Rubber tiered roler, sheeps foot roller	800-1050	10 or less	10-20
		CH	Blue	Inorganic clays of high plasticity, fat clays	Poor to Fair	Medium	High	Practically impervous	Rubber tiered roler, sheeps foot roller	900-1050	15 or less	10-25
		OH	Blue	Organic clays of medium to high plasticity, organic silts	Poor to very Poor	Medium	High	Practically impervous	Rubber tiered roler, sheeps foot roller	800-1100	5 or less	5-20
Highely Organic Soils		Pt	Orange	Peat and other highly organic soils	Not Suitable	Slight	Very high	Fair to poor	Compaction not practical			

4.3 Characteristics of Soil Groups pertaining to roads and airfields.

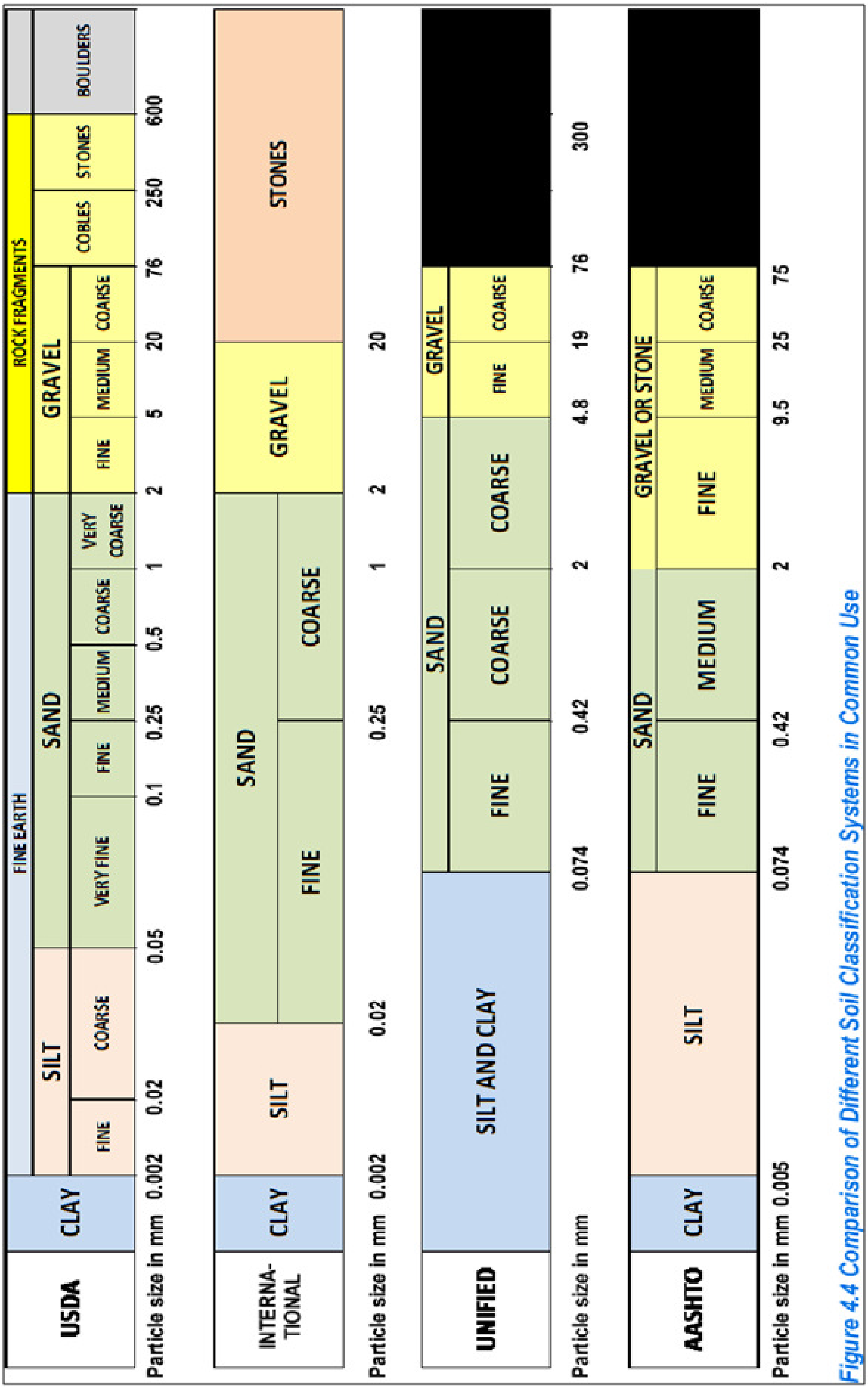


Figure 4.4 Comparison of Different Soil Classification Systems in common use.

It is noted that when RoadCem is used there is no such thing as poor soil for road construction but nevertheless we need to understand the soil classification system before we can do proper pavement design based on RoadCem.

Figure 4.4 gives a comparison of different classification systems in common use today and describes the relationship between particle size classes and different classification systems. Using this figure one can always refer to the Unified Soil Classification System as the base for pavement design purposes.

USCS and other soil classification systems focus on grain size distribution and organic content the primary parameters on which the classification is based. These two parameters also have effect on other soil properties of importance for road construction.

The most important soil properties from the road construction point of view are:

- Grain composition and Colour.
- Soil Structure and Texture.
- Soil Chemistry and Morphology.
- Organic content.
- Consistency (Plasticity, Stiffness, Penetration Resistance).
- Bearing strength.
- Setting behaviour.
- Ground water level.

Each of these parameters is discussed in more detail.

4.2.2 Grain Composition/Particle size distribution

The grain composition/particle size distribution and the condition of the sub-base determine the in situ soil bearing capacity and the intervention/design that might be needed to bring the soil bearing capacity to the desired value (the mix design - soil/cement/RoadCem etc.).

The particle size distribution is determined according to the following procedure:

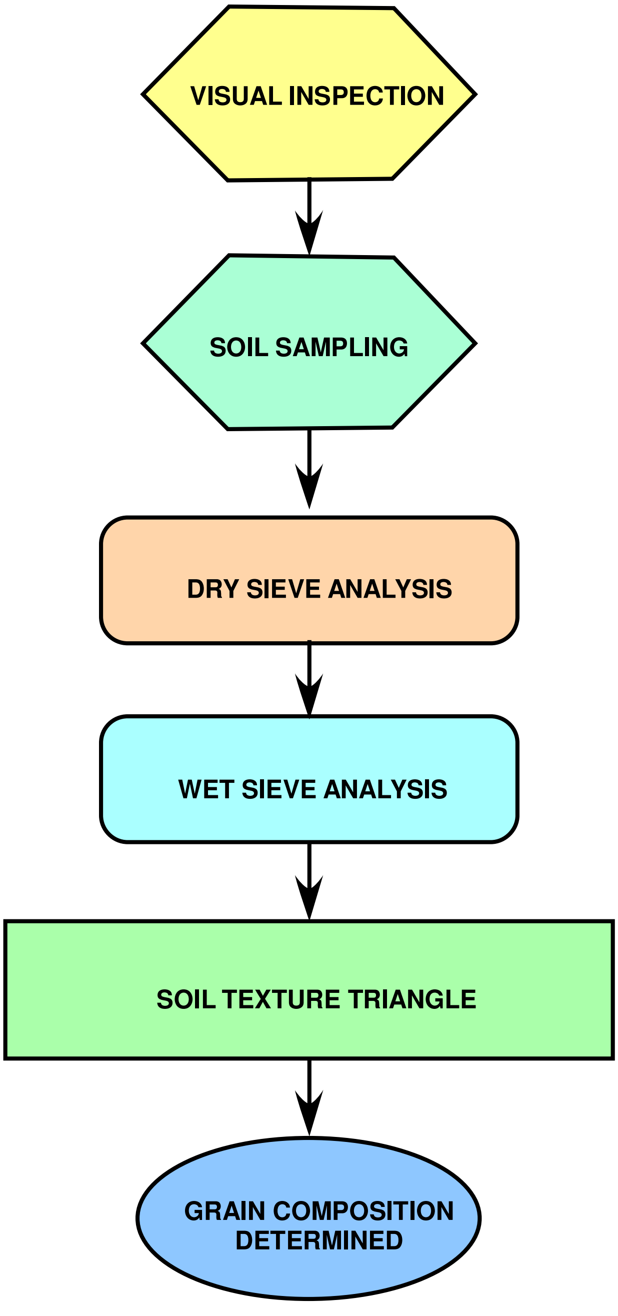


Figure 4.5 Procedure for determining particle size distribution.

A visual inspection can roughly determine what the sub-base is composed of. There are locations where, as a result of erosion many grooves and thin fractions occur. This requires a certain insight into the causes of erosion.

Boulders, gravel, sand, silt and clay fractions are grouped according to the grain size. Erosion occurs from water, and/or wind streams.

Figure 4.6 Wind erosion, Grand Canyon .   *Figure 4.7 Water erosion.*

The biggest grains are found mainly in the mountains where the river originates. The smaller, finer grains are found in the valleys of the mountains in the part of the river where the water flow is less.

Figure 4.8 Origin, Large grain.   *Figure 4.9 Fine grains at the mouth of the river.*

Comparision of the relative volume of a grains of sand, silt and a clay particle is shown in a figure 4.10:

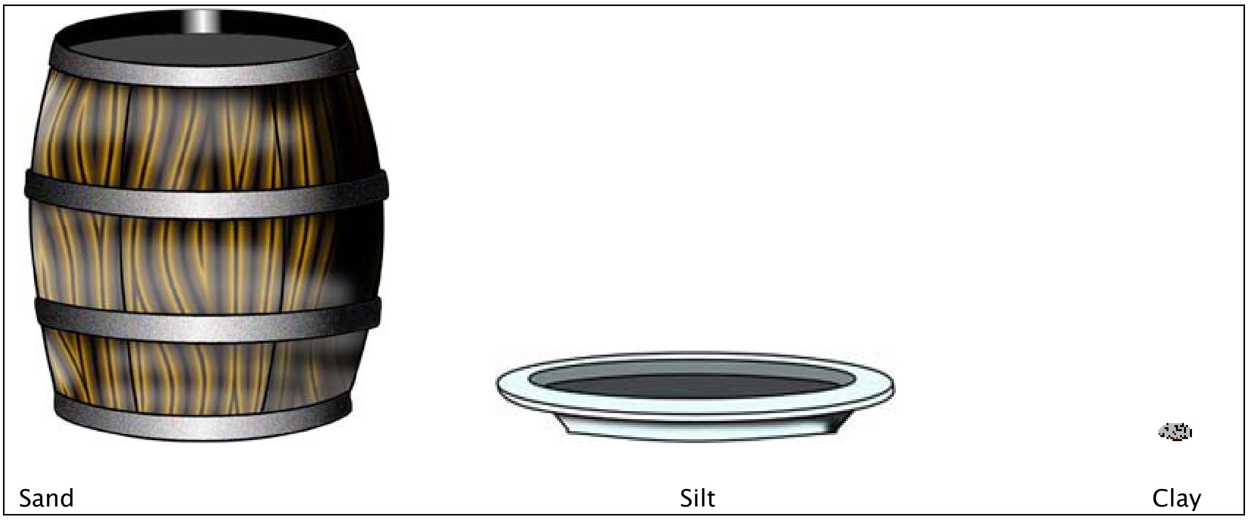


Figure 4.10 Schematic report comparison grains of sand, silt and clay.

Typical raw materials are shown in a figure below:

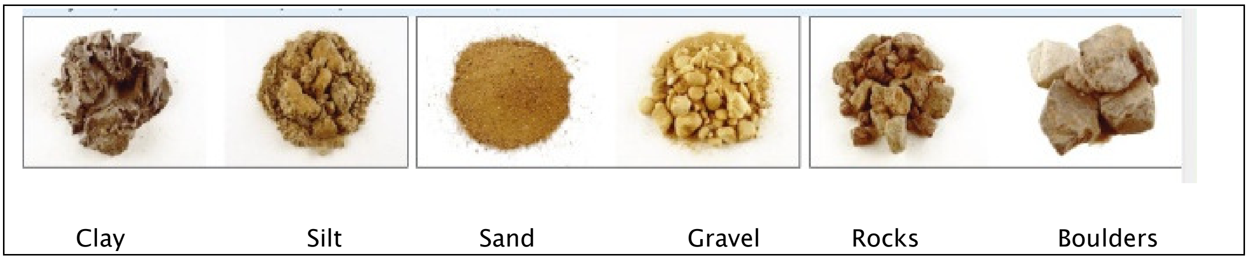


Figure 4.11 Typical appearances of clay, silt, sand, gravel, boulders and rocks.

Typical particle sizes for these different groups are shown in Table 4.1

Table 4.1 Grain sizes.

Raw materials	Grain size
Boulders	100 mm
Rocks	60 mm
Gravel	60 mm – 2 mm
Sand	2 mm – 0,063 mm
Silt	63 µm – 0,002 µm
Clay	< 0,002 µm

Field Description of Soils

Understanding and interpreting soils is an iterative process that begins with a soil description and leads towards an assessment of the soils suitability for a particular job. The factors to consider are: profile description, wetness conditions, and restrictive horizons, aerobic conditions, internal vs. external drainage, etc.. Evaluation of the soil is just one component of fully assessing a site.

Where do we begin to describe a soil? Just like the recipe for woodchuck stew starts with "first find a woodchuck hole" so with soil description we must first find a hole or soil to describe. Some examples of different soils and soil profiles are given in figures 4.12 and 4.13.

Once the hole is dug decisions need to be made as to what do you describe. The level of detail of this description will be related to the proposed soil use, however a soil description should include most if not all of the following; horizon, depth, color, texture, features, consistence, structure, pores, roots, and reaction. Each component of the description will aid in the overall interpretation. However, depending on the intended use some will be more important than others. For our purposes the important factors are: color, texture and structure and consistency parameters such as plasticity, stickyness and penetration resistance.

Soil Colour

Colour is the first soil property to consider. It is perhaps the most obvious and easily determined soil characteristic.

Important characteristics can be inferred from soil colour. Well drained soils have uniform bright colours. Soils with a fluctuating water table have a mottled pattern of gray, yellow, and/or orange colors. Organic matter darkens the soil and is typically associated with surface layers. Organic matter will mask all other colouring agents. Iron (F_e) is the primary coloring agent in the subsoil. The orange brown colors associated with well drained soils are the result of F_e oxide stains coating individual particles. Manganese (Mn) is common in some soils resulting in a very dark black or purplish black color. Several other soil minerals have distinct colors, thus making their identification straight forward. For example, glauconite is green, Quartz has various colors but is often white or gray, feldspars range from pale buff to white, micas may be white, brownish black, or golden, and kaolinite appears gray to white.

Colour determination can be quite subjective if just a verbal description is used. In general each person will perceive color differently, thus there is a need to standardize it.

Figure 4.12 Different soil types and profiles.

Figure 4.13 Different soil types and profiles.

In the early 1900's a study was done to make color description easier. The method devised used the artist's color well. Each pie wedge represented a particular spectral wavelength or HUE (R=Red etc.) These wedges could be further divided into smaller sections (1R = 10% Red, 10R = 100% Red). Typically only the 25, 50, 75 and 100% are used (2.5, 5, 7.5, and 10). The HUE does not tell the whole story. Shading (value) and purity or intensity (chroma) was then added. A measure of lightness or darkness was then added. Value refers to how light or dark the color is (gray scale). Value indicates the degree of lightness or darkness of a color relative to gray. Value extends from pure black (0) to pure white (10) and is a measure of the amount of light that reaches the eye, gray is perceived as about halfway between black and white and has a value notation of 5. Lighter colors have values between 5 and 10; darker colors are between 5 and 0. Chroma is the relative purity or strength of the spectral color. Chroma indicates the degree of saturation of neutral gray by the spectral color. Chromas extend from 0 for neutral colors to 8 as the strongest expression of the color.

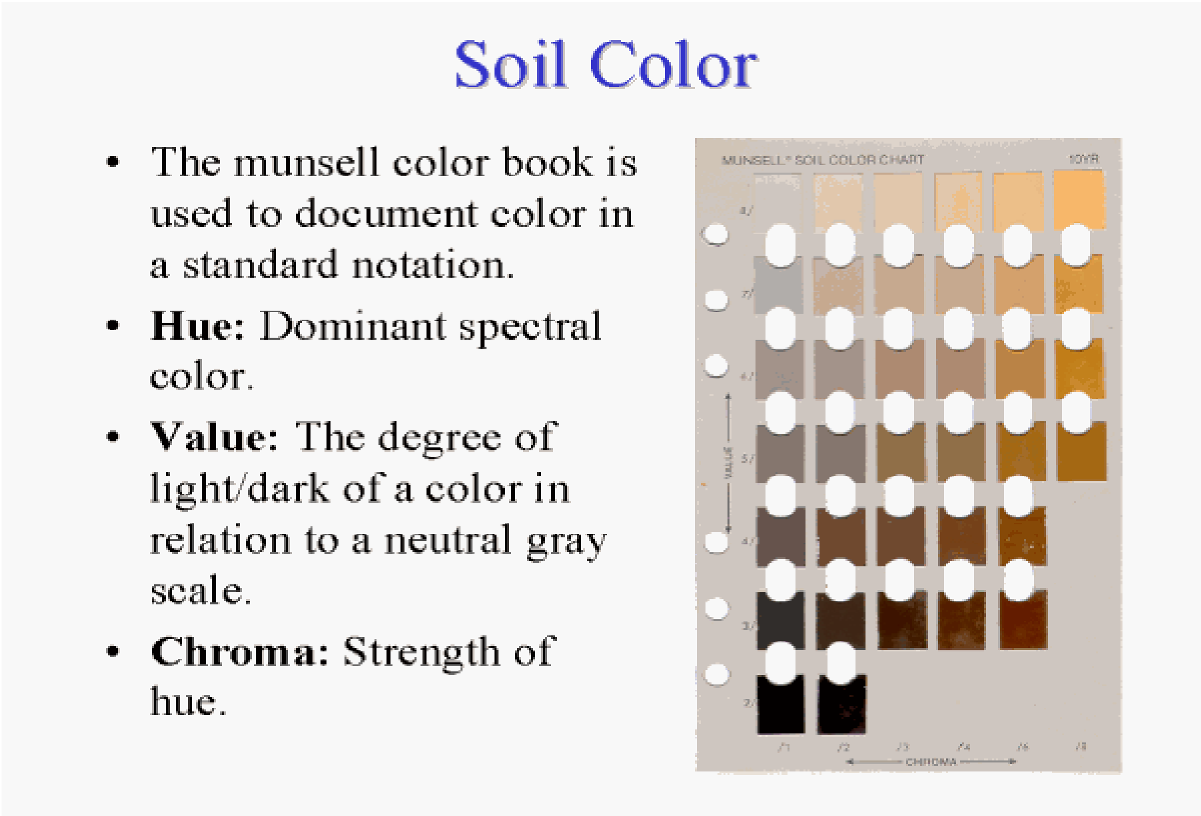


Figure 4.14 The Munsell Color System for Soil Color – Example page.

Putting all this together the Munsell Color System was created (Figure 4.14). It was initially designed for manufacturing but soon made its way into any field that needed to record and communicate color.

Hue refers to the dominant wavelength of light (red, yellow, green, etc.) (Figure 4.15).

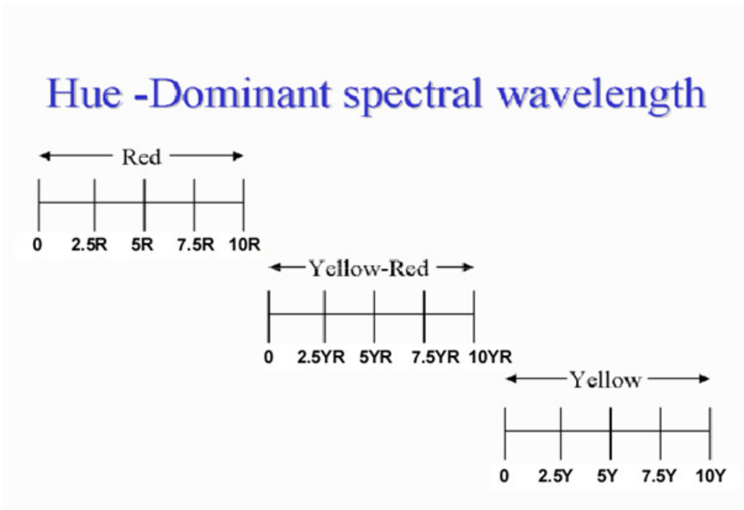


Figure 4.15 Hue-Dominant spectral wavelength.

Value refers to the lightness and darkness of a color in relation to a neutral gray scale.(Figure 4.16)

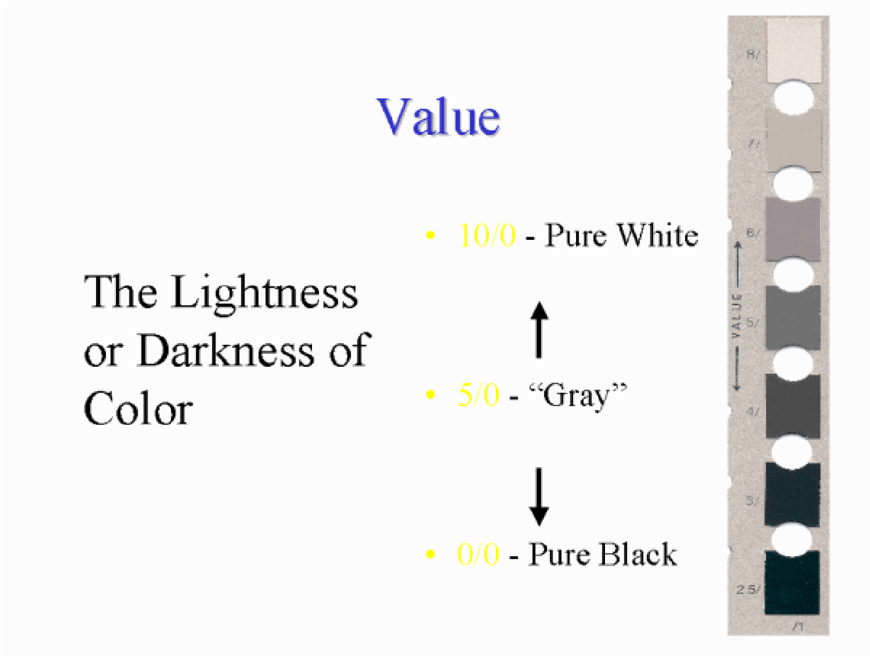


Figure 4.16 Lightness or Darkness of color.

Chroma is the relative purity or strength of the Hue.

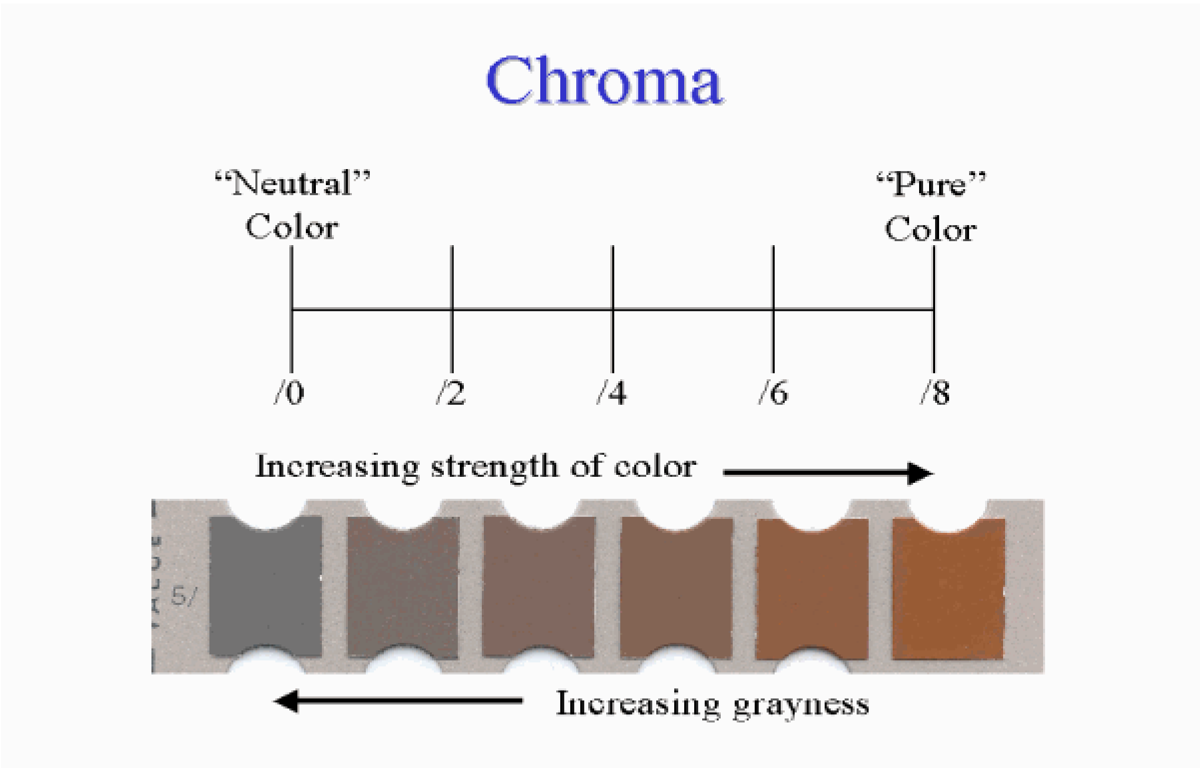


Figure 4.17 Chroma.

The typical notation of color is an alpha-numeric term of Hue Value/Chroma or 10YR 5/6. Some colors have symbols such as N 6/. These are totally achromatic (neutral color), and have no hue and no chroma, only a value.

Colors should be recorded in a specific fashion. Soil should be moist. Although this is the most common way soil colors are recorded they can be recorded in the dry state. At all time the moisture status of the sample should be noted. Always use a freshly exposed face or ped and record what is being colored. Do not crush or rub the soil before getting a color unless it is an organic sample. Colors must always be determined in natural light (direct sunlight). Furthermore, colors should not be determined late or early in the day as the sun angle can alter the observed color. Colors should never be determined under artificial light. Finally, color should not be determined when one is wearing sunglasses or tinted glasses.

In describing colors it is important to determine the variation in color throughout the soil. Matrix color is the color that occupies the greatest volume. Some soils have several colors through the profile, the color that appears the most is recorded first and so forth.

Contrast refers to how easy it is to see a feature as compared to the matrix. There are 3 classes of contrast; faint, distinct, and prominent. Faint contrast is evident only on close examination. Distinct contrast is readily seen but moderate to the color to which compared. Prominent contrast is strongly contrasting colors to which they are compared (Table 4.2).

Table 4.2 Contrast chart.

Contrast Class	Code	Difference in color between Matrix and Mottle			
		Hue	Value		Chroma
Faint	F	same	0 to <2	and	<1
Distinct	D	same	>2 to <4	and	<4
		or			
		same	<4	and	>1 to <4
		1 page	<2	and	<1
Prominent	P	same	>4	or	>4
		1 page	>2	or	>1
		2+ page	>0	or	>0

Taking ground samples (in-situ)

Samples are taken to measure precisely the composition of the grain. The amount of sample needed depends on the location. When there are different types of soil present then tests must be carried out on all the different soil samples. Different soil types can be visually separated based on their color, change in height, etc. 25 dm^3 is needed for each soil sample. This amount is important to carry out extra tests at a later stage. It is also important to weigh the soil sample on the spot before packing it in an airtight bag. In this manner it is possible to determine the moisture content in the sub-base.

Figure 4.18 Measuring the weight of the samples before packing in an airtight bag.

Dry sieve test (laboratory)

The grain composition of the large grains is determined using the dry sieve test. A sample is used for this test which is done in the laboratory. The correct sieve relation is determined between the rocks, gravel, sand, silt or clay. The dry sieving tests can determine which types of soil are present. A wet sieving test is needed to measure the smaller fractions.

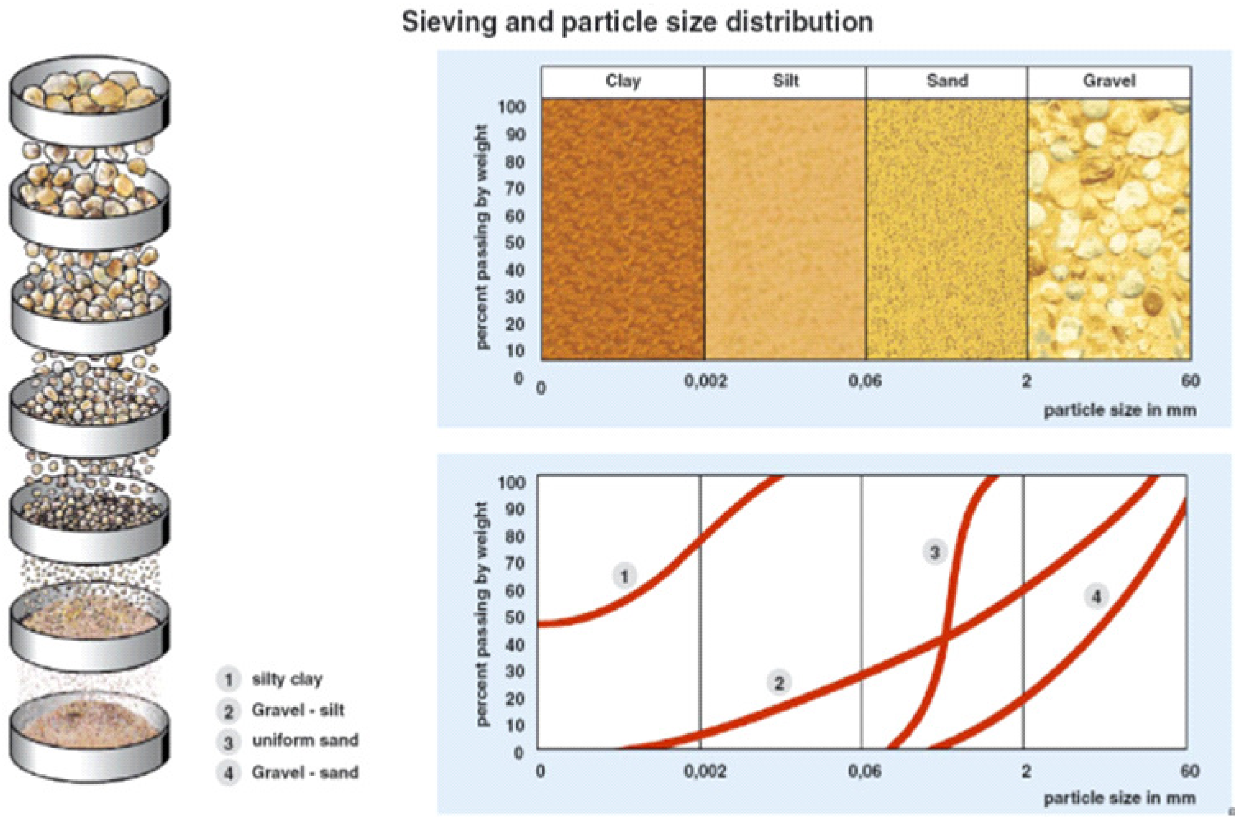


Figure 4.19 Dry Sieve Test.

Wet sieve test (laboratory)

The wet sieving test is used to determine the grain composition of the smaller particles <63 µm. This test is also done in the laboratory. When 10 % or more of the soil is smaller than 63µm then it is necessary to use a wet sieving test.

4.2.3 Chemistry and Morphology

Chemistry and soil morphology are intimately related. Essentially, the soil looks the way it does due to chemical reactions. Three types of reactions, redox reactions, podzolization, and cementation, are important as is the resulting morphology, and interpretation. Other reactions do occur but these three are the most critical in regards to soil evaluation for our purposes.

Redox reactions are short for oxidation-reduction reactions. These reactions occur in all soil but are most common in seasonally saturated and hydric soils. It is these reactions that are responsible for many of the soil colors observed in soil. Other than color redox reactions control organic matter contents and are related to soil water chemistry. The general redox principle is that as OM decomposes it releases electrons. These electrons are taken up by (or given to) another element or compound. The compound that gains an electron is said to be reduced as the electron has a negative charge thus the overall charge or the element or compound is reduced by 1. Conversely a substance that looses an electron is said to be oxidized.

In soil there are aerobic soil reactions. In these reactions oxygen acts as the terminal electron acceptor. This reaction results in the most energy for the living organisms in soil and is preferred. Respiration uses oxygen as the terminal electron acceptor. If the oxygen is removed from the system then the soil is said to be anaerobic, that is without air. Once the oxygen is removed several anaerobic reactions will occur. The sequence that the reactions occur in is dependent on the amount of energy each reaction will produce. The sequence starts with aerobic reactions (respiration), then denitrification, then Mn or Fe reduction, then sulfate reduction, and finally carbon dioxide reduction.

Denitrification occurs when nitrate is used as the terminal electron acceptor. Nitrate is reduced to nitrogen gas. This reaction can be measured in soil by measuring the production of N2 gas. There is no morphologic signature to this reaction.

Iron (Fe) reduction occurs when Fe3+ is used as the terminal electron acceptor. Fe3+ (ferric iron) is reduced to Fe2+ (ferrous iron). Unlike nitrate reduction there is a morphologic signature of Fe reduction. Consider soil particles to be coated or painted with Fe-oxide paint (rust). This is similar to the way in which M&Ms are coated with a colorful candy shell. If the M&Ms get wet the shell is washed or dissolved off leaving the white candy shell beneath. Similarly the rusty coating on soil particles is dissolved off as the Fe3+ is converted to Fe2+. The Fe2+ is colorless and soluble in water. The gray color that remains is the color of the mineral grains.

Sulfate reduction occurs as sulfate is converted to hydrogen sulfide gas, which smells like rotten egg. Generally this odor is only encountered when the soil is saturated and reduced for sulfate.

Redoximorphic features, formerly known as mottles, are formed by changes in redox conditions in seasonally saturated soil, the reduction and oxidation of C, Fe, Mn, and S compounds, and the subsequent translocation of C, Fe, Mn, and S compounds. The best evidence of this process is to find features caused by reduction and oxidation in the same profile. The oxidized features are evidence of translocation. In order to for features to form the following must occur:

- must have anaerobic conditions (reduced and saturated - stagnant);
- must have Fe and/or Mn (electron acceptor);
- must have microbes (bugs);
- must have carbon (food for the bugs).

Within the soil reducing conditions may occur adjacent to organic matter. For example Fe is reduced near the dead root after all the oxygen and nitrate is removed from the water. The reduced Fe is soluble in water and diffuses away from the root area leaving gray minerals behind. As the reduced Fe interacts with the water that has not had all its oxygen removed it will reoxidize or rust leaving a red rim around the reduced area in the middle. Since the bacteria are not mobile the area of reduction will be near a carbon source.

It is important to know the chemical composition of the sub-base to determine how much RoadCem is needed. The organic content has an effect on the binding of the material. When contaminated substances need to be immobilized then the amount of RoadCem that is needed is higher. When there are strongly contaminated substances present then it is maybe required to use ImmoCem. The procedure to use in order to evaluate chemical composition of the soil is specified in figure 4.20.

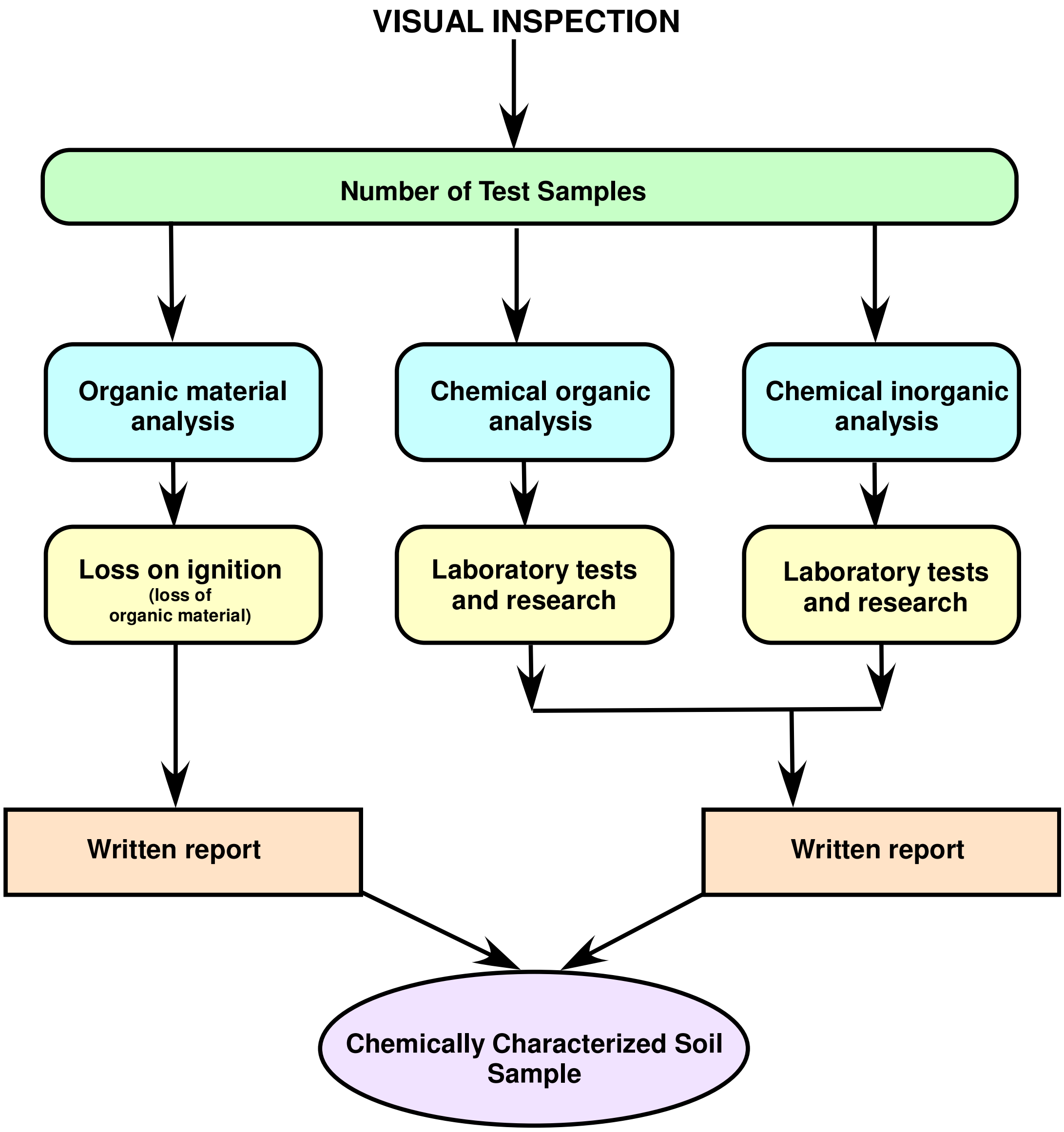


Figure 4.20 Chemical Characterisation of Soils.

During the visual inspection one estimates how many tests (must) be made. In most casess when dealing with polluted soils it is a legal requirement to determine the chemical composition and to prove that the relevant substances that are present in the in-situ material can be immobilized.

Organic Carbon influences soil by acting as a coloring agent, improving the water holding capacity, increasing fertility and improving aggregation. Organic matter may feel smooth (like silt) and sticky (like clay) and therefore interfere with your texture by feel. Organic matter is approximately 1.77x the organic carbon content. A soil is divided into 3 classes based on the organic carbon content related to clay; muck, mucky mineral, and mineral.

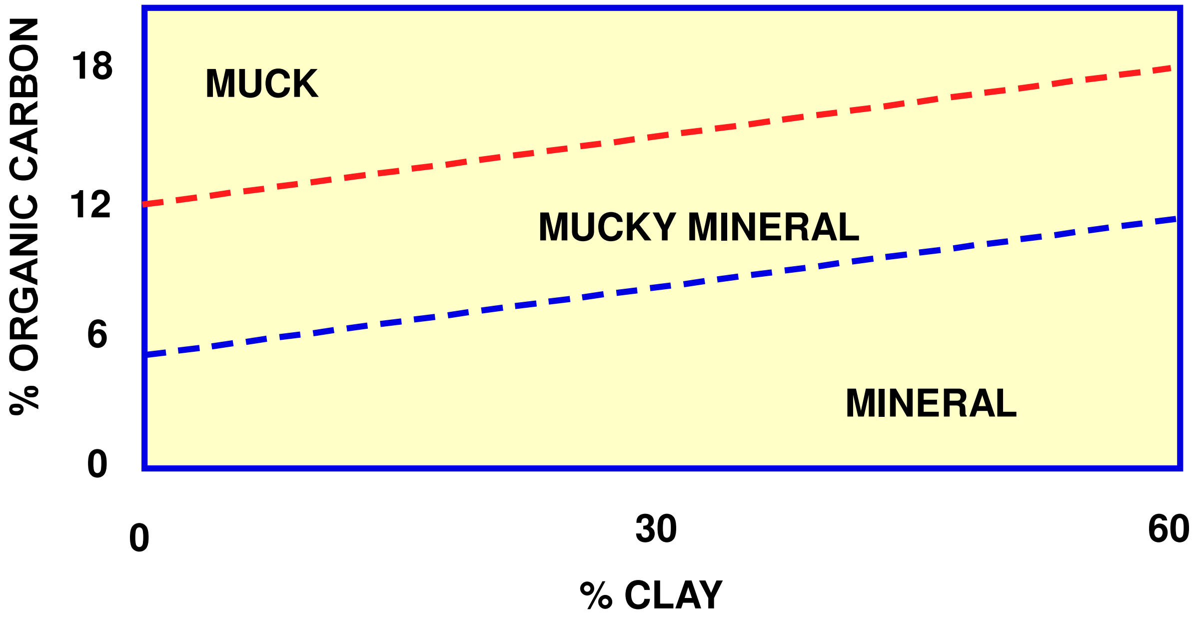


Figure 4.21 Soil and Organic matter.

Organic mater content may be determined in the lab or in the field. For field determination it is best to have known standards to calibrate yourself. In addition to amount of organic mater it may be necessary to determine how decomposed the materials is. There are 3 types of soil organic materials; sapric (Oa) – very decomposed, <17% rubbed fibers, hemic (Oe) – decomposed, 17 to 40% rubbed fibers, fibric (Oi) – least decomposed, > 40% rubbed fibers also referred to as sapric (Oa) – muck, hemic (Oe) – mucky peat, fibric (Oi) – peat.

In order to identify organic soil type, rub moist sample between fingers 10 times. Examine material with hand lens and look for fibers, not live roots, and estimate percent fibers remaining. Fibers are smaller than 2 cm (approx. 1”) and show cellular structure. Muck is highly decomposed, < 1/6 fibers remaining after rubbing (sapric material). Mucky peat is moderately decomposed, between 1/6 and ¾ fibers remaining after rubbing (hemic material). Peat is slightly decomposed, > ¾ fibers remaining after rubbing (fibric material).

It is important to be able to tell the difference between organic and mineral material as this could affect interpretations. Specifically, muck and mucky mineral soils often suggest wet soil conditions, whereas dark soils may not. Thus the difference between these two materials can influence one’s final interpretation of the site.

Determination of organic content

The organic content can be determined visually and it can be seen directly if there is much humus present, this is shown in Step 4.

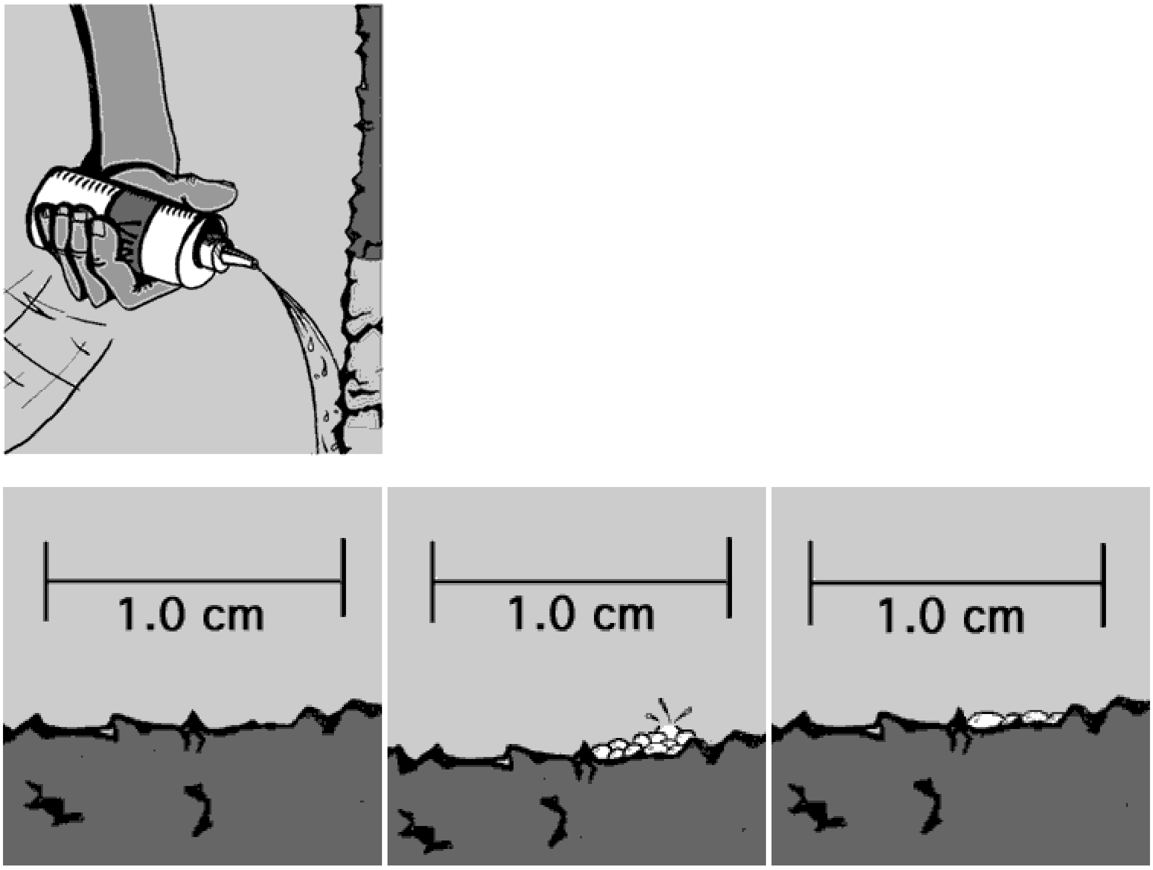
Figure 4.22 Organic content of the sub-base.

In a marshy area the sub-base is often rich in peat and contains a high amount of organic matter.

The organic content can be determined using the “loss of organic material” test. Using this test the amount of organic matter in the material is determined. Organic matter does not bind easily and has a lower bearing strength value. Cement cannot be bound with organic matter. When much organic matter is present in the sub-base the amount of RoadCem must be increased.

Indicative test for soil organics

The organic matter can be determined in-situ. Mixing the ground with vinegar (or other acid) this will froth up if any organic matter is present. This simple test helps to show any organic material present.



No bubbles. When no organic matter is present.	Few bubbles. When relatively little organic matter is present.	Many bubbles. Has relatively much organic matter present.

Figure 4.23 Indicative test determines organic content sub-base.

Determination of organic content

When the exact amount of organic material %m/m must be known this can be ascertained by a burning test. The loss of organic material m/m % is determined by using a test whereby the organic matter is burnt up and this can be done by heating the soil sample to 550 degrees Celsius. The difference in weight of the sample before burning and after burning will determine the mass percentage of organic matter in the soil.

Determination organic and inorganic chemical composition

Chemical composition of soil is important for two reasons:

- To determine chemical proporties of soil
- To establish if the soil is polluted and weather imobilization may be requiered

Tests in the laboratory are necessary for both purposes.

Organic and inorganic substances often found in soils are shown in Table below as are the Dutch requirements regarding the protection of the environemnt for a particular substance (focus is on groundwater quality protection).

Table 4.3 Soil Chemical composition Norms/Standards (Dutch Groundwater Quality Act))

Constituent	**Maximum allowed Emission requirement – leaching from unformed material, mg/kg dry mass**	**Maximum allowed Emission requirement – leaching from formed material, mg/kg dry mass (Gazzeted)**
Arsenic	None	None
Cadmium	None	None
Chromium	None	None
Copper	None	None
Mercury	None	None
Lead	None	None
Nickel	None	None
Zinc	None	None
PAH 10	50	50
Mineral oil	500	500
Antimony	0,16	8,7
Arsenic	0,9	260
Barium	22	1500
Cadmium	0,04	3,8
Chromium	0,63	120
Cobalt	0,54	60
Copper	0,9	98
Mercury	0,02	1,4
Lead	2,3	400
Molybdenum	1	144
Nickel	0,44	81
Selenium	0,15	4,8
Tin	0,4	50
Vanadium	1,8	320
Sink	4,5	800
Bromide	20	670
Chloride	616	110000
Fluoride	55	2500
Sulphate	1730	16500

4.2.4 Soil Texture

Soil texture refers to the weight proportion of the particles less than 2 mm in size as determined from a laboratory particle-size distribution analysis. Field estimates should be checked against laboratory determinations and the field criteria should be adjusted as necessary.

Figure 4.24 Indication of bearing capacity based on soil texture.

Texture is an important indicator of soil bearing capacity which in turn is one of the main pavement design parameters. In section 4.2.5 the determination of the bearing capacity is explained for in-situ and lab test.

The texture of soil tells us much about the soil in a few words. With texture given, approximations and estimates can be made of many properties of a soil, such as bearing value, water-holding capacity, liability to frost-heave, adaptability to soil-cement construction, etc.

Standard Texture groups have been defined as a function of particle size distribution within a given soil. Figure 4.25 shows an example of soil texture classes.

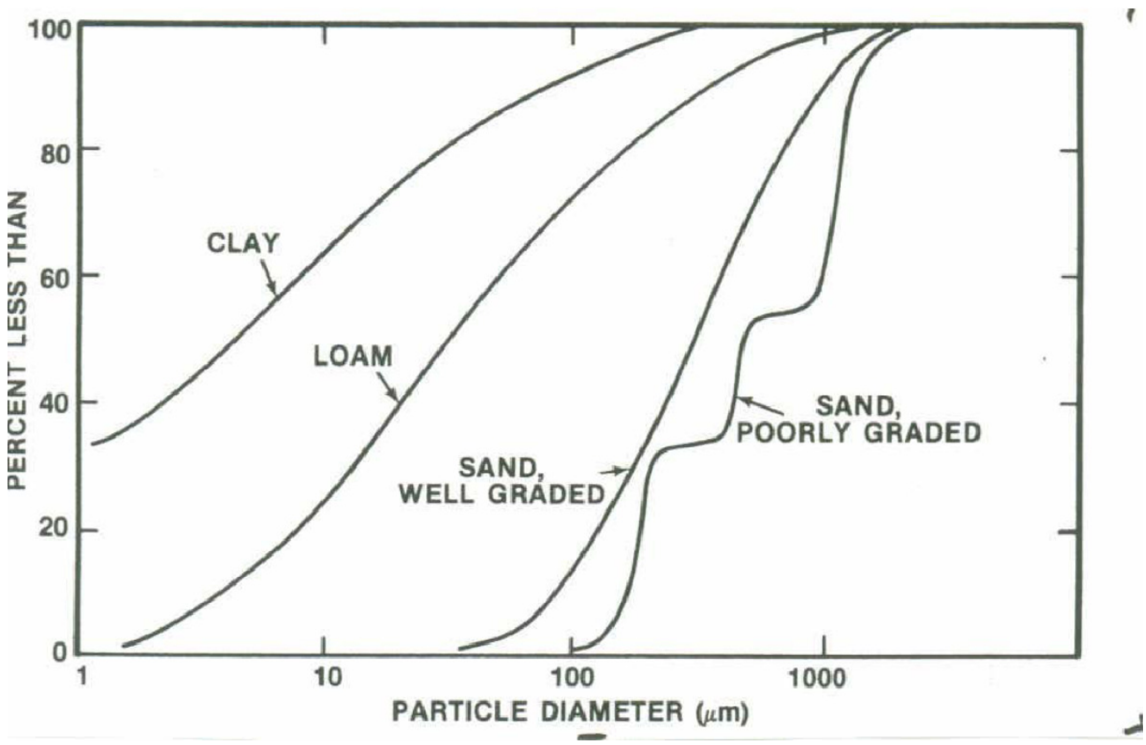


Figure 4.25 Example Soil texture classes.

Full classification with respect to soil texture is sumarised as a “soil texture triangle” (Figure 4.26)

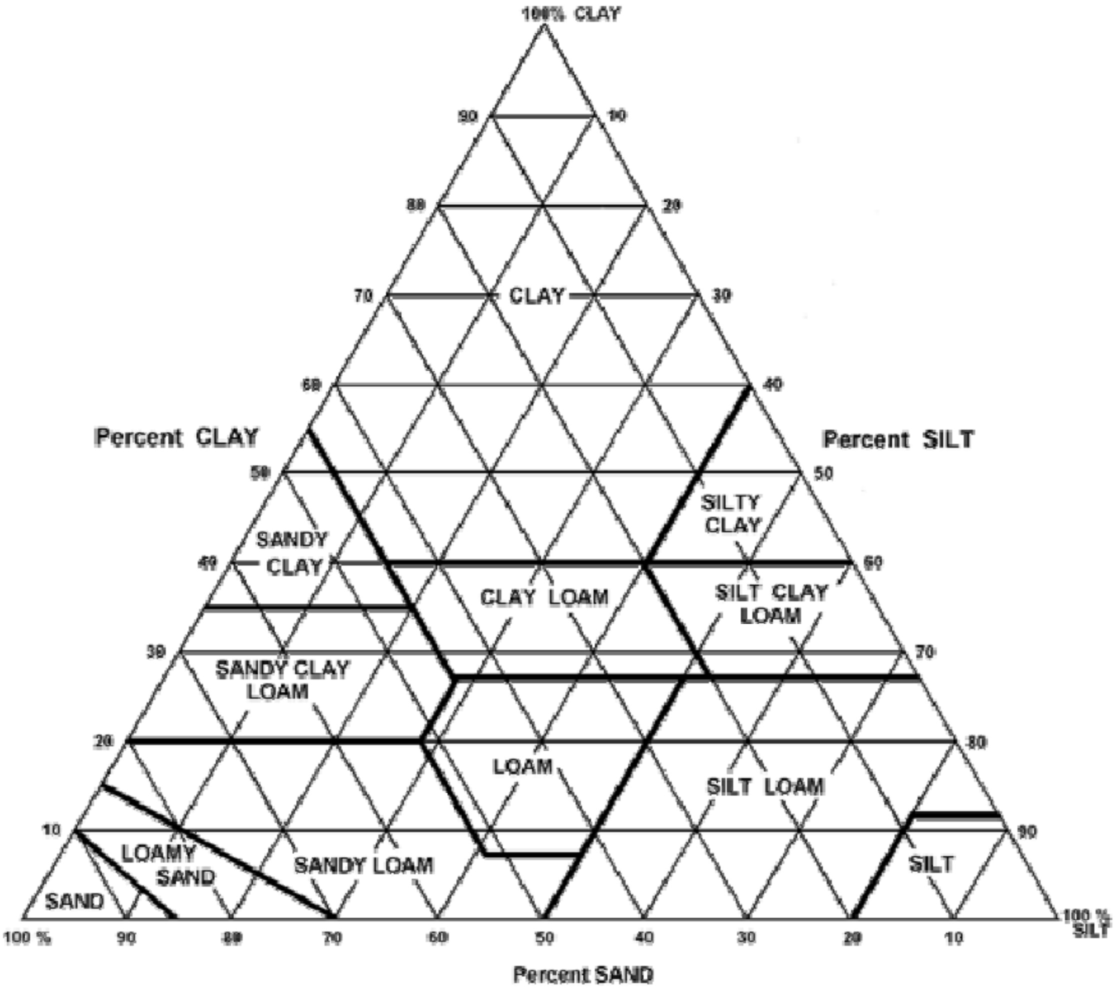


Figure 4.26 The Soil Texture Triangle.

The Triangle is most often used to determine soil texture. In the figures 4.27 up to 4.30 some examples for diferent soil types are shown.

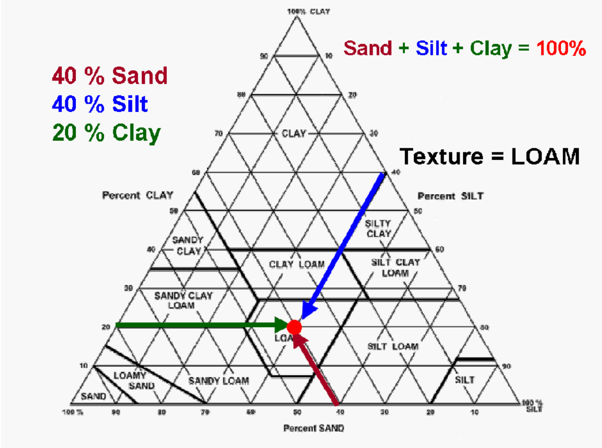


Figure 4.27 Soil Texture = LOAM.

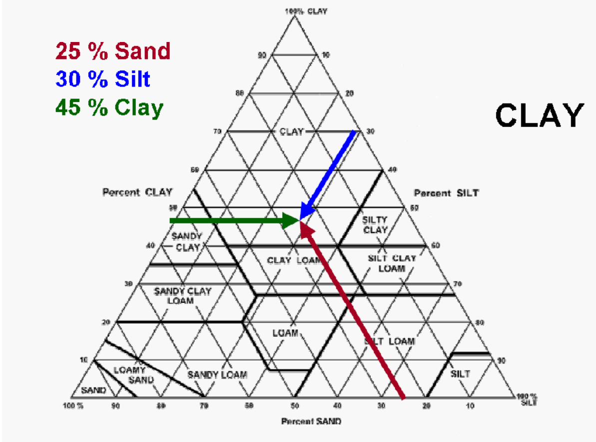


Figure 4.28 Soil Texture = CLAY.

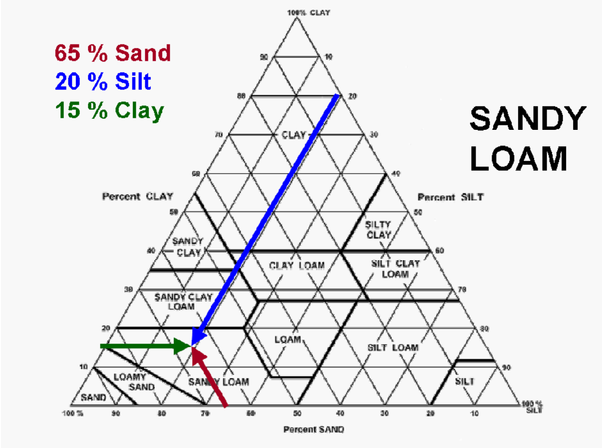


Figure 4.29 Soil Texture = SANDY LOAM.

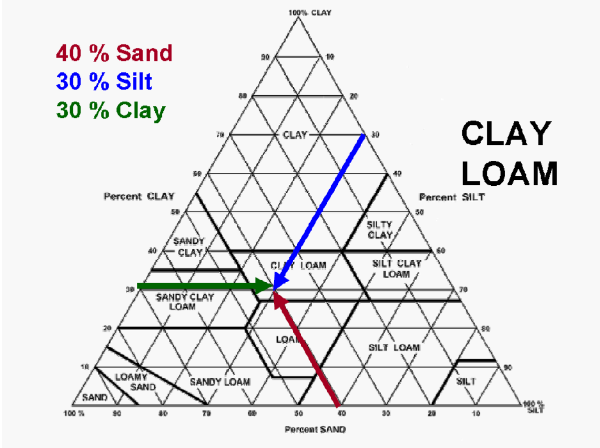


Figure 4.30 Soil Texture = CLAY LOAM.

In the absence of particle size analysis, soil texture can also be estimated by feel and this is usually what happens in the field during field surveys.

The feel and appearance of the textural groups illustrate factors used in determining the texture of a soil in the field and also assist in field classification work. Note that forming a cast of soil, dry and moist, in the hand and pressing a moist ball of soil between the thumb and finger constitute two major field tests to judge soil texture. Samples are given below.

Sand

Individual grains can be seen and felt readily. Squeezed in the hand when dry, this soil will fall apart when the pressure is released. Squeezed when moist, it will form a cast that will hold its shape when the pressure is released but will crumble when touched. (Figure 4.31)

Loamy Sand

Consists largely of sand, but has enough silt and clay present to give it a small amount of stability. Individual sand grains can be seen and felt readily. Squeezed in the hand when dry, this soil will fall apart when the pressure is released. Squeezed when moist, it forms a cast that will not only hold its shape when the pressure is released but will withstand careful handling without breaking. The stability of the moist cast differentiates this soil from sand. (Figure 4.32)

Figure 4.31 Sand.

Figure 4.32 Loamy sand.

Loam

Consists of an even mixture of sand and silt. It contains also a considerable amount of clay. It is easily crumbled when dry and has a slightly gritty, yet fairly smooth feel. It is slightly plastic. Squeezed in the hand when dry, it will form a cast that will withstand careful handling. The cast formed of moist soil can be handled freely without breaking.

Silt loam

Consists of a moderate amount of fine grades of sand, a small amount of clay and a large quantity of silt particles. In a dry undisturbed state, the silt loam appear quite cloddy but they can be pulverized readily; the soil then feels soft and floury. When wet, silt loam runs together and puddles. Either dry or moist casts can be handled freely without breaking. When a ball of moist soil is pressed between thumb and finger, it will not press out into a smooth, unbroken ribbon but will have a broken appearance.

Clay loam

A fine-textured soil which breaks into clods or lumps that are hard when dry. When a ball of moist soil is pressed between the thumb and finger, it will form a thin ribbon that will break readily, barely sustaining its own weight. The moist soil is plastic and will form a cast that will withstand considerable handling.

Clay

A fine-textured soil that breaks into very hard clods or lumps when dry, and is plastic and unusually sticky when wet. When a ball of moist soil is pressed between the thumb and finger, it will form a long ribbon.

The procedure one would use to establish soil texture by feel is summarized in figure 4.33

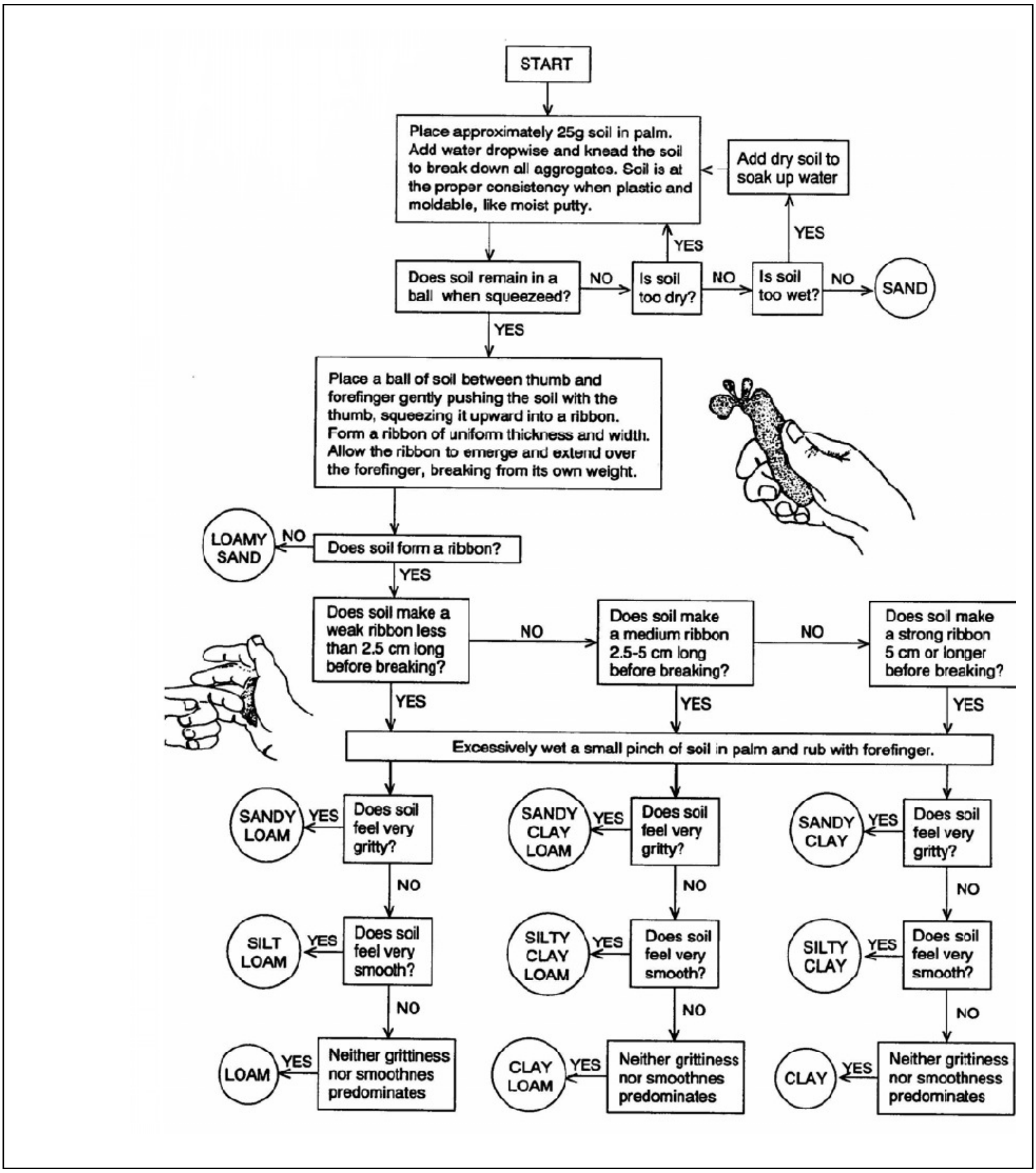


Figure 4.33 Soil texture by feel.

Soil texture is a main determinant of water percolation rates through the soil. Typical water percolation rates for different soil textures are given in table 4.5.

Table 4.5 Soil texture and water percolation.

Median percolation rates for 220 subsoil horizons grouped by textural class			
Textural Class	cm/hr	in/hr	Number of Observations
Silty Clay Loam	1.3	0.5a*	22
Silt Loam	2.3	0.9a	33
Clay Loam	2.5	1.0a	18
Silty Clay	3.3	1.3ab	9
Loam	4.1	1.6ab	71
Clay	4.3	1.7ab	16
Fine Sandy Loam	12.2	4.8b	19
Sandy Loam	14.7	5.8b	17
Loamy Coarse Sand	27.7	10.9b	5
Loamy Sand	47.2	18.6b	4
Sandy Clay Loam	48.8	19.2b	6
Coarse Sand	83.8	33.0b	2

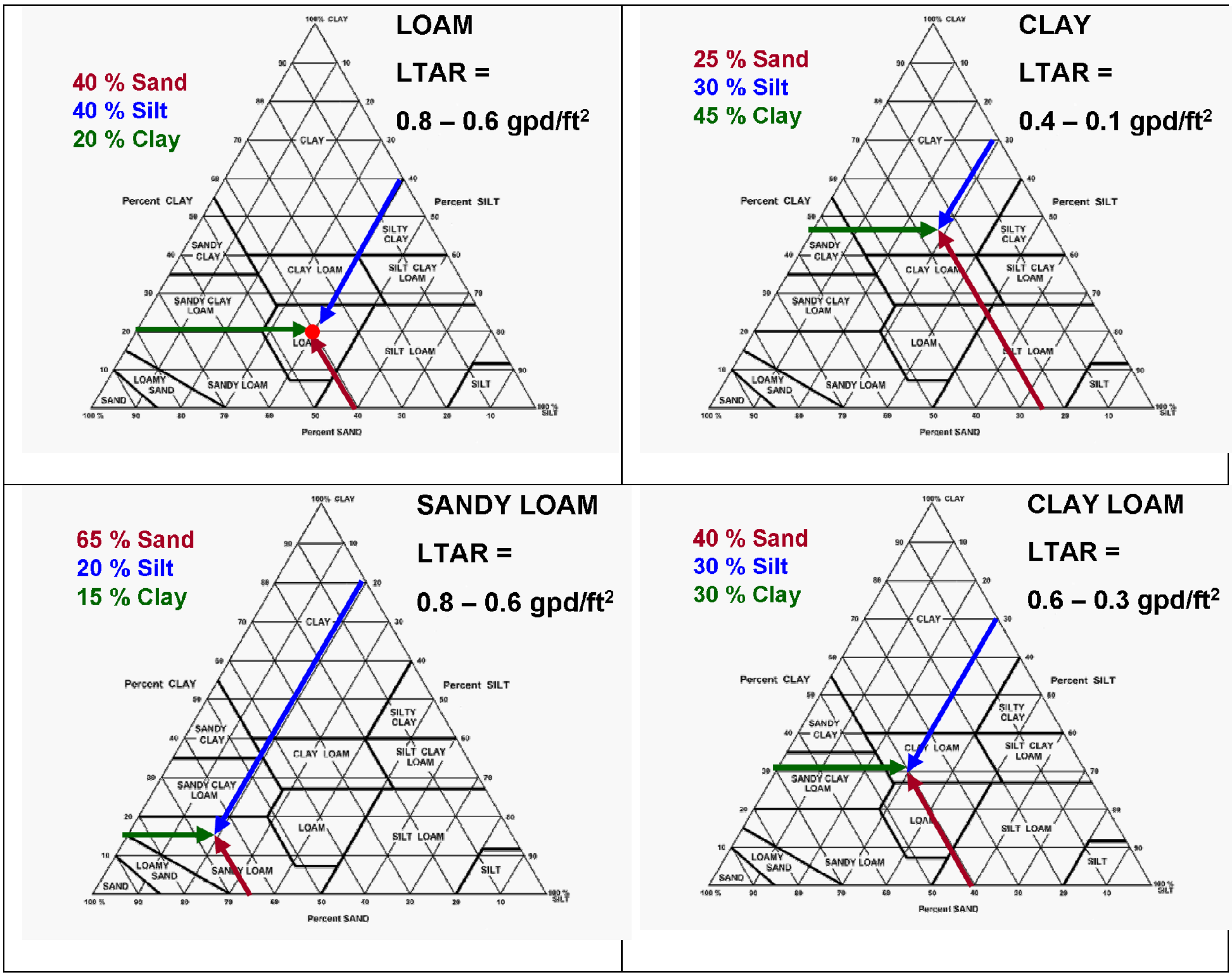


Figure 4.34 Water percolation and soil texture.

4.2.5 Soil Structure

Soil structure is another aspect of soil description that must be considered in order to evaluate a soil. Soil structure relates to the bigger picture of how water will move in the soil. Soils with a good texture may be foiled by a poor structure. One definition of soil structure is the grouping of individual soil particle into a larger grouping. You can also thinks of structure as a brick house in that the brick, mortar and cement are the particles (i.e. texture) and the completed house is the structure. We are concerned about structure because of its relation to use of soils as a road building materials or sub bases.

Certain structures are more likely to be restrictive to water movement and thus more suitable for road construction for example.

Structure is the naturally occurring arrangement of soil particles into aggregates (peds) that result from pedogenic processes. There are three general groups:

1. Natural Soil Structural Units (pedogenic structure).

2. Structure less.

3. Artificial Earthy Fragments or Clods.

These soil structure is described by using 3 components: type, size, and grade, Figures 4.35, 4.36 and 4.37.

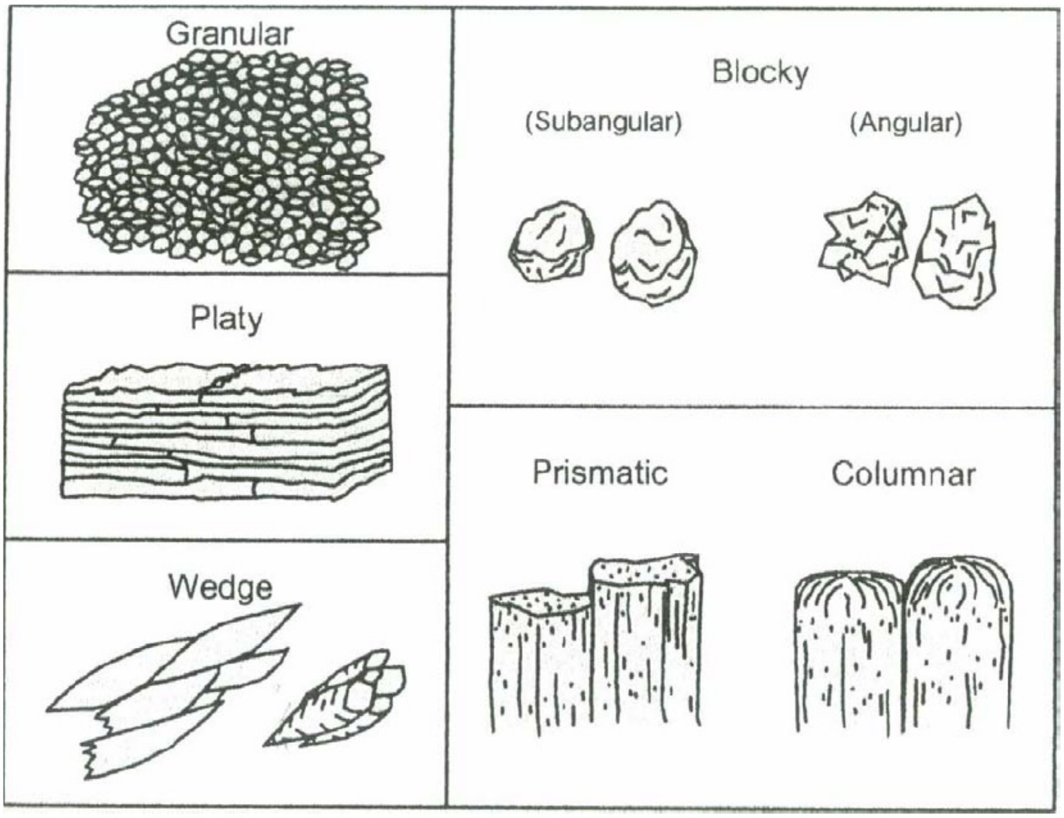


Figure 4.35 Pedogenic soil structure.

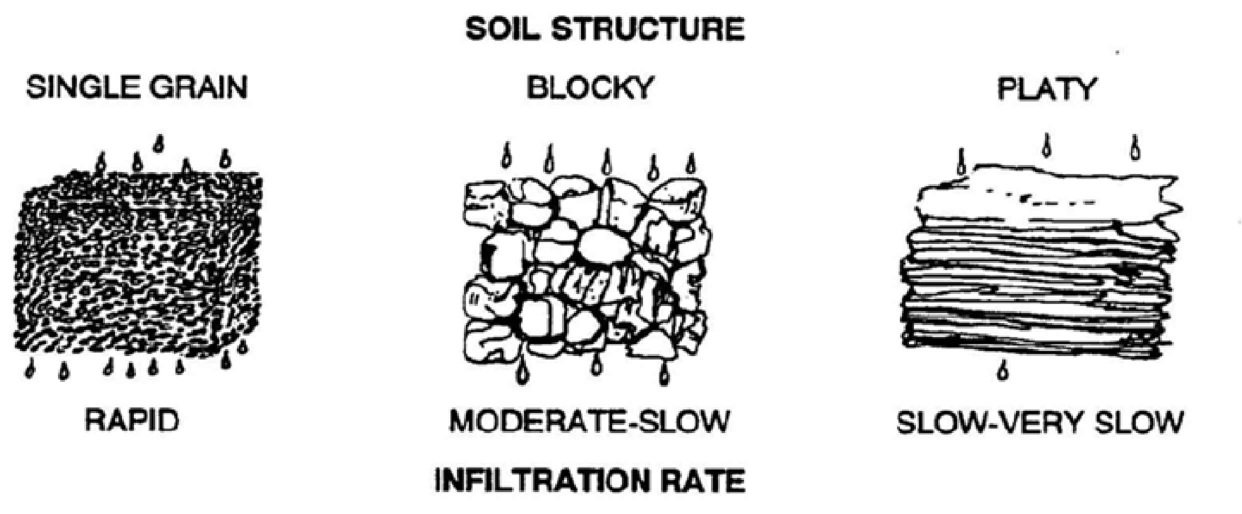


Figure 4.36 Size classes as elements of soil structure.

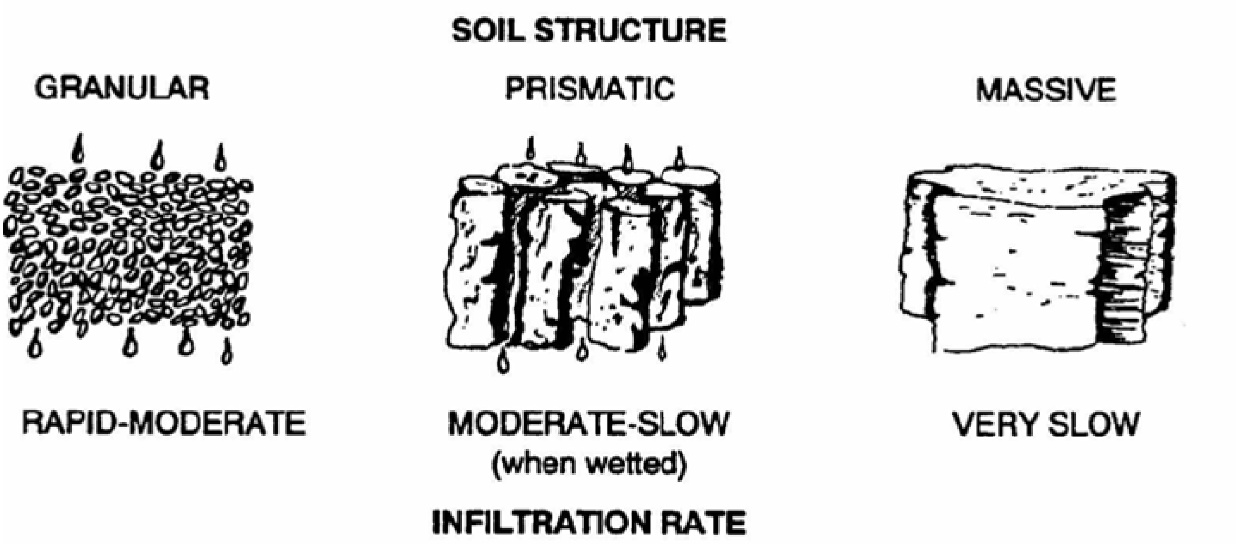


Figure 4.37 Grade classes as elements of soil structure.

Pedogenic structures

Pedogenic structure is divided into 7 classes:

1. Granular.
2. Angular blocky.
3. Sub angular blocky.
4. Platy.
5. Wedge.
6. Prismatic.
7. Columnar.

Typical granular structure looks like granola and is most often found in the surface layers. Angular blocky structure is equidimensional with the faces at sharp angles and the peds fit together well. Sub angular blocky structure is more rounded than angular. Platy structure is wider than deep. Wedge structure has elliptical interlocking peds the often show slickened sides. Prismatic structure is vertically elongated. Columnar structure is similar to prismatic but the unit tops are frequently rounded and bleached due to the high salt content.

Structureless soils

Structureless soils are broken into 2 official groups:

1. Single Grain, Massive and Massive.
2. Rock Controlled Fabric.

Single grain refers to sands whereas massive refers to any soil that does not break apart into any predictable and repeatable type or shape. Massive rock controlled structure is used for soil developed from saprolite. Unlike simple massive structure, rock controlled fabric has a preferred orientation of the minerals. The material may easily break into the individual mineral grains.

Size is broken into 5 groups. The actual size ranges vary depending on the type of structure. Note that platy refers to thickness and columnar and prismatic refer to diameter. (Figure 4.38)

Grade refers to how well expressed or how stable the structure is. There are 4 groups of structure grade (0-3). All structureless soils have a grade of 0. The others range from 1 to 3. (Figure 4.39).

- Structure less are soils where no discrete units observable in place or in hand sample.
- Weak structured soils have units that are barely observable in place or in a hand sample.
- Moderate structured soils have well-formed units that are evident in place or in a hand sample.
- Strong structured soils have units that are distinct in place (undisturbed soil), and separate cleanly when disturbed.
- Compound structure is described when smaller structural units held together to form larger units. For example a soil may be described as having "Moderate coarse prismatic structure parting to strong medium sub angular blocky structure." This means that sub angular blocky is the primary structure and prismatic is the secondary structure.

The formation of structure in soils has not received the level of scrutiny proportional to its importance in road construction. Structure formation is related to physical, chemical and biological processes at work in the soil. The physical processes that affect structure are:

- Alleviations/eluviations.
- Freeze/thaw.
- Compaction.
- Disruption (mechanical, natural i.e. slope movement)
- Wet/dry
- Shrink/swell.

Eluviated zones generally have weaker structure or are structureless where as the Illuviated zones show stronger structures as the illuviated material will help define the structures units by coating and stabilizing peds.

Even if the material does not have a high amount of expandable clay minerals, desiccation will cause cracks. These cracks may become stabilized as clay, oxides or organic matter move through and/or coats them. When expandable clays are present their action can help define and form wedge structures. In regions that experience freezing of the ground surface such action may aid in structural development. In some ways this is similar to shrink/swell because the soil is compacted as object is force upward. The compaction form ped faces which, if stabilized may form structural units. However the next freeze/thaw cycle could destroy the original feature.

Compaction generally results in denser soil maybe even structureless.

The soil water chemistry affects structure as well. As with physical influences these affects can be both positive and negative. Flocculation is the bringing of the particles close together and is enhanced by polyvalent cations (Al^{+++}, Ca^{++}, etc.). The flocculated units may form some of the initial building blocks for structural units (This is for example one of the mechanisms of RoadCem activation).

Fe oxides may coat and bridge particles. These oxides may be attached to clay or other particle charges. The oxides may help define a weak subangular blocky structure. Similar to oxides, organic acids will coat and stabilize. Commonly these acids will overwhelm the particles and cement the particles in the horizon together.

The biological influence generally enhances the structure. Microbes and fungus add to structure by their by-products, their mediation of redox reactions (Fe oxides), and binding particles together. This phenomenon is most common in the topsoil but can occur wherever enough carbon is present for food.

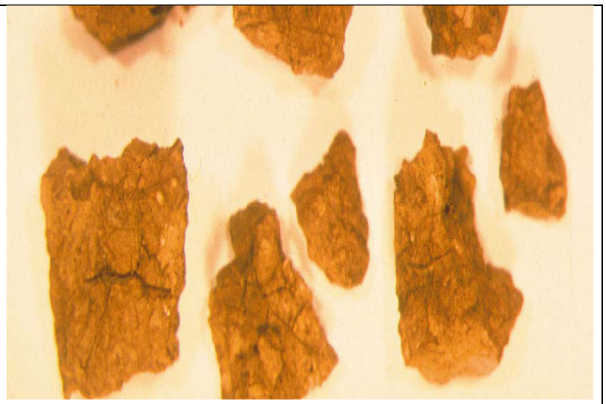
The type of structure has a profound impact on how water will move through the soil. A well structured soil will conduct water away faster as the larger voids will have a greater conductivity and may allow for deeper flow.

In Conclusion structure is an important but overlooked aspect of soil evaluation

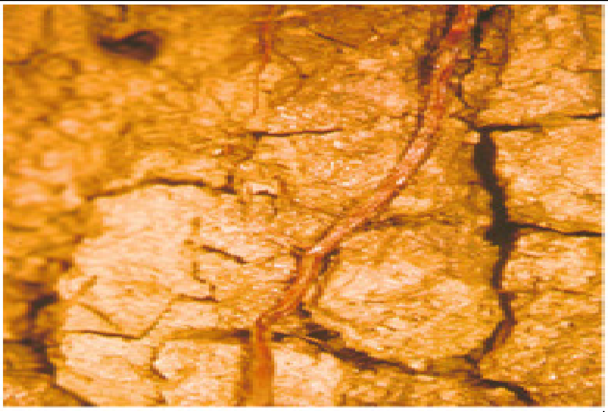
If possible structure should be viewed in a pit. Structure should be assessed in the field with an eye for how will water flow through the soil. This can best be done by looking at roots and ped faces. The relationship between structure and water movement is complex and differs depending on moisture content.

Examples of different soil structures are given in figure 4.38 and 4.39.

Granular



Angular Blocky



Subangular blocky

Platy – Flat and tabular like units

Wedge – elliptical interlocking lenses terminating in acute angles

Prismatic – vertically elongated units with flat tops

Figure 4.38 Examples of soil structures.

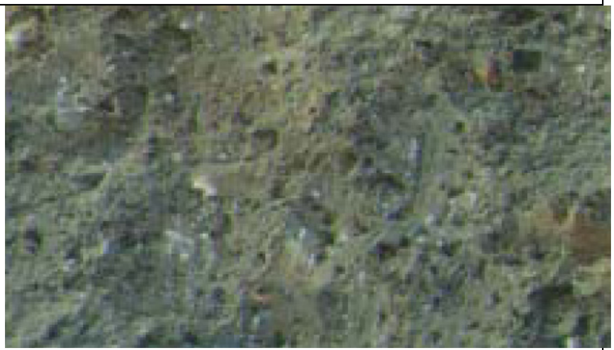
 Columnar – vertically elongated units with rounded tops (usually bleached)	 Single grain – no structure (loose sand)
 Structureless Single Grain: No discrete structural units observable in place or in hand sample. Composed of individual particles. Material is noncoherent	 Structureless --Massive: No discrete structural units observable in place or in hand sample. Material is coherent
 Structureless --Massive: RockMassive: Rock--controlled fabric. No discrete structural units observable in place or in hand sample	 Moderate --Units well--formed and evident in place or in a hand sample

Figure 4.38 Continued.

Strong --Units are distinct in place (undisturbed soil), and separate cleanly when disturbed

Moderate, very coarse, prismatic

Moderate/strong, thick, platy

Weak, medium subangular blocky

Figure 4.38 Continued.

4.2.6 Stickiness

Stickiness is the capacity of a soil material to adhere to other objects. A sample of soil is crushed in the hand, water is applied while manipulating with thumb and forefinger. Stickiness is estimated at the moisture content that displays maximum adherence between thumb and forefinger.

Table 4.6 Table stickiness.

Class	Criteria
Non sticky	Little or no soil adheres to fingers after release of pressure. Sligthly sticky soils adheres to both fingeres after release of pressure with little stretching on separation of fingers.
Moderately sticky	Soil adheres to both fingers after release of pressure with some stretching on seperation of fingers. Very sticky soil adheres firmly to both fingers after release of pressure with much stretching on separation of fingers.

Figure 4.40 Stickiness.

4.2.7 Plasticity

Plasticity is the degree to which puddled or reworked soil material can be permanently deformed without rupturing. The evaluation is made by forming a roll (wire) of soil at a water content where the maximum plasticity is expressed.

Plasticity Class	Code			Criteria : Make a roll of soil 4 cm long
	Conv	PDP	NASIS	
Non-Plastic	(w) po	PO	PO	Will not form a 6 mm diameter roll, or if formed, can't support itself if held on end.
Slightly Plastic	(w) ps	SP	SP	6 mm Diameter roll supports itself; 4 mm diameter roll does not.
Moderately Plastic [1]	(w) p	P	MP	4 mm Diameter roll spports itself 2 mm diameter roll does not.
Very Plastic	(w) vp	VP	VP	2 mm Diameter roll supports its weight.

[1] Historically, the Moderately Plastic class was simply called Plastic

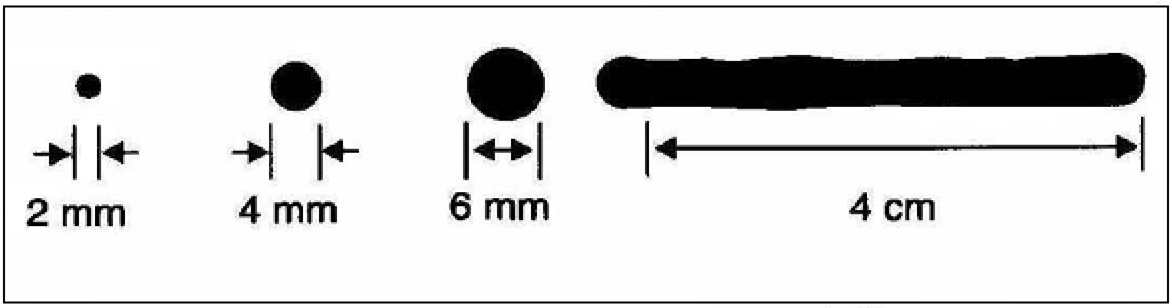


Figure 4.41 Plasticity classes.

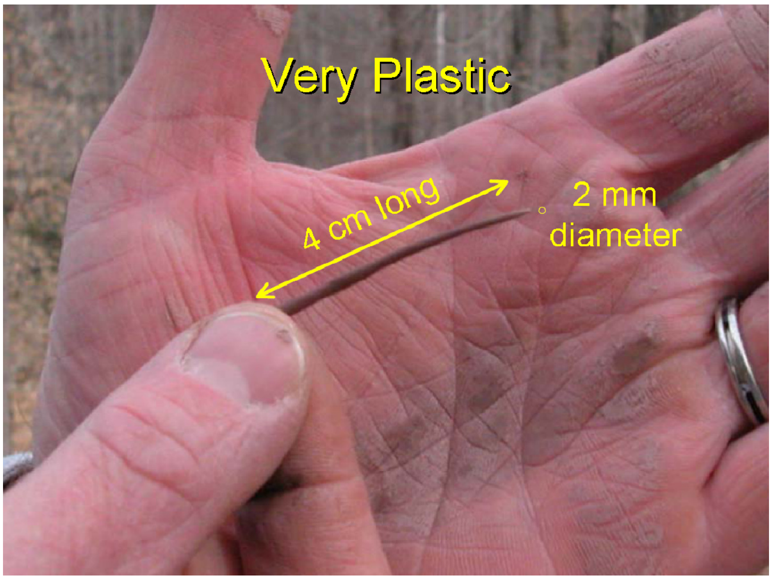


Figure 4.42 Example of a very plastic soil.

4.2.8 Bearing capacity

When the user and client requirements are known, the pavement design can start. The first important factor to consider is the soil bearing capacity as this is the factor which determines the bearing strength of the sub-base and in turn has the most influence on the structural pavement design that will be placed on top of this particular soil.

The soil bearing capacity or sub base bearing strength is a material property which is responsible for the way the weight of the traffic is carried off through to the sub-base. There are different ways of determining the bearing strength and it must be known to a depth of minimum of 1,5 meters.

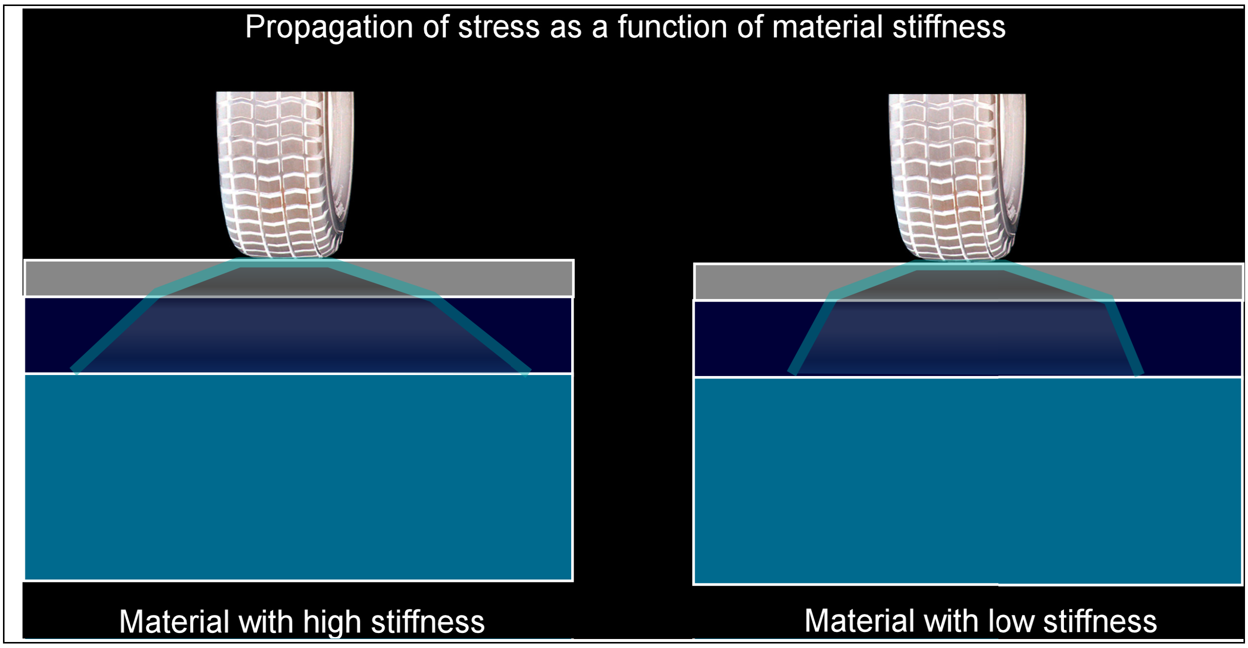


Figure 4.43 Division of load on sub-base.

Having insight into the bearing strength of the soil and soil sub-base can indicate if tests can be carried out in-situ or in the laboratory.

The procedure one should carry out to determine the soil and or sub base bearing capacity is specified in Figure 4.44.

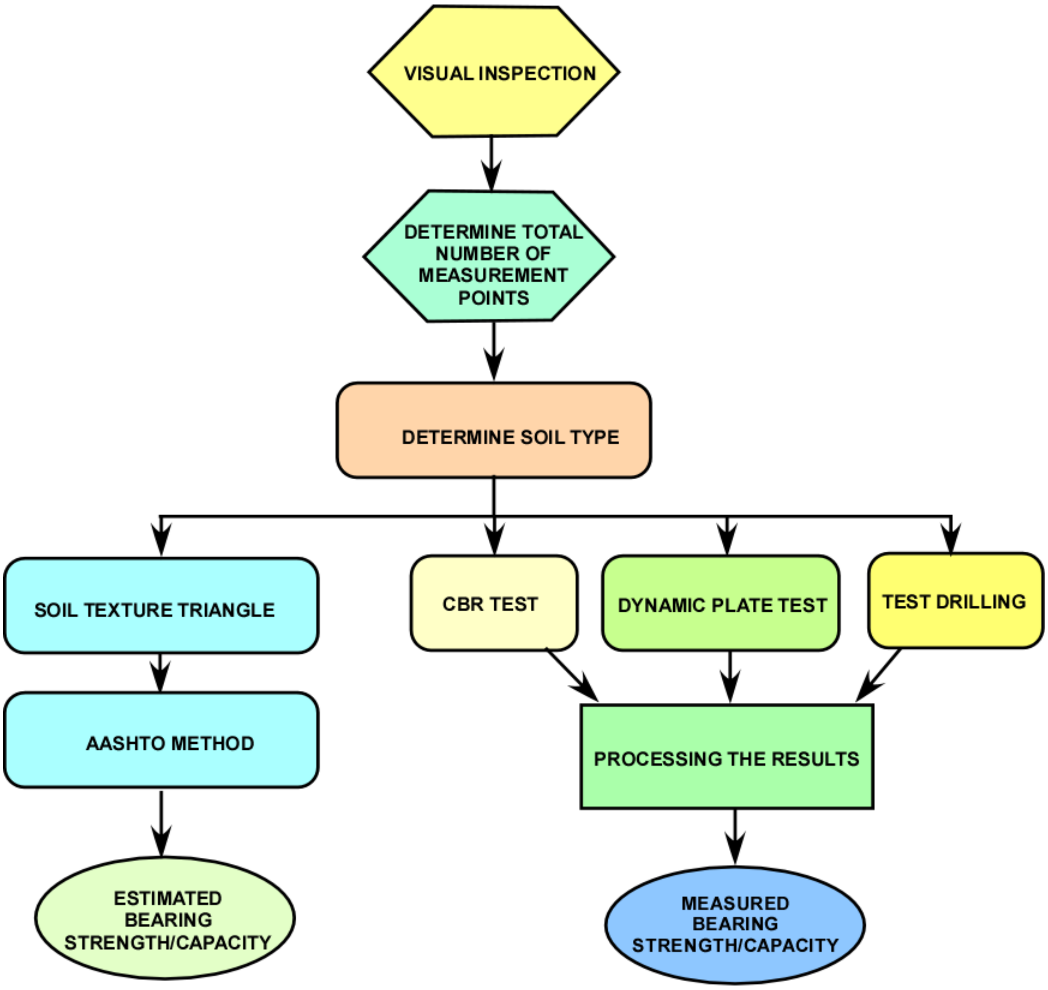


Figure 4.44 Procedure used to determine soil bearing capacity and sub-base bearing strength.

Figure 4.45 Car in clay soil area.

Insight into the bearing strength of the soil and/or sub-base can be obtained by visual inspection. In areas where the ground is relatively soft (in soaked conditions) there is a typically bad bearing strength. Figure 4.45 shows an example.

The bearing strength can also be qualitatively determined on the basis of the of the grain size and its distribution. The grain size is the main factor determining the bearing strength of a soil and/or sub base. Typical bearing strength values for different soil sub-bases under soaked conditions are given in table 4.7. With dry conditions higher values can be reached for the bearing strength but these are not representative since we use the worst possible scenario in the design criteria for the pavement foundation!

Table 4.7 bearing strength for different soils.

Soil sort	Bearing strength E_{dyn} [MPa]
Rocks	400
Gravel	400
Sand	100 - 150
Clay	25 - 75
Peat (fine fraction with high organic content)	5 - 15

The California Bearing Ration (CBR) is a parameter that is developed to measure (estimate) soil/sub base bearing strength (Methodology for measuring of CBR is given in the appendix). When the CBR value is known then the following formula can be used to get an indication for the soil/sub base bearing strength.

$$E_{dyn} = 10 * CBR$$

Determination of a number of required measurements (in-situ)

The bearing strength of soil/sub base varies spatially and should therefore be determined/estimated at a number of different and characteristic points along the road.

Once the soil/sub base bearing strength capacity has been determined it is necessary to determine the soil grain composition as this is the main characteristic that governs the soil/sub base bearing strength.

A number of samples needs to be taken for this purpose and and this is a function of the location and the variability of soil types along the route. It is essential that a soil/sub base bearing strength is determined for all locations with different characteristics.

Determination of soil/sub base bearing strength

There are 4 different methods to determine the soil/sub base bearing strength:

- The A.A.S.H.T.O method which gives an indicative value for the bearing strength. In this method the CBR value can be determined on the basis of the grain composition of the soil/sub base in conformance with the A.A.S.H.T.O method.

- Carrying out a CBR test in the laboratory.

- Carrying out a Dynamic Cone Penetrometer (DCP) test in-situ.

- Carrying out a ground drilling in situ and taking cores for further analysis

It is noted that a combination of these tests is always recommended as it adds additional insight into the expected behavior of the soil/subbase under load.

The A.A.S.H.T.O. method is an easy and inexpensive way to get an indication of the grain composition and estimate the soil/sub base bearing strength. The indicative value obtained can be used in preliminary design but additional analysis and measurements which are more accurate should be used for final design and once the contract has been awarded. It should be noted that this must be agreed with the client up front as additional measurements may not be acceptable to all the clients. In such a situation a more accurate method of measurement should be done at the early stage.

A DCP test is much quicker to do than a ground drilling and coring. It is recommended that that ground drilling takes place every 100 m, along the path of the road and a DCP test every 50 m. These advised distances should be changed up or down if the soils are unusually uniform or unusually variable.

Laboratory tests are conducted on the samples that are used for the Proctor test and they can also be used for a CBR test. With the results of the Proctor test the optimal water content is determined and thus the maximum compaction of the soil/sub base that can be achieved in the field is established. Good compaction of the sub-base is very important to get a bearing strength value for the sub-base and the pavement structure.

A.A.S.H.T.O Method

The A.S.S.H.T.O method gives insight into what types of material are present. An estimation can be made of what the bearing strength of the sub-base might be.

CBR test

The CBR test is often used to determine the bearing strength. This test is only suitable for testing granular material and not for bound material!

The CBR test shows the bearing strength, for a given moisture content and compaction.

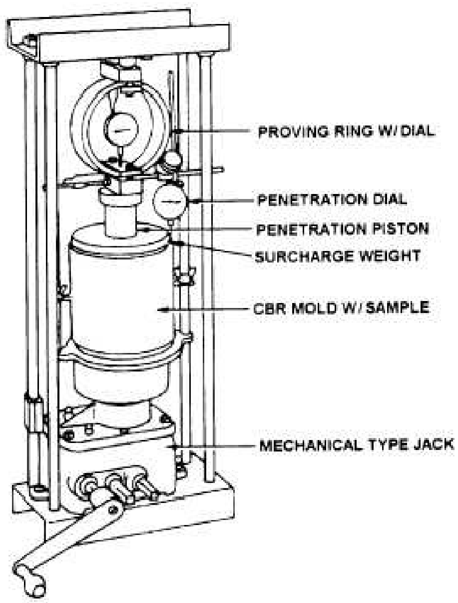


Figure 4.46 CBR devices.

Dynamic slab test

For this test a slab is placed on the ground and a weight is dropped from a height on to the slab. The slab shall be partially pushed into the sub-base. The bearing strength is determined based on the weight, the surface of the slab and the indentation that is made.

Hand/Machine soil drilling

Soil drilling can indicate which kinds of soils are present in the sub-base. A sonar can help show any resistance to the penetration of the cone.

Penetration resistance is the ability of soil in a confined (field) state to resist penetration by a rigid object of specific size. Classes are based on the pressure required to push the flat end of a cylindrical rod (penetrometer can be purchased from many engineering/forestry,/geology/environmental supply centers) with a diameter of 6.4 mm a distance of 6.4 mm into the soil in about one second.

Table 4.8 Penetration Resistance.

PENETRATION RESISTANCE	
Penetration Resistance Class	Criteria : Penetration Resistance (MPa)
Extremely Low	< 0.01
Very Low	0.01 to <0.1
Low	0.1 to <1
Moderate	1 to <2
High	2 to <4
Very High	4 to <9
Extremely High	$\geq$8

Processing results

The thickness of the foundation is determined based on the minimum bearing strength value of various locations on the road.

4.2.9 Ground water level

The ground water level has an effect on the frost-thaw behaviour of the sub-base and the capillary effect on it. When the water level is too high the sub-base has a lower bearing strength.There is also chance of frost-thaw damage in the sub-base.To avoid this in a traditional construction a drainage or a thicker foundation is necessary. With the use of RoadCem the need for drainage is reduced but is not eliminated and the extent will depend on the actual consditions in the field.

Different methods for establishing what the ground water levels are and how much they vary over the year. In most cases existing geological and groundwater reports are used for this purpose but on occasions when these are not available drilling of piezometers is needed to take the actual field measurements. Figure 4.7 shows a Hydrologist making a ground water level measurement in a piezometer. It should be noted that our interest in ground water levels is only for those siituations where ground water level can get close to a caplliary zone of the foundation layer. If this is not likelly to occur than we do not worry about groundwater levels

Figure 4.47 Plan to determine ground water level.

If the ground water level could form a problem for the construction measurements must be taken when the highest water level is less than 1 meter under the top edge of the construction. When the water level is lower then 1 m then no problems are expected. The water level in the construction is important for freeze/thaw and for the internal drainage in the construction.

Figure 4.48 Low water level.

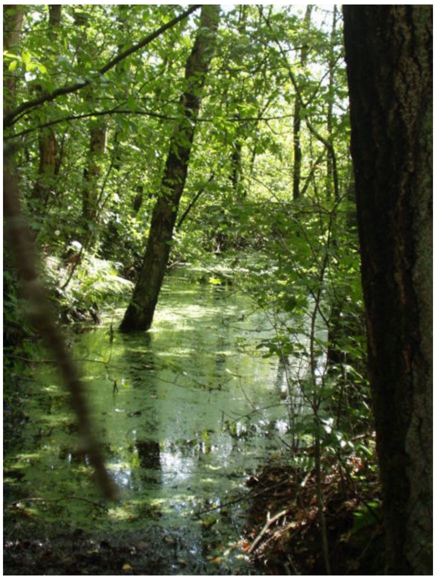


Figure 4.49 High water level.

The types (as determined by Soil Texture triangle) will determine the capillarity of the soil. Table 4.5 can be used to estimate the capillarity of various materials.

Table 4.9 Capillarity different soil types.

Soil Type	Capillarity [m]
Rocks	0
Gravel	0
Sand	0-0,3
Clay	1-10
Peat	> 10

It is njoted that it is very important to report what the highest groundwater levels will be and what the likely air temperature is at that time. This level and the temperature together with the capilarity will determine likelyhood that damage will occur due too frost/thaw and a potential for a reduced bearing capacity due too higher groundwater levels.

4.2.10 Moisture content

The moisture content greatly determines the compressibility of the material. The more a material can be compressed the higher the bearing strength will be. A material is best compressed when the optimal moisture is achieved.

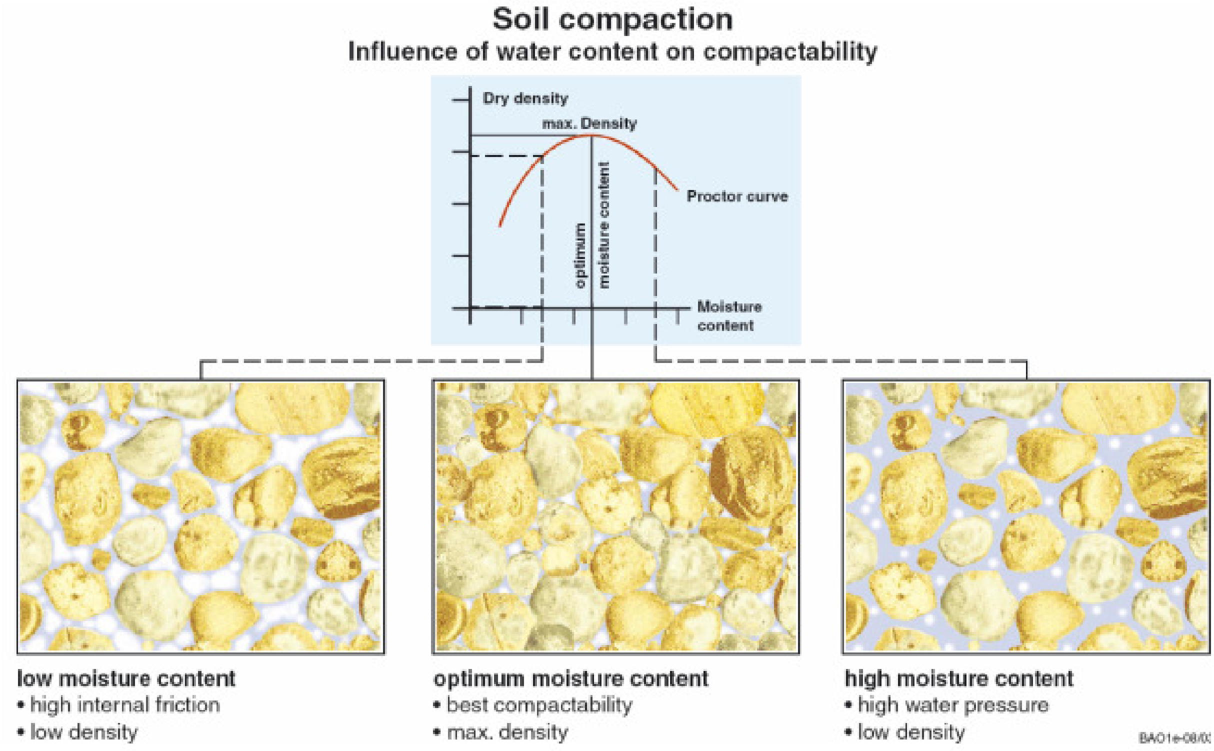


Figure 4.50 Effect of moisture content for compression.

To determine the optimum moisture content at which maximum compaction can occur it is also important to know:

- What the moisture content is of the natural soil/sample.
- The moisture content at which the material compacted most.

Figure 4.50 shows the typical relation between moisture content and compaction for typical soils.

The procedure to determine the optimum moisture content is summarized in Figure 4.51

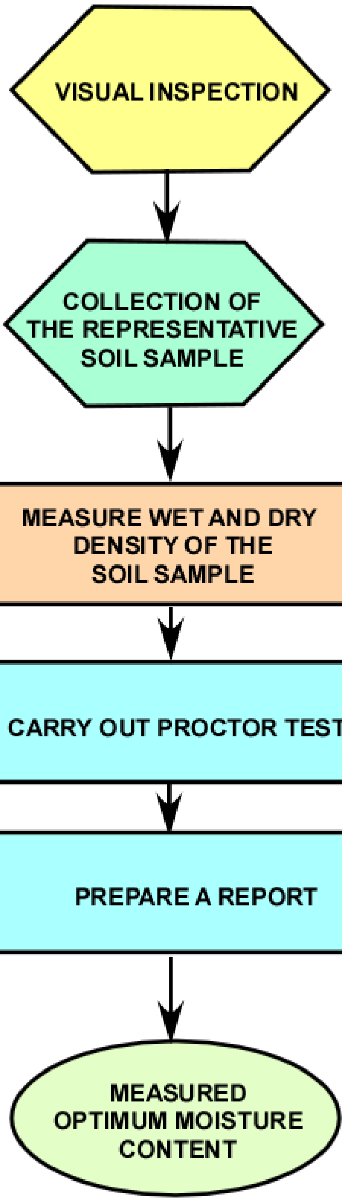


Figure 4.51 Research plan determine moisture content.

Soil samples are collected and the in-situ "wet" density of the soil is determined. This is later used to calculate the natural moisture content of the soil at the time of sample collection. It is noted that the soil sample should be collected from a depth at which the foundation of the future road is estimated to be, i.e. it may be necessary to remove the syrface layers before the soil sample is collected andits "wet" density determined.

The sample is then used to determine the soil dry density - the sample is dried in an oven until all the moisture is removed (standard prcedure). The dry soil density is then measured. Knowledge of the dry density is necessary for the determination of optimum moisture content.

The Proctor test determines at what moisture content a maximum "wet" soil density can be achieved by compaction. The better the compaction the higher the "wet" density is. To achieve best compaction a certain amount of water is needed and this is determined by using the Proctor test. The material is compacted at a number of different moisture contents and its "wet" density is measured. A plot of density against moisture content is made and the moisture content at which a maximum density is achieved is the optimum moisture content for a given soil (Figure 4.51).

During execution of the works in the field, the actual moisture content of the in situ soil is measured and if lower than the optimum moisture content determined during the Proctor test water is added to achieve optimum moisture content prior to compaction. If the field moisture content is higher than the opimum moisture content is than either one has to wait for the soil to dry to optimum moisture content naturally or addition of drying agents and mixing of the soil is needed prior to compaction (Cement or lime can be used as dryng agents). The first option is usually applied.

4.2.11 Settling behaviour

Weak soils have a tendency to settle under the weight of the road construction on top. If such cases, and especially when settlement is irregular unevenes of the road surface (longitudional and traversal) can occur. Settling typically occurs when the latent bound water between the grains of soils is squezed out creating room for the closer packing odf the soil grains and a resulting reduction of specific volume and thus settling. With sandy soils this typically is not a problem and almost no setting shall occur. However, with clay, silt, sludge and peat settling can continue for a few years. To control the settling measures need to be put in place. A number of options is available, the most common one being the installation of an appropriate drainage system to remove the latent (excess) water and induce the settling prior to the actual construction of the road or preloading of the foundation to the extent needed to induce the settling (less frequent). The problem of settling requiers special attention and for soils prone to settling it is advised that proper geotechnical study and advise be sought.

5. The RoadCem method

My country was never so rich that it could afford poor roads

5.1 Introduction

5.1 1 General

The successful provision of roads, in developing countries especially, requires ingenuity, imagination and innovation. It entails "working with nature" and using locally available, non standard materials and other resources in an optimal and environmentally sustainable manner. It will rely on planning, design, construction and maintenance techniques that maximize the involvement of local communities and contractors. When properly engineered, such roads will reduce transport costs and through its impact on people, economy and commerce facilitate socio-economic growth and development.

The majority of rural roads and a significant proportion of the main roads in many countries are currently unsurfaced and are relatively lightly trafficked. For these roads the following points of attention need to be considered:

- Roads impact significantly on the livelihoods of the majority of the population of many countries.
- Roads are central to sustained socio-economic growth and development of the country and are a key component of development programs targeted by donors and governments.
- Unfortunately, the poor condition of roads, which can be largely attributed to the way in which they have customarily been provided and maintained, has acted as a brake on economic development.
- New, more appropriate approaches to the provision of roads are now required. If the world is to improve road transport efficiency and attain its broader goals of socio-economic growth and development.

The traditional methods of road provision are inappropriate in a modern world for a number of reasons:

- Traditional approaches to the provision of roads have stemmed from technology and research carried out in Europe and the USA over 50 years ago in very different socio economic environments that existed at the time.
- Locally prevailing circumstances are usually very different in terms of climate, traffic, materials and road users as are the current socio economic conditions in the world. It is therefore not surprising that many of the traditional approaches, designs and technologies are inappropriate for application in today's world.

- Technology, research and knowledge about road building materials and construction methods have advanced significantly and not only question much of the accepted wisdom on road provision but also show quite clearly the need to revise conventional approaches.

Unfortunately, there has been little effective dissemination and uptake of the results of research carried out in the past.

SEALED ROADS

The substantial length of unsurfaced, particularly gravel roads are becoming increasingly difficult to sustain since such roads:

- Impose a logistical, technical and financial burden on most road agencies due to constraints on physical, human, financial and natural resources.
- Require the continuous use of a non-renewable resource (gravel) which is being seriously depleted in many countries and, in the process, is causing serious environmental problems

Implementation of the results of recent research and innovation (for example, reduce construction costs through the increased use of natural soils and new binders), enables the sealing of gravel roads to be economically justified at less than 100 vehicles per day (vpd). This figure is in contrast to the previously recommended threshold which were in excess of 200 vpd as a justification for sealed roads and is a figure that still persists in the minds of many practitioners.

Failure to observe the optimal timing for sealing gravel roads can be very costly to national economies, not only in terms of incurring excess transport costs but, also, in the continuing excessive maintenance burden and adverse socio-environmental effects. This provides a strong impetus for the adoption of alternative, cost-effective, design, construction and surfacing strategies promoted by the use of RoadCem as one of road building materials of choice.

5.1.2 The benefits of RoadCem method

The benefits of RoadCem method includes:

- lower transport (construction, maintenance and vehicle operating) costs;
- increased social benefits (more reliable access to schools, clinics, etc);
- reduced adverse environmental impacts and health and safety problems.

The above benefits hinge critically on the ability of the responsible authority to maintain the roads to the level of service for which they were designed.

Achieving sustainability in all aspects of road provision is absolutely critical if the world's long term goals of sustained economic growth and development are to be attained. In the past attempts to achieve such sustainability have failed because one or more of the seven key dimensions (Figure 5.1) have been missing or been inadequate. The result has been that many roads have fallen into disrepair and, consequently, have not only failed to serve the needs of the people and the economy but also often adversely affected the environment in very complex ways.

5.1 3 The 7 key dimensions of sustainability of road infrastructure

There has been a tendency to focus predominantly on the technical and economic aspects of road provision and inadequate attention has been given to other aspects of sustainability in the past. The result has often been a lack of responsiveness to various other requirements and a reduced likelihood of achieving sustainable solutions, even when substantial funding is made available.

The seven key dimensions of a sustainable road system, which should always be observed in the provision of roads are shown in figure 5.1.

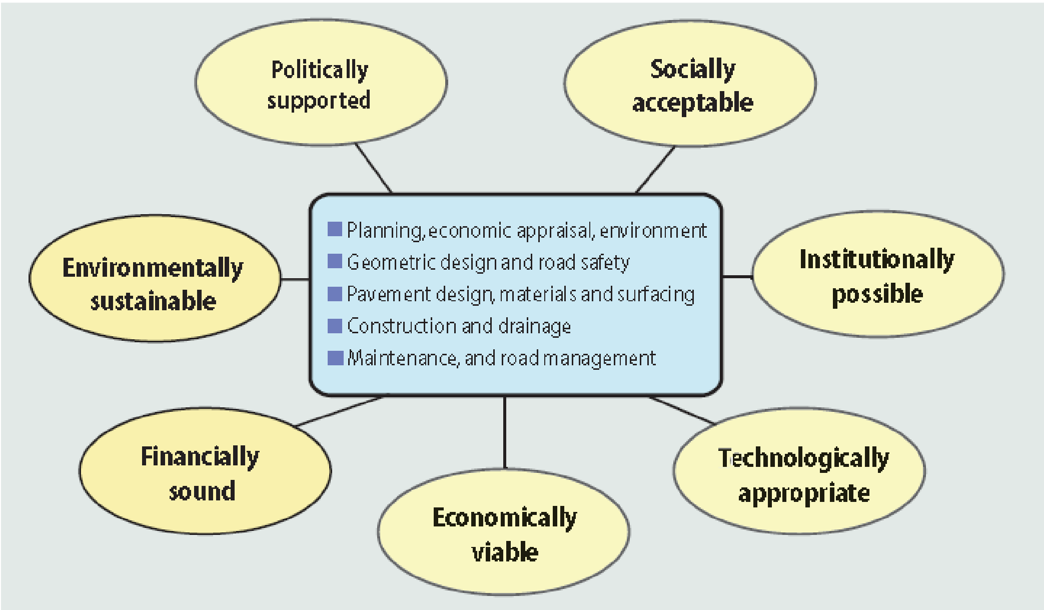


Figure 5.1 The 7 keys dimensions of sustainability of road infrastructure.

Sustainability in all aspects of road provision should now become the basis of a more demanding policy of users, governments and other clients. This will require that a practitioner adopt a more broadly based approach and pays full attention to all seven dimensions of sustainability.

There are a number of benefits to be derived from adopting the new RoadCem based approach advocated in this manual. These include providing roads that are:

- Less expensive in economic terms to build and to maintain through the adoption of more appropriate, locally-derived technology and design/construction techniques that are better suited to local conditions.
- Minimize adverse environmental impacts, particularly as regards the use of non-renewable resources (gravel).
- Increase employment opportunities through the use of more appropriate technology, including the use of labour-based methods, where feasible.
- Improve road safety in all aspects of road provision.
- Take better account of the needs of all stakeholders, particularly the local communities served by these roads.
- Foster local road building and maintenance capacity through the greater use of small-scale, local contractors.
- Ultimately, facilitate the longer-term goal of socio-economic growth.

However, there are a number of barriers which will tend to frustrate the adoption of new and innovative approaches.

A few of these barriers are:

- An inevitable and natural tendency to resist change. Because change hasn't and the conservative nature of clients, practitioners and governments which tend to institutionalize this resistance
- The fact that many of aspects of RoadCem method may be in conflict with existing, often out-dated, country manuals and standards

Ultimately, the successful move from vision to practice will require endorsement at technical, academic and political level, as well as the full support of all stakeholders. In addition, it will require considerable technology transfer effort including:

- Support and technical assistance to facilitate the implementation of the RoadCem method.
- Updating country guidelines, codes of practice, norms and standards.
- Technical staff training to address potential internal resistance to change.
- Careful monitoring of acceptance, adoption, refinement and satisfaction amongst RoadCem users.

Figure 5.2 A road where one or more of the seven dimensions of sustainability is missing.

The road hierarchy and function are defined in figure 5.3.

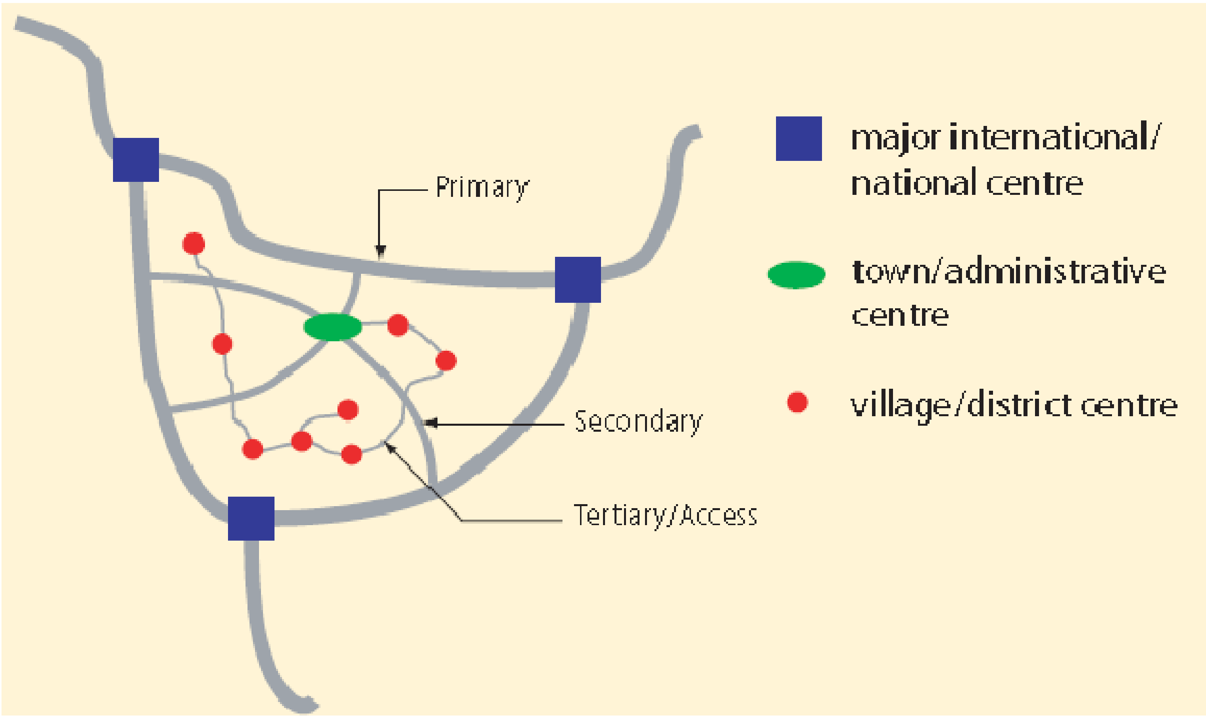


Figure 5.3 Road hierarchy and function.

The multifunctional nature of roads is indicated in Figure 5.4.

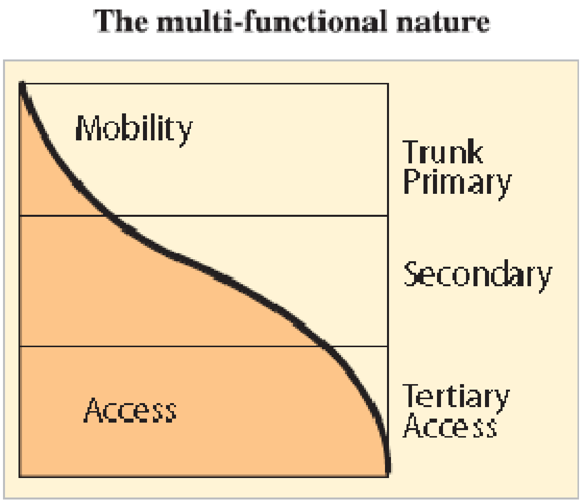


Figure 5.4 the multi-functional nature.

It is also enlightening to establish a link between wealth and road infrastructure. In essence this is shown in the Figure 5.5, where a few countries of the world are compared with to eagh other.

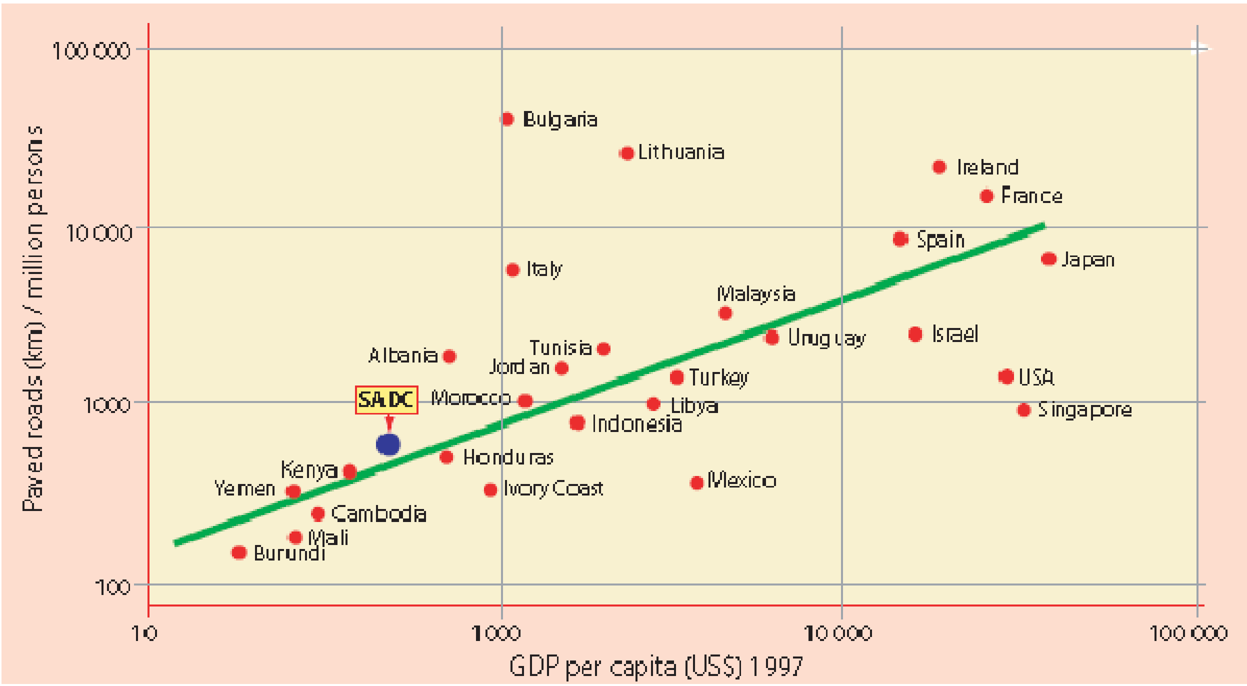


Figure 5.5 Relation between wealth and road infrastructure.

The precise role that roads play in economic development is complex but the fact that there is a link is widely accepted and most economists agree that investment in transport infrastructure makes a positive contribution.

For clarity we also need to define/classify different roads. This is done in table 5.1.

Table 5.1 Road Functions and Classifications.

Road Function				Design Class
Tr	P	S	Te	
				A
				B
				C
				D
				E

Tr = Trunk P = Primary S = Secondary Te = Tertiary/access

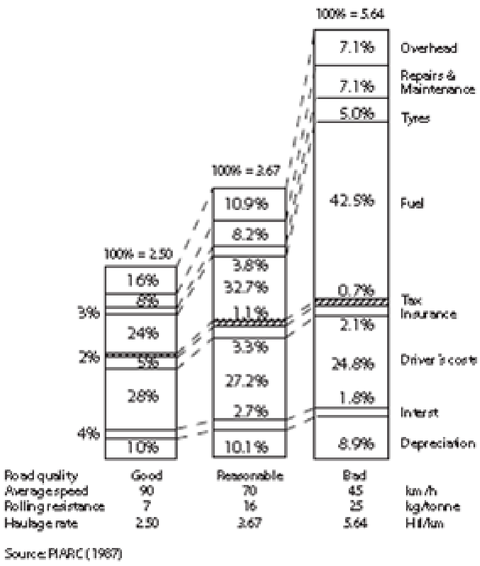
5.1.4 The Challenge

A number of factors combine to pose a major challenge to road provision. In this regard the following aspects are important:

- Available resources are severely limited.
- Social and developmental benefits are often dealt with inadequately in traditional investment appraisal methodology.
- There has been a tendency to focus predominantly on the technical aspects, with inadequate attention being paid to the other environments within which they operate and which influence their long-term sustainability.
- Traditional highway engineering, planning and standards that are applied to roads are often not appropriate
- Although traffic volumes may be relatively low, vehicle loads are often high, with significant overloading. This makes the relatively light pavement structures that would otherwise be appropriate, vulnerable to overloading.
- Other challenges are also present in many parts of the world as is shown in the figure 5.6 on the next page.

Pedestrians and non-motorised traffic often constitue a significant proportion of traffic near vllages.

"My country was never so rich that it could afford poor roads" (William the Conqueror, Doomsday Survey, 1066).



The influence of road conditions on haulage Costs-both the operating and maintenance

Consumption of gravel is of the order of 150 million cubic metres in SADC

Figure 5.6 Some of the challenges for provision of roads in different parts of the world.

By far the biggest challenge in all parts of the world is the issue of operation and maintenance costs for road infrastructure. The relationship between capital and O&M costs for a typical road is shown in figure 5.7.

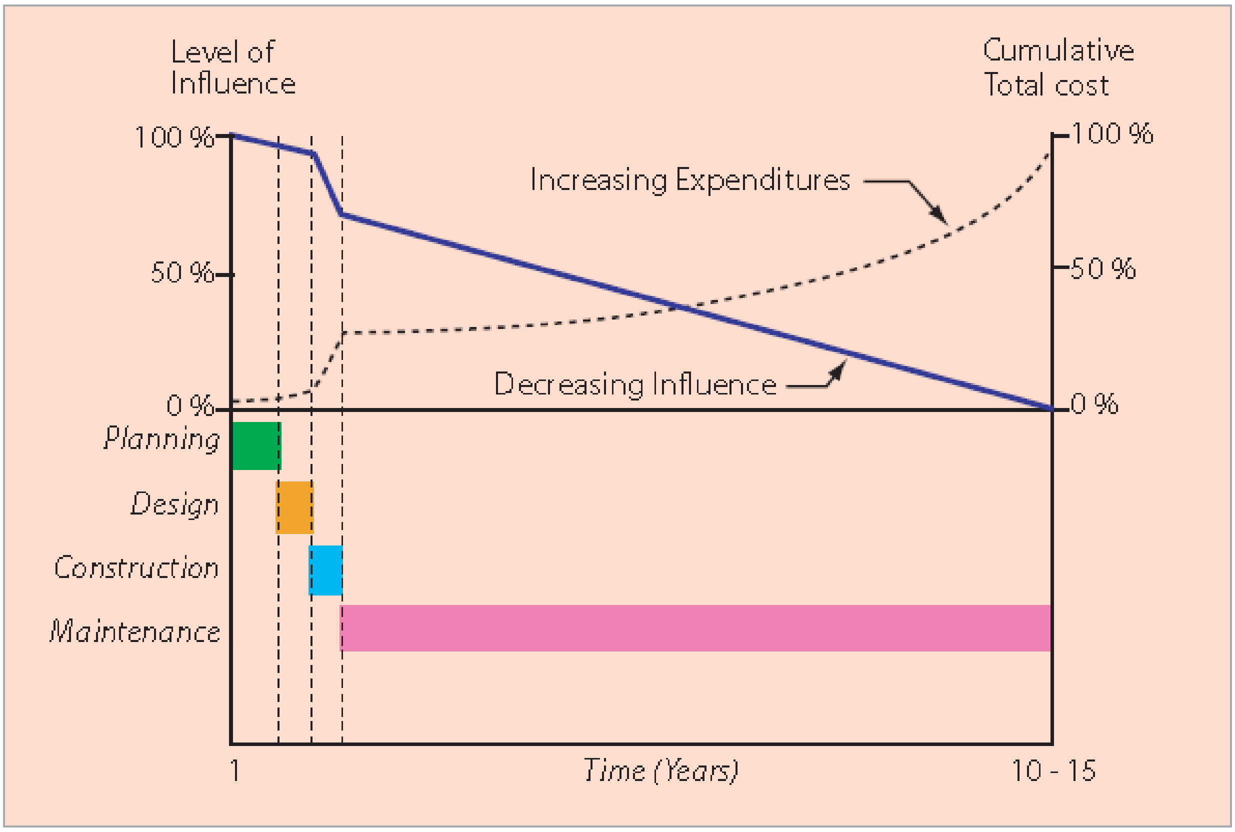


Figure 5.7 relationship between Capital and O&M Costs for a typical road.

In essence there are 4 factors:

1. Costs during the planning and design phases are relatively small compared with the total expenditure and are incurred during a relatively short period of the project's life. However, their downstream level of influence is very large in terms of decisions and commitments made during the early phases of the project.
   This emphasizes the importance of employing a broadly-based, holistic approach to the planning of roads with the main stakeholders being involved in the decision-making process. In addition, the designs employed (geometric and pavement) should be appropriate and relevant to the environment in which the road is being constructed.

2. The capital costs for construction are a fraction of the operating and maintenance costs associated with a pavement life-cycle. However, the decisions made during the construction phase, and the methods of construction adopted, can have a great impact on the cost of maintaining the road.
   This emphasizes the importance of ensuring a high degree of quality control in the use of local materials and the adoption of construction methods that are appropriate to the multi-dimensional environment in which the road is being provided.

3. Maintenance occupies a significant number of years in the life of the project and the type and cost of maintenance required is influenced significantly by the preceding planning, design and construction phases.

This emphasizes the importance of ensuring that the maintenance phase is prolonged as much as possible to extend the useful life of the road and the period of time during which benefits are incurred.

4. At the beginning of the project, the roads agency controls all factors (100 per cent influence) in determining future expenditures. The key issue is how to optimize the use of scarce resources in the provision of roads in an efficient, effective, appropriate and sustainable manner.

The RoadCem Method of road provision in fact has a significant positive influence on all four of the above essential factors.

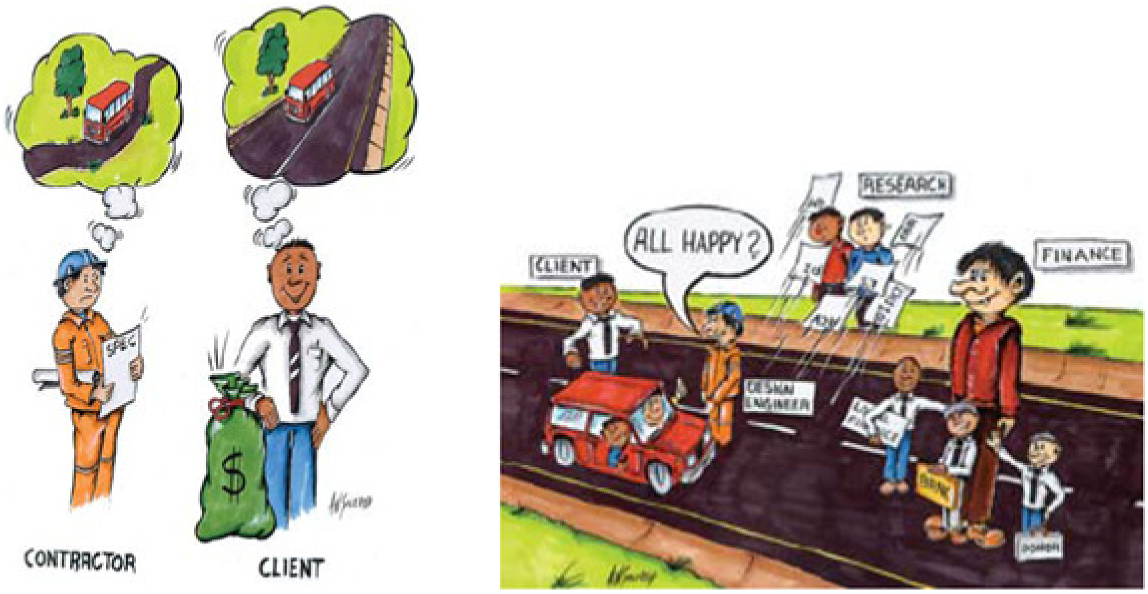
5.1 5 Planning, Appraisal and Environmental Issues

Planning and Appraisal

The RoadCem Method does not change the traditional approach to Planning and Appraisal. This traditional framework is shown in table 5.2.

Table 5.2 Traditional Planning and Appraisal Framework.

Project Cycle	Planning Activity	Typical Evaluation Tools	Output
Identification	Selection	Policy resource analysis Master Plans Local/regional plans	Long list of projects
Feasibility	Screening	Livelihoods analysis Integrated Rural Accessibility Planning	Shorter list of projects
Design	Evaluation	Cost-benefit analysis – Consumer surplus (e.g. RED) – Producer surplus – Compound ranking – Multi-criteria analysis	Short list of projects
Commitment and negotiation	Prioritization	Budget considerations – Ranking by economic or socio-economic criteria	Final list of projects



The end result, a successfully completed project that meets the requirements of all stakeholders by satisfying the seven key dimensions of sustainability

It is important that both the client and the contractor share a common vision on the Standard of the road to be constructed.

Figure 5.8 Common Understanding is Critical.

In figure 5.9 the economics of the Application of the RoadCem Approach in Comparision to the traditional approach are compared with each other.

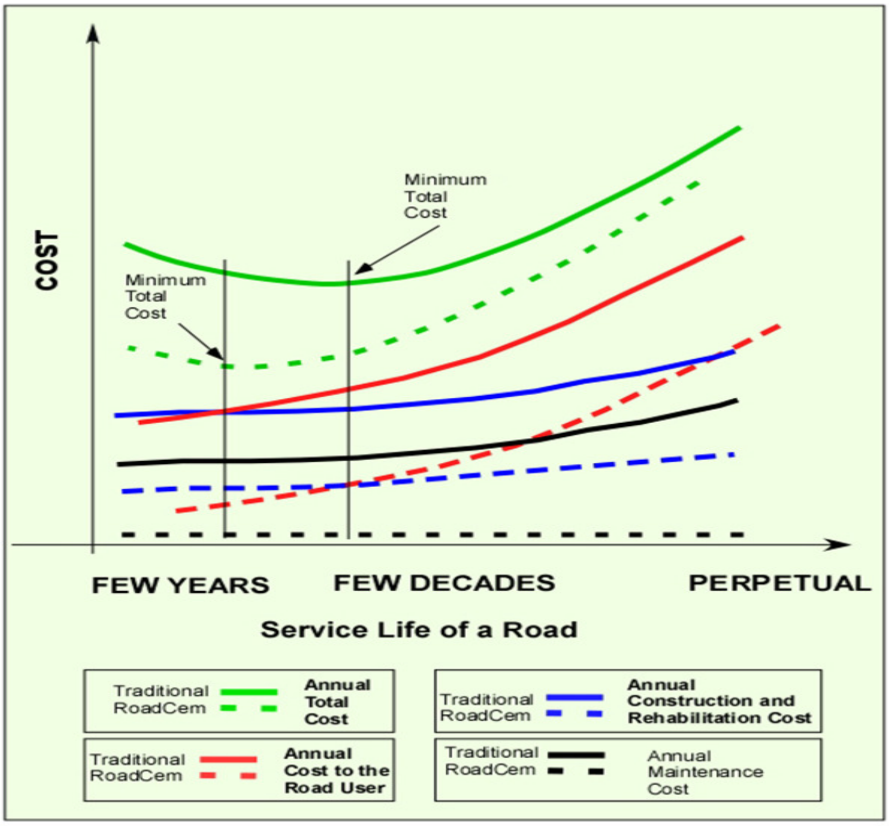


Figure 5.9 Effects of the RoadCem Approach.

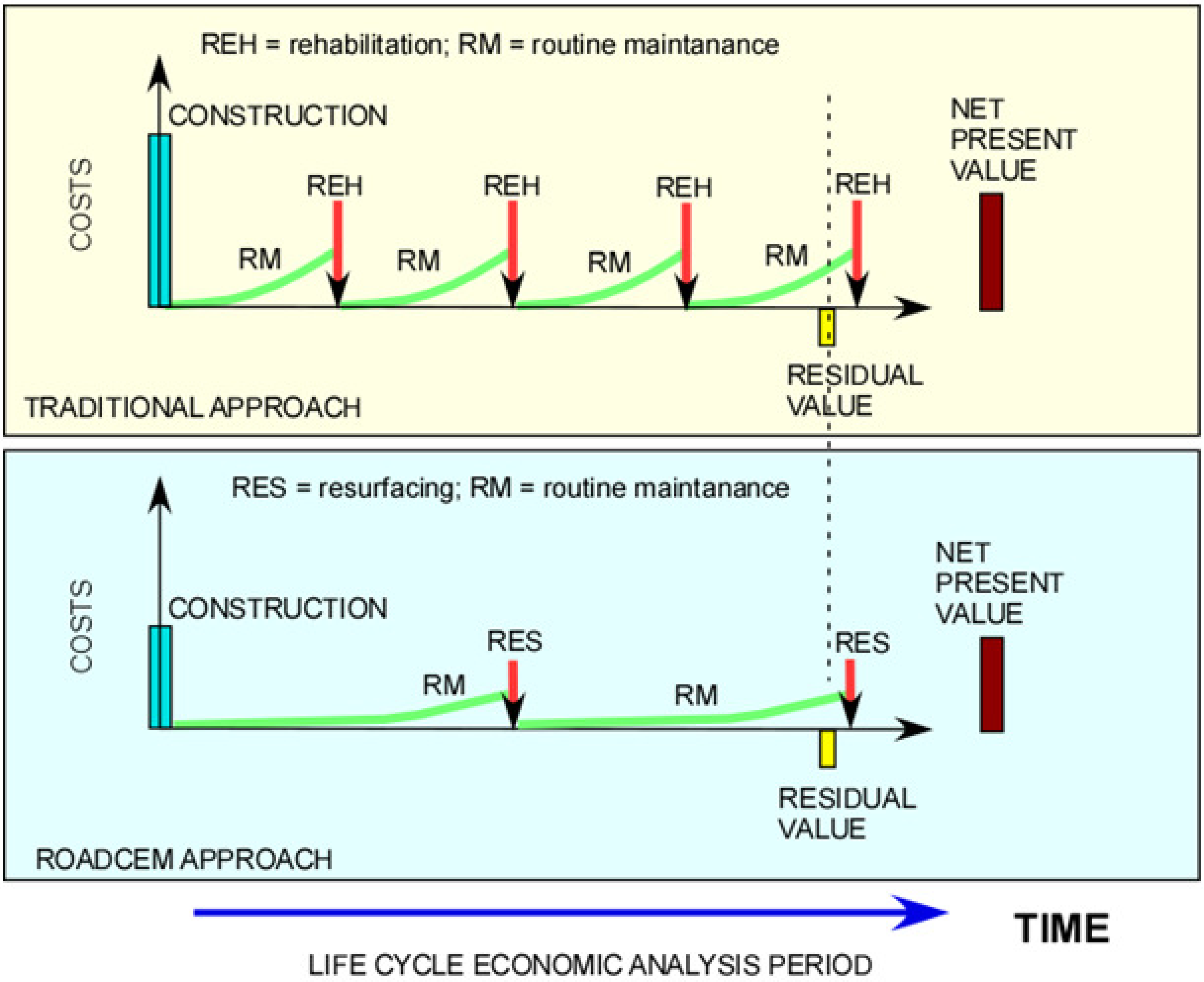


Figure 5.10 Cost History Comparison Between Traditional and RoadCem Approach.

ENVIRONMENTAL ISSUES

The main factors related to environmental issues are summarized in table 5.3;

Table 5.3 Environmental Issues.

ENVIRONMENT	**Ecological**	– Impact of flora and fauna. – Deforestation. – Disturbance of natural eco-system. – Decrease in bio-diversity. – Threats to exotic and non-indigenous species. – Depletion of scarce material resources. – Regressive or progressive soil erosion.
	Economic	– Capital costs (design and construction). – Maintenance costs. – Flood damage costs. – Loss/degradation of agriculture/arable land. – Sterilisation of land for future use. – Land value reduced (designated borrows, severed farms).
	Social	– Severance/dislocation of local communities. – Adverse impacts of women. – Destruction of cultural antiquities. – Conflicts arising from changing land use/ownership of land. – Traffic accidents. – Health and safety (e.g. danger to humans, especially children, and wildlife from drowning in borrow pits). – Construction impacts.
	Physical	– Aesthetic. – E.g. loss of natural beauty and scars on landscape. – Natural vegetation is not, or cannot be replaced. – Noise, air, water pollution. – Dust impact. – Disruption of drainage courses.

From our point of view and of importance for this manual the RoadCem approach and the Traditional Approach to road provision differ most significantly with respect to:

- Ecological impacts
- Economic impacts (addressed in the previous section), and
- Physical impacts (aesthetic, biodiversity, resource depletion, disruption of drainage courses)

Traditional road provision approaches are based on import of road building material as this is imposed by the conventional pavement design practice.

Figure 5.11 Original pit. *Figure 5.12 Gravel stockpile.*

For example the dependence of a traditional road construction approach on imported material requires large amounts of gravel. This creates borrow pits with huge impacts on the environment (Figures 5.11 and 5.12)

Table 5.4 gives a summary of the negative aspescts of the use of traditional materials. In contrast to this the RoadCem method does not rely on imported material and these impacts are therefore avoided.

Table 5.4 Negative aspects of the use of traditional materials.

Material resources	– Permanent loss of natural resources.
Morphological damage	– Modification of the natural drainage. – Increased soil erosion and siltation of watercourses by disturbance of soil. – Destabilisation of slopes.
Ecology	– Loss of wilderness and forest. – Displacement of species and habitats. – Loss of potential prodouctivity of agricultural land.
Pollution	– Contamination of water and soil by fuel and oil spillage. – Generation of dust during the processing, loading and transporting of materials. – Increased dust generated by vihicles along access tracks. – Littering.
Social and health impacts	– Creation of habitats for disease. – Landscape alteratioin and interference with natural beauty. – Bisection of communities or farms. – Loss of land legacy. – Loss of antiquities, cultural heritage, areas of cultural concern (e.g. graves). – Hazards to pedestrians and animals, including open or inmarked trial pits, demarcation beacons, etc. – Safety risks to local population by exposure to heavy plant and traffic. – Noise of drilling, blasting, traffic and plant.

If we consider the environmental impact assessment framework summarized in figure 5.13 where we evaluate the magnitude and value of impacts that may occur from the environmental point of view and qualitatively compare the relative positioning of two equivalent roads, one is based on traditional approach and the other on the RoadCem approach (all other factors being equal, it can be safely concluded that the RoadCem approach road is much more likely to end up on the positive impact side where as traditional approach road will almost certainly end up on the negative impact side of the adopted assessment framework (Figure 5.14).

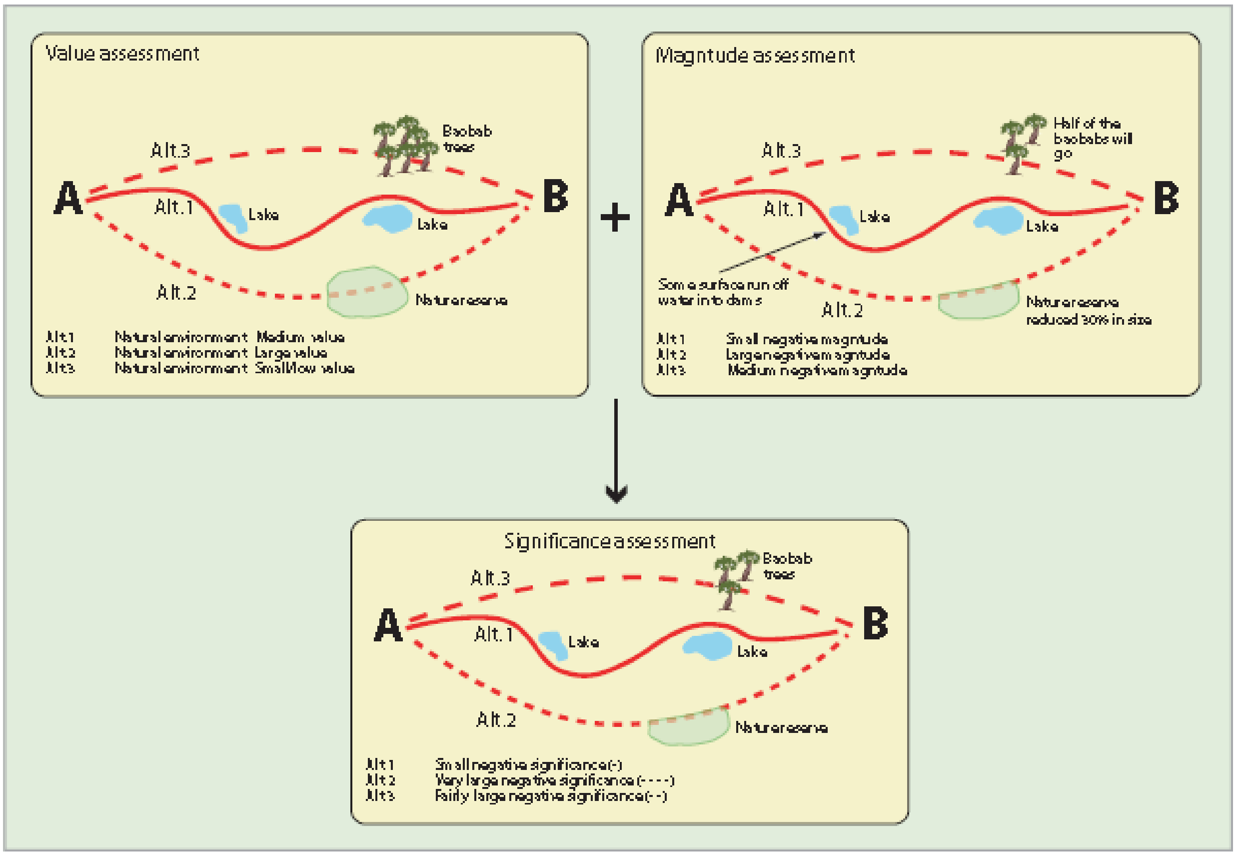


Figure 5.13 Impact Assessment Framework.

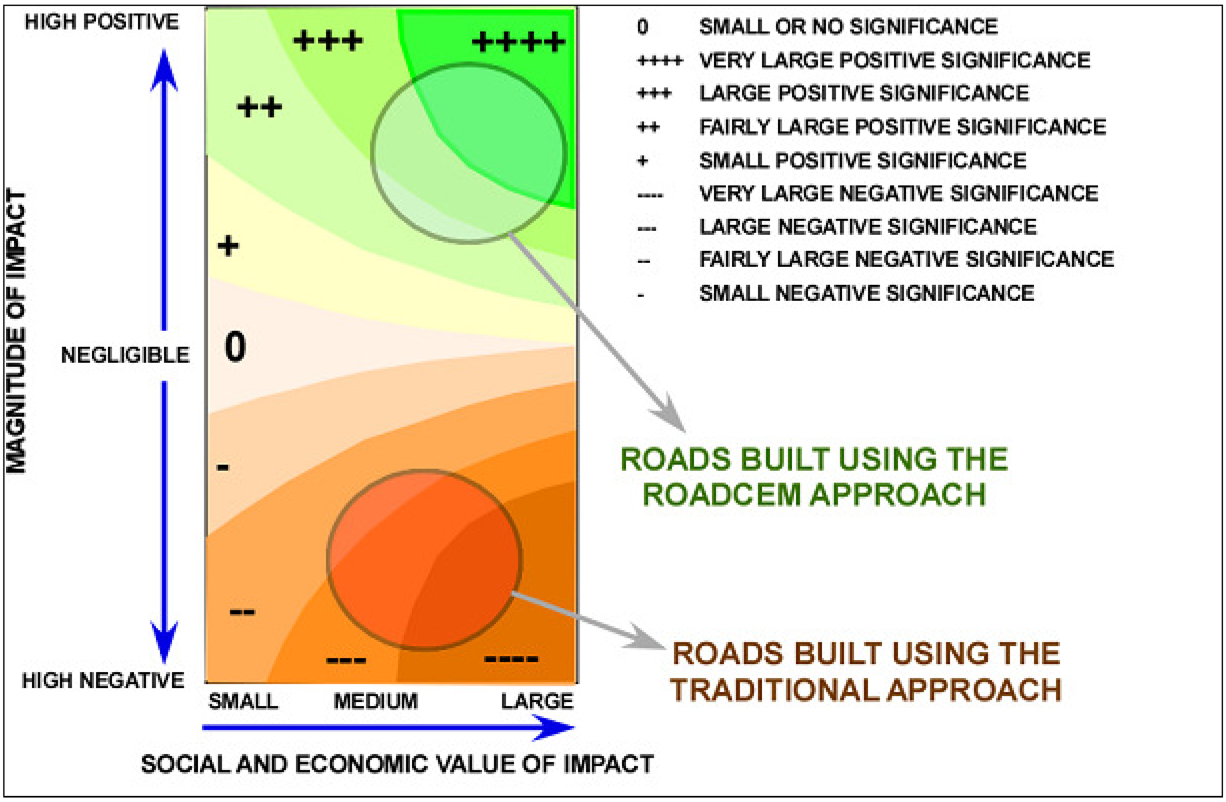


Figure 5.14 Value versus Magnitude (relative comparision).

5.2 In Situ Material as the Basis for the RoadCem method

5.2 1 General

Traditional pavement designs usually consist of a typical pavement structure shown in Figure 5.15.

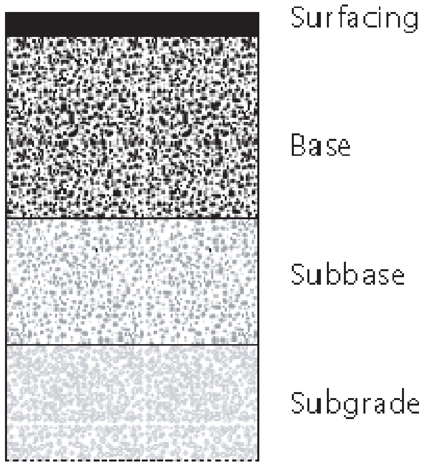


Figure 5.15 Typical pavement structure.

Surfacing

The surfacing is the uppermost layer of the pavement and forms an interface with traffic and the environment. It normally consists of some kind of non-structural, impermeable bituminous surface treatment or a structural layer of premixed bituminous material (asphaltic concrete).

Base

The base is the main load-bearing and load-spreading layer of the pavement and normally consists of natural gravel, gravelly soils, decomposed rock, sands and sand-clays. The granular materials are often stabilized with cement, lime or bitumen. On relatively highly trafficked roads, asphalt concrete and crushed stone may also be used.

Subbase

The subbase is the secondary load-spreading layer underlying the base and normally consists of a material of lower quality than that used in the base. This layer protects the subgrade and, importantly, acts as a construction platform and also provides a stiff platform against which the base can be adequately compacted.

Subgrade

The subgrade is the upper layer of the natural soil that supports the pavement structure. It may be undisturbed local material or soil imported from elsewhere and placed as fill. In either case, it is compacted during construction to give added strength. The ultimate strength characteristics of the subgrade dictate the type of pavement structure required, in terms of layer thickness and material quality, to reduce the surface load by traffic to a magnitude that can be supported without unacceptable permanent deformation and settlement.

Each of the components of a traditional approach pavement structure forms a part of a typical road cross section as shown in Figure 5.16.

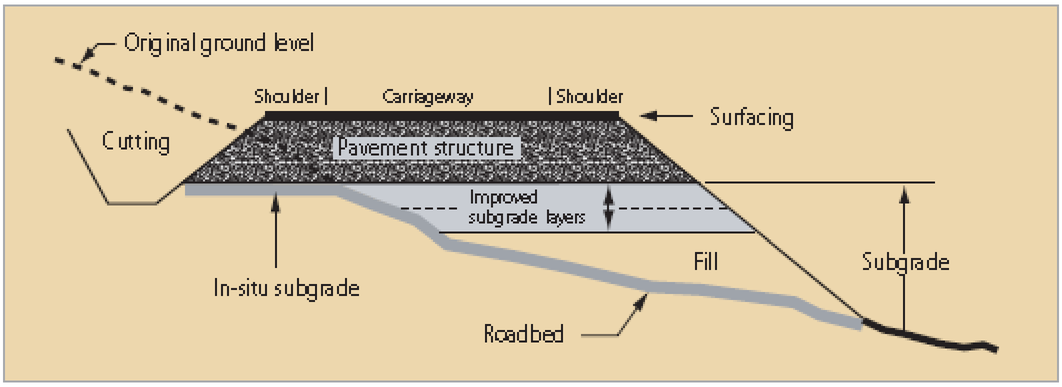


Figure 5.16 Cross section of a typical road pavement.

A pavement must be designed to meet both functional and structural requirements.

- Functionally, it should serve traffic safety, comfortably and efficiently at a minimum "reasonable" cost.
- Structurally, it is a load bearing structure that is required to perform under prevailing traffic and environmental conditions with minimum maintenance.

The pavement structure transfers the wheel loads from the surface to the underlying subgrade. As shown in Figure 5.19. The wheel load and tire pressure at the surface is effectively reduced within the pavement structure by being spread over a wide area of subgrade. The strength characteristics of the road bed soil dictate the type of pavement structure required to spread the applied load and to reduce the load to a magnitude that can be supported by the subgrade.

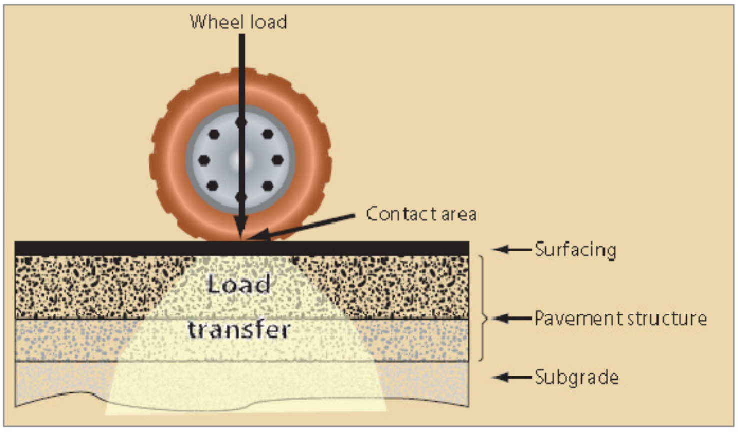


Figure 5.17 Spread of wheel load through pavement structure.

In other words, the load bearing capacity of the sub base determines the structure of the pavement, but this is not the only factor. The ability of the pavement structure to spread load over a larger and larger area is just an important parameter that determines the design of the pavement structure. In fact this is where RoadCem approach to pavement design comes in. The RoadCem approach in fact modifies and increases the area of load spreading onto the sub base by the pavement structure and this is because with RoadCemt the material has a higher Elastic modulus and a higher breaking strength.

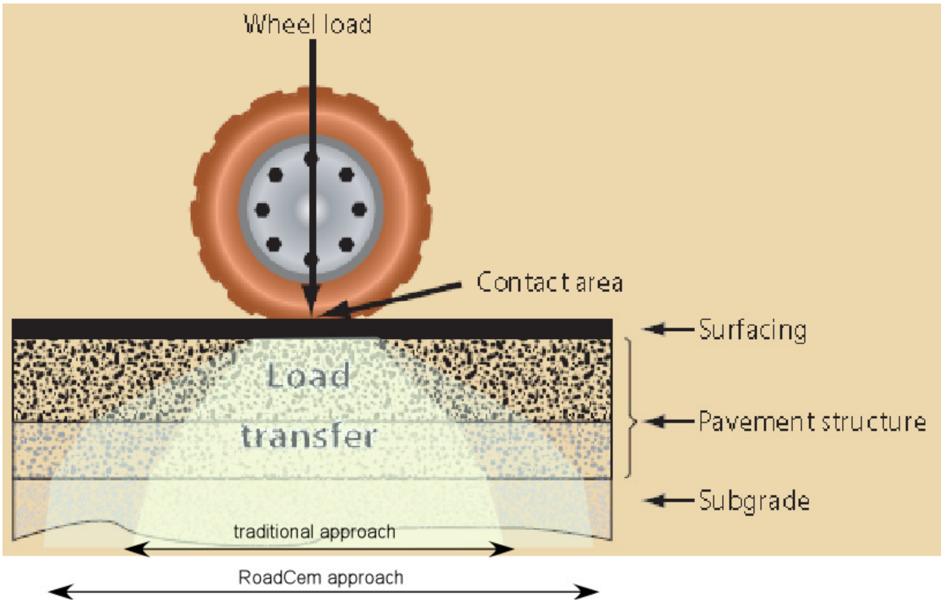


Figure 5.18 RoadCem based effect of increasing spread of wheel load through modification of In-situ material.

In order to further understand the RoadCem Method we now also need to consider the performance of the pavement structure.

Pavements deteriorate gradually with time for a number of reasons, the two most important being:

- Environmental effects.
- Traffic loading, comprising effects caused by wheel loads and tire pressures, and which is dependent on the stresses and the number of times they are applied.

These factors have the effect of reducing the riding quality of the pavement, as manifested by obvious visible features such as surface roughness, rutting and cracking. In figure 5.19 the manner in which the damage develops for an asphalt pavement is illustrated.

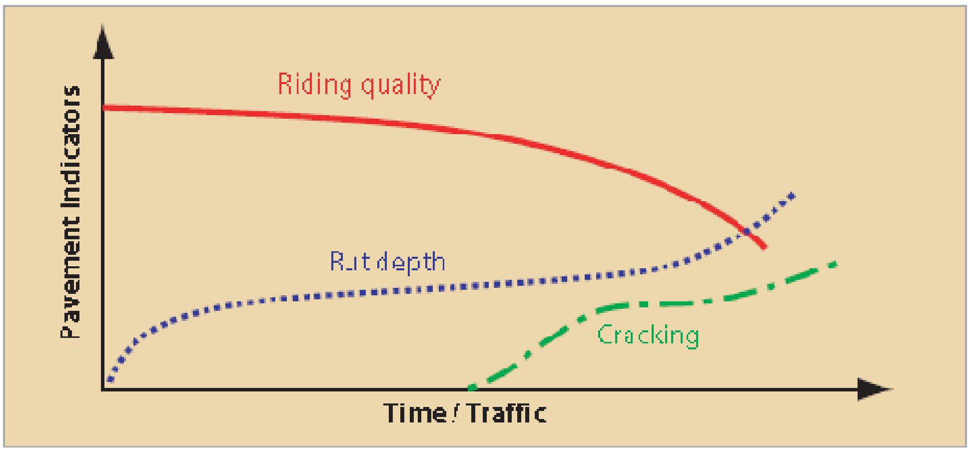


Figure 5.19 Generalized pavement behavior characteristics and indicators

Ultimately, the challenge of good pavement design is to provide a pavement that fulfills its function at minimum life-cycle cost at an optimal level of service.

However, positive action in the form of timely and appropriate maintenance will be necessary, to ensure that the assumptions of the design phase hold true over the design life.

5.2.2 Environmental Effects

Environmentally induced distress through climatic influences, including temperature and rainfall, play a particularly important role in the performance of road pavements. For example, high temperature can accelerate hardening of binders in road surfacings through loss of volatiles and oxidation, resulting in their loss of flexibility and consequent ravelling of the aggregate and brittle fracture of the layer.

High rainfall can also result in a change in the moisture content of the pavement and subgrade materials. Poor drainage conditions and moisture sensitive materials adversely affect the pavement structure and its performance under traffic. It should be noted that when RoadCem is used the pavement structure is highly unlikely to be vulnerable to a high moisture content and this mode of failure is largely eliminated.

Carbonation of traditional materials stabilised with lime and cement can also occur. This is a reaction between the traditional stabilising agents and carbon dioxide in the air or under road pavements and leads to a weakened material. It is noted that when RoadCem is used the mechanism of interaction between pavement structure and carbon dioxide in the atmosphere is very different than in the case of traditional material and as a result carbonation problem is significantley. The pavement structure may actually be sequestering carbon dioxide which in these days of climate change is a positive effect.

Damage can also occur to road surfacings as result of salt crystallisation. This effect is especially prevalent in dry climates and/or in circumstances where pavements have been constructed with traditional materials or water with a relatively high salt content (e.g. mine waste).When RoadCem is used the problem with salts is reduced. Even during the binding process salt water can be used because salts have no influences on the binding and hardening process of RoadCem treated layers.

A traditional view of what causes the failure of a pavement is shown in table 5.5.

Table 5.5 traditional view of what causes the failure.

PARAMETER	RELATED ISSUES
Poor drainage	– Water ingress to pavement structure. – Inadequate maintenance of drainage structures. – Poor roadside drainage/flood water scour. – Poor geometric design.
Inadequate maintenance	– Poor/lack of/insufficient maintenance. – Poor maintenance techniques. – Integrity of seal/delayed reseal/unsealed cracks.
Overleading	– Unexpected heavy loads after design. – Very high tyre contact pressures, sometimes associated with weakening of upper base layers due to crushing or carbonation.
Quality of construction	– Inadequate/poor compaction. – Poor workmanship/supervision/construction standards. – Inadequate use of appropriate plant. – Poor mixing of materials/permeable pavements.
Materials quality	– Inadequate classification of soils. – Non-availability of good natural gravels, presence of poor subgrade soils. – Salt damage. – Low quality of surfacings. – Sodic, dispersive and other problem soils.
Environmental extremes	– Climatic (temperature and weather) extremes. – Erosion of shoulders and side slopes.
Design	– Inadequate pavement design/design specifications. – Poor shoulder design/lack of sealed shoulder. – Low embankments/inadequate camber. – Increased generated traffic.

The RoadCem approch eliminates many of these causes of failure, i.e.:

- Water ingress to pavement structure.
- Pavement structure integrity.
- Reduced cracking.
- Reduced crushing and carbonation.
- Reduced Salt damage.
- Climatic extremes impacts eliminated.

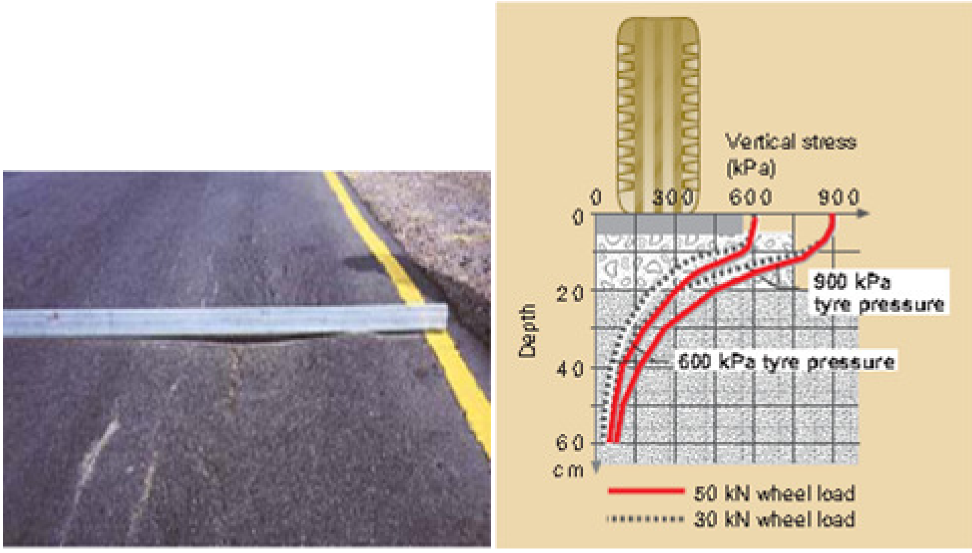


Figure 5.20 Examples of pavement failure and causes thereof

5.2.3 Pavement Structure Materials

When discussing pavement structure materials we can group them into a number of categories:

Naturally occurring materials

These include natural soils, gravel-soil mixtures and gravels. Little or no processing is required other than, possibly, loosening the In-situ material by ripping and breaking down (usually with a grid roller) or removing oversize particles. The cost of such materials is, typically, about 25% of crushed stone. Although crushing may occasionally be required.

Standard/traditional materials

These are defined as materials which meet traditional specifications, such as those of the American Association of State Highway and Transportation Officials (AASHTO). Such materials are tolerant of construction mishandling and adverse environmental conditions and will probably perform well in most cases.

An essential feature of most traditional specifications for standard materials is a requirement for strict compliance with limitations on particle size distribution (grading), plasticity index and aggregate strength. This is partly to avoid the use of any materials in pavement layers that are susceptible to the weakening effects of water and frost. Crushed rock and river-washed and fluvio-glacial gravels are thus the predominant materials used for building roads in temperate climates. The export of these practices to tropical and subtropical regions has meant that the potential of natural gravels, especially in the drier areas of such regions, have often been neglected.

Non-standard/non-traditional materials

These comprise any material that is not wholly in compliance with the specifications used in a country or region for a standard or traditional material, for example, as regards grading or PI. Nonetheless, it has become increasingly recognized worldwide that, under favorable circumstances, or when using appropriate material property modifiers such as RoadCem, almost all such materials can and, indeed, have been used successfully. However, this requires an in-depth knowledge and experience of the properties of such materials and the conditions necessary for successful performance.

It should be noted that the concept of “non-standard” in relation to materials is specific to a particular time and place associated with our level of understanding of the behavior of the material and knowledge of how to use it.

For example, forty or fifty years ago, gravel was considered as a nonstandard material because crushed stone, the “standard” material, was used in the construction of Macadam and Telford pavements.

5.2.4 Characteristics of Pavement Materials

Materials used in pavement layers can be classified into three categories as follows:

- Unbound granular:
    - Unprocessed (naturally occurring, as dug).
    - Processed (screened, mechanically stabilized).
    - Highly processed (crushed to specified grading).
- Bound granular.
- Cement, lime, bitumen or pozollanic material.

The material types described above derive their strength from a combination of the following intrinsic properties:

- Inter-particle friction.
- Cohesive effects from fine particles.
- Soil suction forces.
- Physic-chemical (stabilization) forces.

The relative dependence of a material and the influence of moisture on each of the above components of shear strength will significantly influence the manner in which they can be incorporated within a pavement. For example, unbound/unprocessed materials (e.g. calcrete or ferricrete) are highly dependent on suction and cohesion forces for development of shear resistance that will only be generated at relatively low moisture contents. Special measures therefore have to be taken to ensure that moisture ingress into the pavement is prevented. Otherwise suction forces and shear strength will be reduced as illustrated (notionally) in Figure 5.21, possibly resulting in failures.

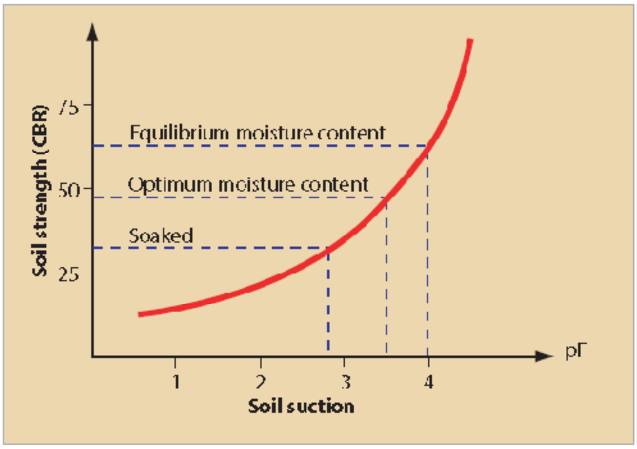


Figure 5.21 Illustrative soil strength/suction relationship

RoadCem approach is actually based on the ability of RoadCem, in tandem with Cement, to modify the characteristics of pavement materials and in so doing enhance those desirable characteristics and reduce the characteristics which could be responsible for the failure of the pavement structure.

Working of RoadCem

As the grain size of a fine-grained material decreases, the total exposed surface area becomes very large in relation to the volume of voids within it. Under these circumstances, molecular forces, which are only effective for very short distances from the surface, begin to play an increasingly important role. They are essentially attractive in nature and can provide significant additional strength. The forces are equivalent to, and can be described by, a reduction in pressure in the “pores” or voids in the material.

This is referred to as suction. As the magnitude of soil suction can be very much greater than normal atmospheric pressure, the effective pressure can become highly negative. Its value depends not only on the amount of fluid in the pores (voids) but also on its nature, i.e. dissolved salts. As the pores fill with water, the magnitude of the suction decreases rapidly.

RoadCem/Cement modified materials are essentially water proof and have a highly reduced porosity as a result of treatment so suction forces can never develop to significant level.

The shear strength of granular materials and normally consolidated fine-grained soils is described by the well known effective stress equation:

Shear strength = (cohesion) + [(normal stress) – (pore pressure)] Tan (angle of internal friction)

The strength and stiffness of a pavement layer are reduced if pore pressure is increased (at high moisture contents) and conversely are increased when pore water pressure is decreased (at low moisture contents). When the pore pressure equals the total stress, internal friction becomes negligible and the shear strength is directley proportional to cohesion.

Thus, it is pore water pressure or suction of the water in the pavement, rather than the amount of water, that affects pavement behaviour. Two soils of different textures may have similar strength, and stiffnesses, even though their moisture contents may be quite different.

RoadCem/Cement modified materials effectively eliminate the negative term in the equation for shear strength making shear strength significantly higher under critical environmental conditions.The RoadCem approach especially becomes beneficial when problem soils and materials are in question.

Problem soils and materials are those materials which by virtue of their unfavourable properties would normally require special treatment before acceptance in the pavement structure or for a sub base. This category of soils and materials includes:

- Low-strength soils.
- Expansive clays ("black cotton" soil).
- Collapsible sands.
- Dispersive soils.
- Organic soils.
- Saline soils or presence of saline water.
- Weathered materials.

The characteristics, investigation, testing and design counter-measures to deal with problem soils are well covered in the literature and are not dealt with in depth in this manual.

In dealing with such materials, a careful balance has to be struck between the cost of RoadCem and Cement treatment. The benefits to be derived from avoiding the import of other suitable material and the costs of environmental damage needs to be taking into account.

Low-strength soils

Soils with a soaked CBR of less than 3 per cent (< 2 per cent in dry climates) are described as Low-strength soils.

Traditional

Typical traditional treatment measures for such soils include:

- Removal and replacement with suitable material.
- Chemical or mechanical stabilization.
- Elevation of the vertical alignment to increase soil cover and thereby redefine the design depth within the pavement structure.

RoadCem

RoadCem/Cement treatment falls in the second category and makes the use of these materials for pavement structure viable and justified.

Expansive soils

These clay soils exhibit particularly large volumetric changes (swell and shrinkage) following variations in their moisture contents. They shrink and crack when dry. The cracks allow water to penetrate deep into the soil, hence causing considerable expansion which results in deformation and failure of the pavement if these materials are used.

Traditional

Typical traditional treatment methods for such soils include:

- Realignment, where possible avoiding.
- Excavation and replacement.
- Chemical treatment.
- Control of moisture changes.

RoadCem

RoadCem/Cement treatment falls in the third category and makes the use of these materials for pavement structure viable and justified. The mechanism of action is the control of swell and shrinkage behavior of such soils.

Collapsible sands

These soils exhibit a weakly cemented soil fabric which, under certain circumstances, may be induced to rapid settlement. A characteristic of these soils is that there are all unsaturated, generally have a low dry density and a low clay content. At In-situ moisture content there can withstand relatively large imposed loads with little or no settlement. However, without any change in the loading but an increase of moisture content significant settlement can occur (figure 5.22). The rate of settlement will depend on the permeability of the soil.

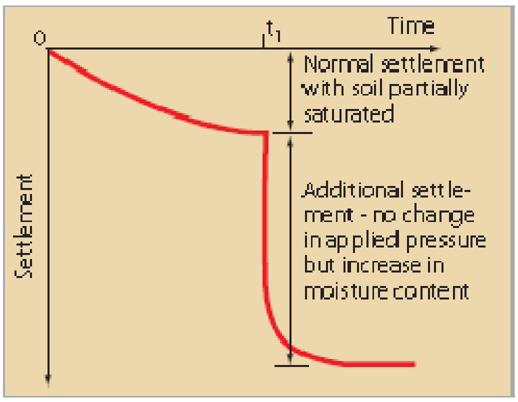


Figure 5.22 Collapsable sands behavior with moisture content increase

TRADITIONAL

Traditional methods of dealing with collapsible soils includes the following:

- Excavation of material to a specified depth below ground level and replacement in thin lifts (typically 200 mm).
- Ripping of the road bed, inundation with water and compaction with heavy vibrating rollers.
- Use of high energy impact compaction at In-situ moisture content
- Chemical treatment

ROADCEM

RoadCen treatment falls in the fourth category and makes the use of these materials for pavement structure viable and justified. The mechanism of action is the overall reduction in effective loading thus preventing settlement.

The above measures are all relatively expensive to undertake and a careful balance should be struck between the costs and benefits of their application.

Dispersive soils

These soils, some of which are clayey gravels, are easily eroded in the presence of water - a property that makes them problematic when they occur in cut slopes and in drainage channels. They have almost no resistance to erosion, are susceptible to pipe developments in earthworks, crack easily and have low shear strength. Their identification involves the use of a combination of indicator tests, observations of erosion patterns, soil colour, terrain features and vegetation.

TRADITIONAL

The following measures are typically employed where dispersive soils are encountered:

- Erosion protection in cut slopes and drainage channels.
- Modification with 2% to 3 % lime or alternative chemical treatment.

ROADCEM

RoadCem/Cement treatment falls in the second category and makes the use of these materials for pavement structure viable and justified. The mechanism of action is through stabilization and erosion control.

Saline soils or presence of saline water

The presence of soluble salts in pavement materials or subgrades can cause damage to the bituminous or other surfacing of roads. This problem occurs mostly in the semi-arid regions where the dry climate, combined with presence of saline materials (often calcrete or minewaste) and/or saline ground or surface water, create conditions that are conducive to the occurrence of salt damage. Such damage occurs when the dissolved salts migrate to the road surface, mainly due to evaporation. At he surface tehy become supersaturated and then crystallize with associated volume change. This creates pressures which can lift and physically degrade the surfacing and break the adhesion with the underlying pavement layer.

Generally, the thinner the surfacing layer is, the more likely the damage, primes being the most susceptible and thick, impermeable seals the least susceptible.

Figure 5.23 Saline soils

RoadCem/Cement offers an opportunity to avoid these saline effects as it will prevent salt migration to the surface of the pavement structure.

5.3 Making Good" Pavement Materials "from "Bad" Pavement Materials

Most of the time suitable naturally occurring gravels are not available within an economical haulage distance.

The In-situ material can be transformed through stabilization into a suitable material. Economically, stabilization of insitu material becomes the method of choice. Stabilization is the process by which additives are used to enhance the properties of subgrade and pavement materials - in order to improve the materials' properties, including strength, volume stability, durability and permeability.

The additives in traditionally used are:

- Portland cement.
- Lime (quicklime and hydrated lime).
- Pozzolans (fly-ash, pumice, scoria).
- Bitumen and tar.
- More recently to the above we can now add.
- Portland cement and/or Fly-Ash in combination with RoadCem.

The following factors influence the selection of the most suitable method of treatment:

- Site constraints.
- Materials.
- Climate and drainage.
- Economics of the various options (performance, durability, maintenance, cost).

As a general guide to the stabilisation of soils with one of the above methods figure 5.24 can be used.

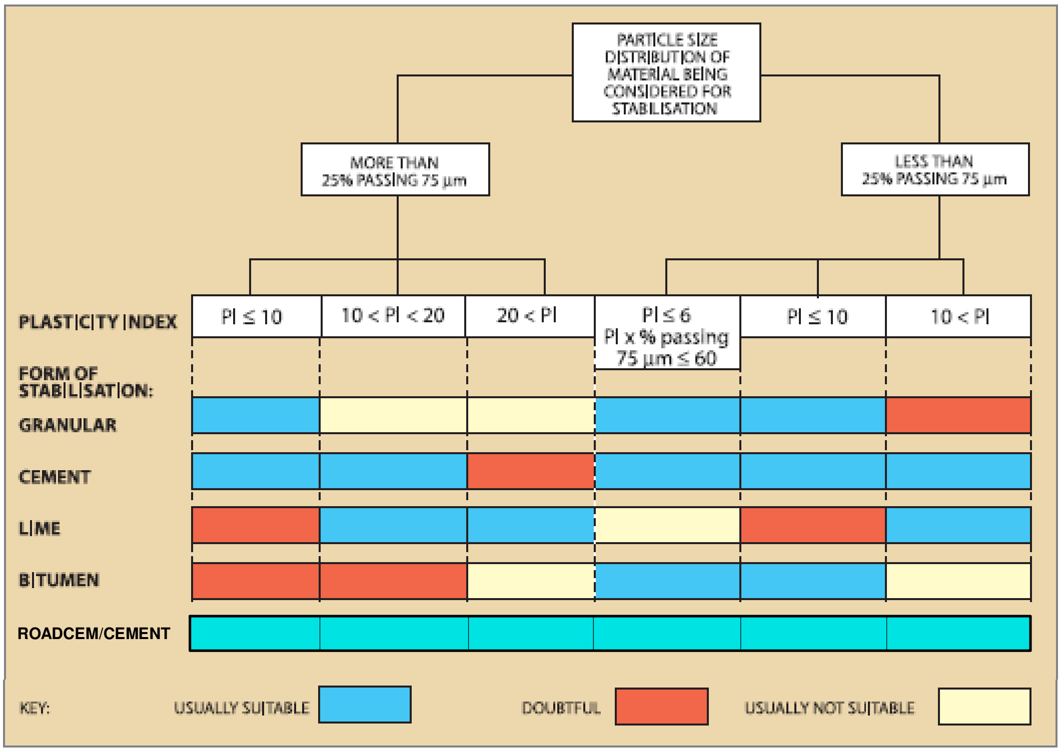


Figure 5.24 General guide to soil stabilization

Note that only RoadCem based stabilization can be applied to the whole range of soil.

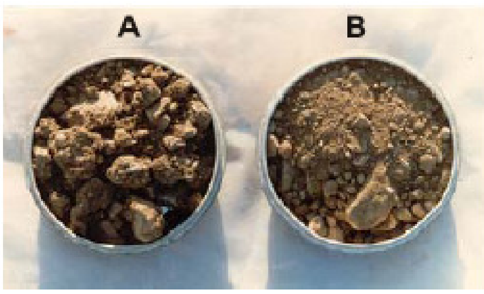


Figure 5.25 Example of the effects of treatment A. Untreated, B Treated

The main objective of stabilisation is to enhance the suitability of In-situ natural materials for pavement construction, thereby avoiding the need to import other materials. This leads to more cost-effective use of available materials with the following beneficial properties by comparison with the material import and/or use of untreated parent material:

- Increased strength or stability.
- Improved load-spreading capability.
- Increased resistance to erosion.

- Reduced sensitivity to moisture changes.
- Improved workability.
- Increased durability.
- Reduced maintenance.
- Reduced environmental impact.

As indicated in Figure 5.28 the choice of chemical stabiliser will depend on the material to be stabilised and the position in the road pavement it is to occupy. However, our experience has shown that only RoadCem options offers consistant and continous benefits and advantages.

These stabilisers are generally applied at relatively low dosages, typically between 3 and 6 per cent by mass. However, if problems are to be avoided, they must be subjected to careful and well-controlled processing and construction.

Specifications for chemically treated materials vary in different parts of the world and for different road authorities.

With the exception of RoadCem based stabilization potential problems and pitfalls with these type of materials includes:

- Propensity to crack particularly with cement treatment (cement only).
- Degradation of cementing action due to carbonation.
- Requirements for greater level of skill and control during construction.

Effects of carbonation

Lime- and, to a lesser degree, cement-stabilized soils can lose strength through carbonation. This effect is particularly evident in lime-stabilized fine-grained and relatively weak soils (especially calcretes). For base course materials, prolonged exposure of these lime or cement stabilized soils to the air before sealing can also result in a weak upper layer being produced prior to surfacing. Subsequent crushing of the aggregate as well as poor bonding between surface and the base can occur, leading to pavement failure. Measures that ameliorate the effects of carbonation during the stabilization process includes:

- Immediate covering with the next layer of material.
- Immediate application of a bitumen prime coat.
- Full moist curing (with no drying of the surface).
- Construction of layer with a sacrificial thickness to be bladed off.

Figure 5.26 Phenolpthalein reaction in stabilised subbase.

5.4 RoadCem Stabilization - Mix Specification

Using RoadCem/Cement as the stabilizing agent in pavement structure based on in-situ material is a function of many different parameters which are location specific. These parameters are:

- In-site material characteristics.
- Geotechnical conditions along the route of the road to be constructed.
- Cement type.
- Traffic load, intensity and growth.
- Required durability of the road.
- Maintenance specifications.

This requires that each specific case has to be considered separately in order to prepare an optimal design and a custom most economial solution. To do this requires that laboratory test samples are prepared and tested before the final design is specified.

However, in practice one is often asked to consider a situation where only limited data and information is available and yet it is expected to come up with a sufficientley robust design that represent the basis for the techno-economical comparison of different alternatives and this often without adequate resources allocated for field and laboratory tests.

The guidelines given for mix specification in this document have been prepared with the above situation in mind and to provide sufficent elements for the **conceptual** design. The manual can be used at the earley stage of the project when different design alternatives are considered and when an appropriate selection of the most appropriate design needs to be made.

The starting point is the Unified Soil Clasification System discussed and presented in Chapter 4 and summarised in figure 4.2. For each of the soil groups within the USCS the dose of RoadCem and Cement (based on CEM I 42.5N) is defined and this is a starting point for more detailed analysis at the later stages of the design process.

In principle, the following rules will apply:

- The courser the material, the lower the dose of Cement and RoadCem is.
- The finer the material, the higher the dose of Cement and RoadCem is.
- The higher the organic fraction in the soil, the higher the dose of Cement and RoadCem.
- The higher the silt contents of the soil, the higher the dose of Cement and RoadCem.
- The higher the clay contents of the soil, the higher the dose of Cement and RoadCem.

<table>
<tr><td rowspan="8">COARSE GRAINED SOILS</td><td colspan="2" rowspan="4">GRAVELLY SOILS - More than half coarse frction larger than 4.75 mm</td><td colspan="3" rowspan="2">CLEAN GRAVELS - Will not leave stain on a wet palm</td><td>Substantial ammount of all grain particle sizes</td><td>GW</td></tr>
<tr><td>Predominantley one size or range of sizes with some intermediate sizes</td><td>GP</td></tr>
<tr><td colspan="3" rowspan="2">DIRTY GRAVELS - Will leave stain on a wet palm</td><td>Non plastic fines</td><td>GM</td></tr>
<tr><td>Plastic fines</td><td>GC</td></tr>
<tr><td colspan="2" rowspan="4">SANDY SOILS - More than half coarse fraction smaller than 4.75 mm</td><td colspan="3" rowspan="2">CLEAN SANDS - Will not leave stain on a wet palm</td><td>Wide range of grain sizes and substantialrange of all grain particle</td><td>SW</td></tr>
<tr><td>Predominantlly one size or range of sizes with some intermediate sizes</td><td>SP</td></tr>
<tr><td colspan="3" rowspan="2">DIRTY SANDS - Will leave stain on a wet palm</td><td>Non plastic fines</td><td>SM</td></tr>
<tr><td>Plastic fines</td><td>SC</td></tr>
<tr><td rowspan="5">FINE GRAINED SOILS</td><td>Ribbon</td><td>Liquid Limit</td><td colspan="2">Dry Crushing Strength</td><td>Toughness</td><td>Stickiness</td><td></td></tr>
<tr><td>None</td><td><50</td><td>None to Slight</td><td>Rapid</td><td>Low</td><td>None</td><td>ML</td></tr>
<tr><td>Week</td><td><50</td><td>Medium to High</td><td>None to Very Slow</td><td>Medium to High</td><td>Medium</td><td>CL</td></tr>
<tr><td>Strong</td><td>>50</td><td>Slight to Medium</td><td>Slow to None</td><td>Medium</td><td>Low</td><td>MH</td></tr>
<tr><td>Very Strong</td><td>>50</td><td>High to Very High</td><td>None to Very Slow</td><td>High</td><td>Very High</td><td>CH</td></tr>
<tr><td rowspan="3">HIGHLY ORGANIC SOILS</td><td colspan="6" rowspan="3">Readily identified by color, odor, spongy feel and frequentkly by fibrous texture</td><td>OL</td></tr>
<tr><td>OH</td></tr>
<tr><td>Pt</td></tr>
</table>

Figure 5.27 Soil classification.

Another factor that has an influence on the dose of stabilizing agents Cement and RoadCem is the traffic intensity and maximum load expected on the road during the design life time of the road. This is related to the breaking strength and fatigue of the stabilized (bound) material after treatment.

In principle, the following basic rules will be applied:

- The longer the design life, the higher the dose of Cement and RoadCem will be.
- The higher the wheel load expected, the higher the dose of Cement will be.
- The higher the intensity of expected traffic, the higher the dose of RoadCem will be.

If we assume that the layer below the stabilization layer (sub garade in the traditional pavement structure) consists of the same material as the stabilized layer, than the equivalent pavement structure for the RoadCem method would be as shown in figure 5.28.

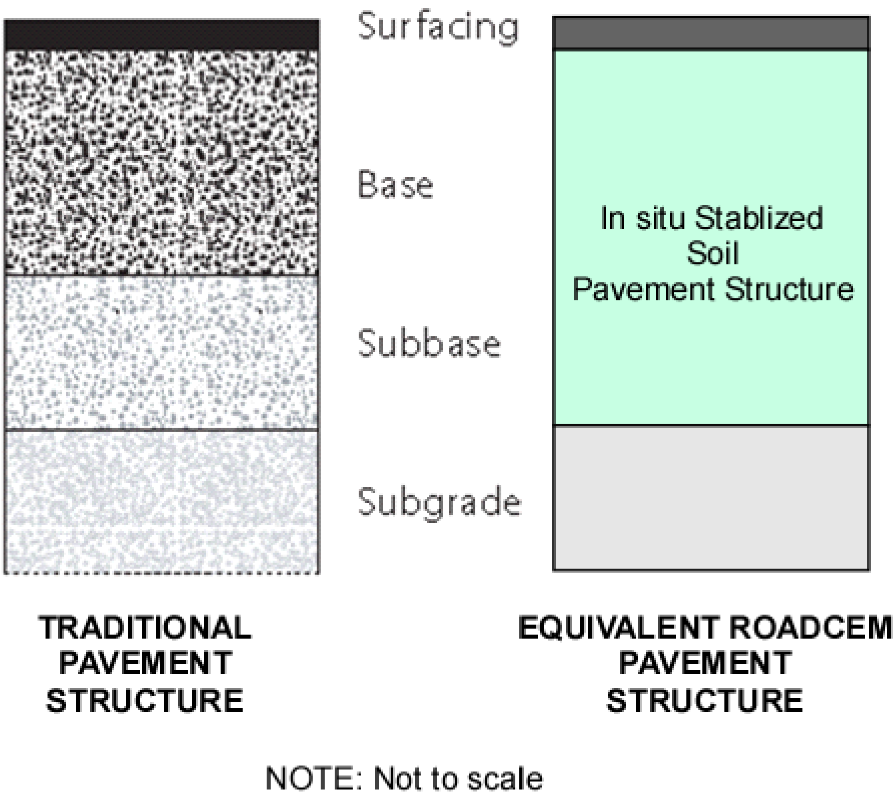


Figure 5.28 Comparison between Traditional pavement and RoadCem construction.

The final aspect to be considered is the thickness of the pavement structure. Here too some general rules are applied but this factor is also under the influence of the expected life time or the design life time of the road without any or minimal maintanance. The general rules are:

- The higher the wheel load, the thicker the pavement structure is.
- The higher the intensity of traffic, the thicker the pavement structure is.
- The longer the design life of the pavement, the thicker the pavement structure is.

When we combine all of the above factors we end up with general Cement, RoadCem and pavement structure requirements as a function of the soil class as given by the USCS. These general recommendations are used as the starting point for the design and design optimization process shown in figure 5.29 and are shown in table 5.6.

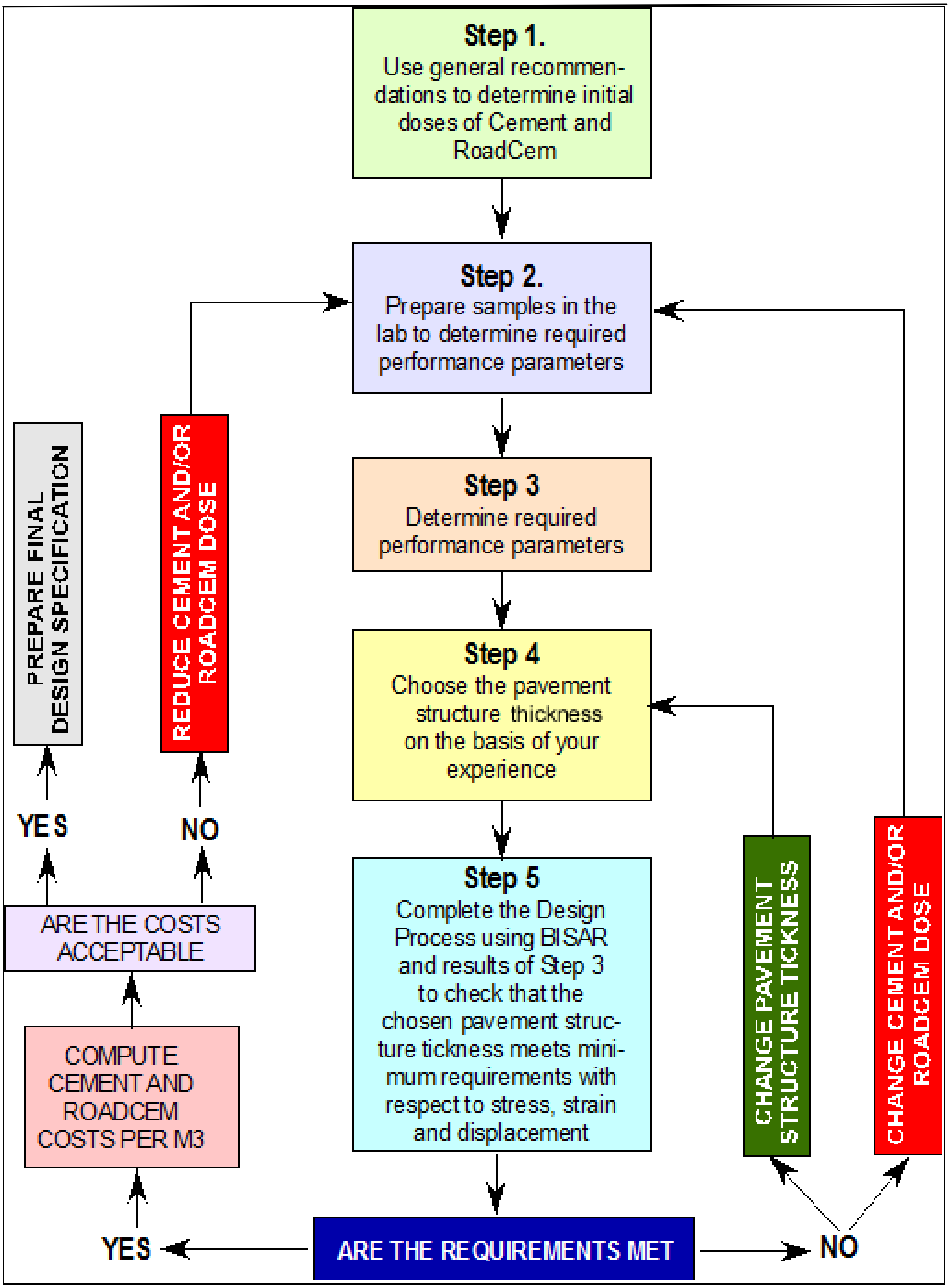


Figure 5.29 Design Optimization Proccess.

Table 5.6 General Mix Design Recommendations.

GENERAL ROADCEM DESIGN GUIDELINES FOR DIFFERENT SOIL CLASSESS ACCORDING TO THE UNIFIED SOIL CLASSIFICATION SYSTEM AND FOR DIFFERENT AXLE LOADS AND TRAFFIC VOLUME CATEGORIES - ESTIMATED LIFETIME 20 YEARS

(Note: The guideline value is a starting point for design - optimization is possible and lower doses may be appropriate if field and laboratory test results so justify. For each particular project laboratory test samples should be prepared to optimise the Cement and RadCem dose. The values given in the table below are based on the use of CEM I 32.5N. If other Cements are used appropriate adjustments need to be made)

	Heavey Traffic - Axle Load 120 KN - Tandem				Medium Traffic - Axle Load 100 KN - Tandem				Light Traffic - Axle Load 80 KN - Tandem			
SOIL CLASS	Cement Dose, kg/m3	RoadCem Dose, kg/m3	Thickness of Soil Stabilization, mm	Tickness of Wearing Course - Asphalt, mm	Cement Dose, kg/m3	RoadCem Dose, kg/m3	Thickness of Soil Stabilization, mm	Tickness of Wearing Course - Asphalt, mm	Cement Dose, kg/m3	RoadCem Dose, kg/m3	Thickness of Soil Stabilization, mm	Tickness of Wearing Course - Asphalt, mm
GW	150	1.5	250	70	150	1.5	200	50	140	1.5	150	50
GP	150	1.5	250	70	150	1.5	200	50	140	1.5	150	50
GM	150	1.6	250	70	150	1.6	200	50	140	1.6	150	50
GC	150	1.6	250	70	150	1.6	200	50	150	1.6	150	50
SW	160	1.6	250	70	160	1.6	200	50	150	1.6	150	50
SP	160	1.6	250	70	160	1.6	200	50	160	1.6	150	50
SM	160	1.7	250	70	160	1.7	200	50	160	1.7	150	50
SC	165	1.7	250	70	165	1.7	200	50	160	1.7	150	50
ML	165	1.7	250	70	165	1.7	200	50	165	1.7	150	50
CL	165	1.7	250	70	165	1.7	200	50	165	1.7	150	50
OL	170	1.7	250	70	170	1.7	200	50	170	1.7	150	50
MH	170	1.7	250	70	170	1.7	200	50	170	1.7	150	50
CH	170	1.8	250	70	170	1.8	200	50	170	1.8	150	50
OH	180	1.8	250	70	180	1.8	200	50	180	1.8	150	50
PT	200	2	300	70	200	2	250	70	200	2	200	70

It is noted that the values in the above figure are a starting point for the design and in no way represent the final and optimal design for each given project and field conditions.

Then values given in the table are accurate enough to allow for techno economic analysis of different alternatives. If the RoadCem alternative as defined in the guidelines is accepted as the one to be considered further, detailed analysis need to be implemented and this would involve field and laboratory tests to determine more accurately the input parameters needed for the final design.

What we in fact have is a classical “Rubic Cube” design problem which we can graphically represent, as in table 5.6. Each element of the Rubic cube will have an associated dose for Cement and RoadCem. Once these doses are established from the general guideline table 5.6 samples need to be prepared with the actual soil that will be used in the pavement structure and a predetermined set of tests carried in the laboratory to obtain the actual design parameters for the final design. This will determine the thickness of the pavement structure.

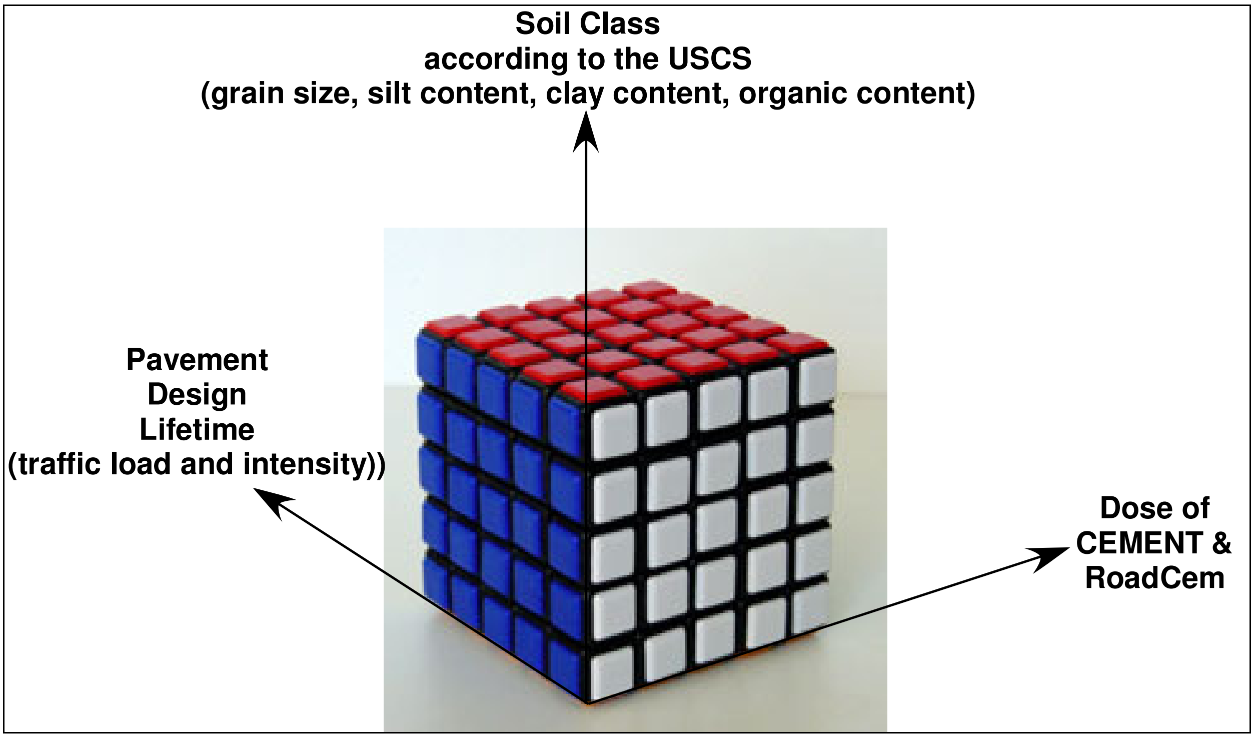


Figure 5.30 Soil class.

5.5 Laboratorium testing

RoadCem is an additive to Cement and consists of about 20 different components some of which are present in very small quantities. In order to avoid the wrong test results when working with RoadCem it is therefore necessary to determine the minimum soil sample size for the required dose of RoadCem so that at least 100 grams of RoadCem are used in the preparation of the test samples.

RoadCem is a pro-active dry powder, grayish in color and causes a chemical/ physical reaction when added to a binder and water. In general, in the field, RoadCem achieves a 5-10% higher results in relation to laboratory testing. The reason for this is due to the mass effect of the pro active RoadCem powder.

The procedure to determine the minimum soil sample size for laboratory specimen preparation is as follows.

1. Determine the density of Soil (dry density) (Density, Ds, kg/m3)
2. Determine the optimum moisture content of the soil (Prepare a proctor Curve, Determine Optimum MC)
3. Use the formula below to determine the minimum required soil sample size (Ss, m3):

$$Min\ Ss,\ m3 = \frac{0.100}{DDrc}$$

where DDrc = Design dose for RoadCem (for Queretaro this is 1.2 kg/m3)

4. Calculate the dry weight of soil sample, Ws, needed for the preparation of the sample using the formula below:

$$Ws,\ kg = SS * Ds,\ kg$$

5. Calculate the wet weight of soil sample, SWw, needed for the preparation of the sample using the formula below:

$$SWw,\ kg = Ms + Ms * Smc$$

where Smc is the soil moisture content of sample as collected (in situ)

6. Calculate the amount of water needed to prepare the sample, Ww, kg, using the formula below:

$$Mw,\ kg = Ms * OMC - Smc$$

where Smc is the actual moisture content of the soil sample as colected,

OMC = Optimum misture content of the soil from proctor curve

Once all the above values have been determined the procedure to prepare the samples is as follows:

Step 1. Measure SWw, kg of soil and place in a mixer and homogenize making sure that there are no lumps of any significant size forming

Step 2. Add 100 gr of RoadCem and Mix well to ensure uniform distribution

Step 3. Add the required amount of Cement as per Cement design dose (for Queretaro the design dose is 120 kg/m3 of soil) – To calculate the amount of Cement needed multiply the design dose by a fraction represented by sample size, i.e. and mix to ensure uniform distribution.

$$C,\ kg = \frac{Cdd}{SWw}$$

where C = ammount of Cement for the preparation of sample

Step 4. Add the required amount of water+2% and mix thoroughly

Step 5. Prepare cylinders and/or cubes and beams for testing by placing the material in appropriate moulds and compacting to MPD, maximum Proctor Density. Cover with moist cloth.

Step 6. De-mould after 24 hours and cure in air under wet cloth until testing date.

It is often necessary to prepare more than one mix with different doses of RoadCem and Cement in order to find the optimum dosage rate for a prticular application. In such cases for each dose the minimum sample size has to be determined. The samples prepared are than tested at 7, 14, 28 days etc.

More detailed analysis will involve field sample collection and determination of the load bearing characteristics of the soil under field conditions. As a minimum the laboratory tests should involve the determination of:

- Modulus of Elasticity.
- Compressive Strength.
- Flexural Strength.
- Breaking Strain.

- Poisson Ratio.
- Fatigue behaviour.

The results of these tests are than used as input into the design process. Determination of the optimum design involves:

- The determination of the required pavement thickness.
- Confirmation that the stresses, strains and displacement within the pavement structure meet the desired criteria.
- Adjustments of the mix design, should the above requirements not be met.

This is an itterative process. It will take a number of itterations before an optimum design is obtained. An additional factor which is considered at this point in time is the cost of Cement and RoadCem. This too should be minimized if the client requirements are to be met. This procedure is outlined in the figure 5.32.

The design optimization procedure shown in Figure 5.34 calls for the use of BISAR pavement Design Software or similar design method. BISAR is a software design package developed for flexible pavement design by Shell and is widely used in practice. BISAR is not all that data intensive and this is why it is recommended. Other software packages are also available and can be used but will typically call for more laboratory and field data collection.

The use of BISAR is not subject of this manual but software package and its user manual are available on request from the supplier or through PCT in the Netherlands.

RoadCem based Design approach is in fact a balancing act between a number of factors as shown in figure 5.31.

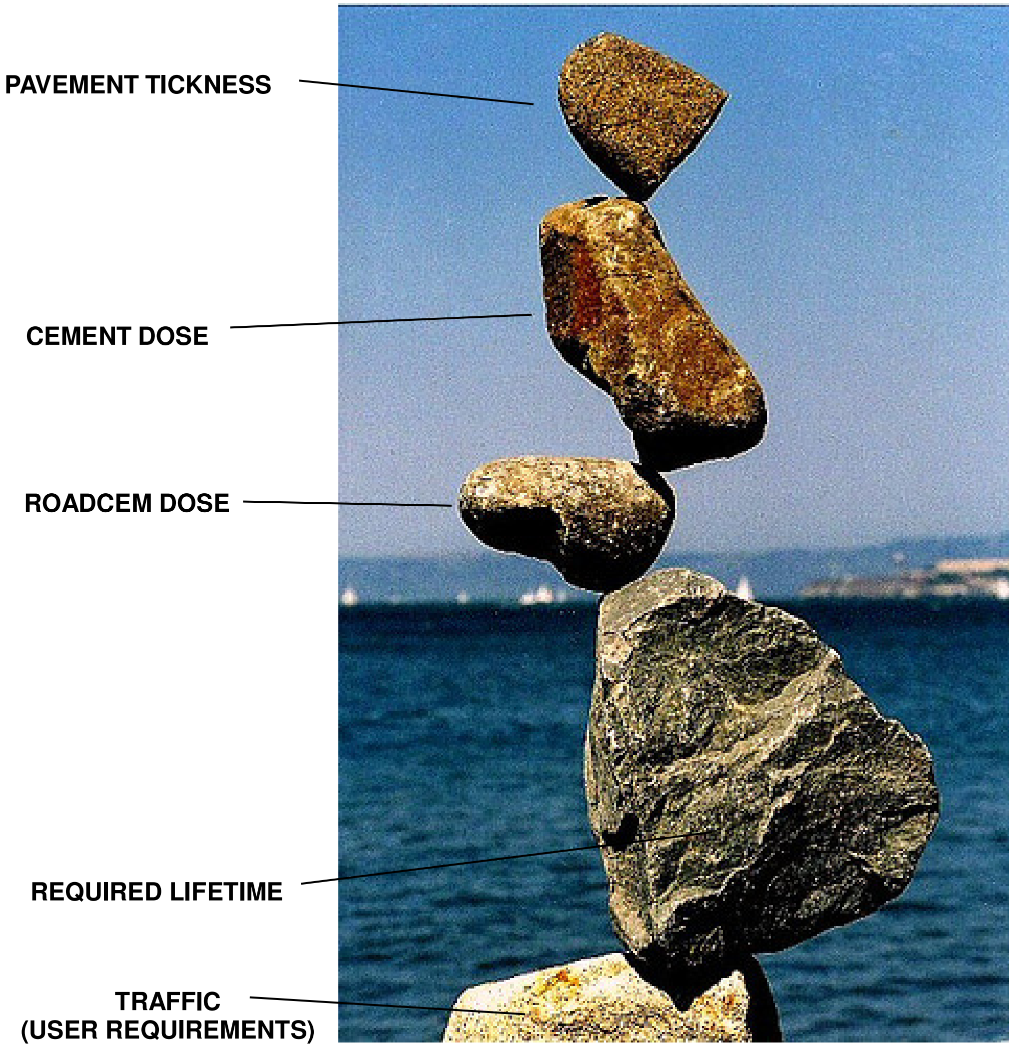


Figure 5.31 RoadCem based balancing Design Act.

5.6 Final Comments on the Mix and Pavement Structure Design

5.6.1 Cement and Binder Types

In presenting the mix and pavement structure design we assumed that the binder to be used is CEM I 42.5N and a modifying additive RoadCem manufactured by PowerCem Technologies in the Netherlands.

Table 5.7 Example of different Types of cement.

Name	Indication	K (%)	Other main substances (%)
Portland cement	CEM I	95 -100	
Portland fly-ash cement	CEM II/ B-V	65 - 79	21 - 35 V (Fly-ash)
Furnace cement	CEM III/A	35 - 64	36 - 65 S (furnace slag)
Furnace cement	CEM III/B	20 - 34	66 - 80 S (furnace slag)

K= Portland cement clinker

However different type of Cements are available on the market as are Cement improvement and replacement additives such as fly ash, blast furnace slag and silica fume. The RoadCem approach does not preclude the use of any Cement type available on the market. The design approach and process will not change with other cement types. In fact the RoadCem binds very good when there is a relative high amount of fly ash in the cement. It is known that 50:50 blend of CEM I 41.5N and fly- ash should give similar design solutions at a significantly reduced cost but this for the time being needs to be confirmed by laboratory replacement.

5.6.2 Waste materials and Industrial Residues

In many situations it is possible and economically advantageous to use waste and recycled material instead of the in situ soil. Experience has shown that with the use of RoadCem this material is highly viable and leads to acceptable designs. However, field and laboratory testing is required to come up with appropriate solutions and eliminate any possible negative environmental effects due to potential leaching of pollutants from the waste material such as waste sludge or industrial residues.

5.7 Determination of Stabilized (Bound) Material Properties

5.7.1 General

Once the mix design is chosen, the amount of material, cement, fly-ash and RoadCem, are known and a new composite material is created. This new material will have certain properties, depending on the composition. These properties will determine the pavement structure design. For example, the layer thickness and lifespan of the pavement structure are based on these properties as well as the stresses and strains that occur in the final pavement structure.

The material properties that need to be determined are shown in the figure 5.32:

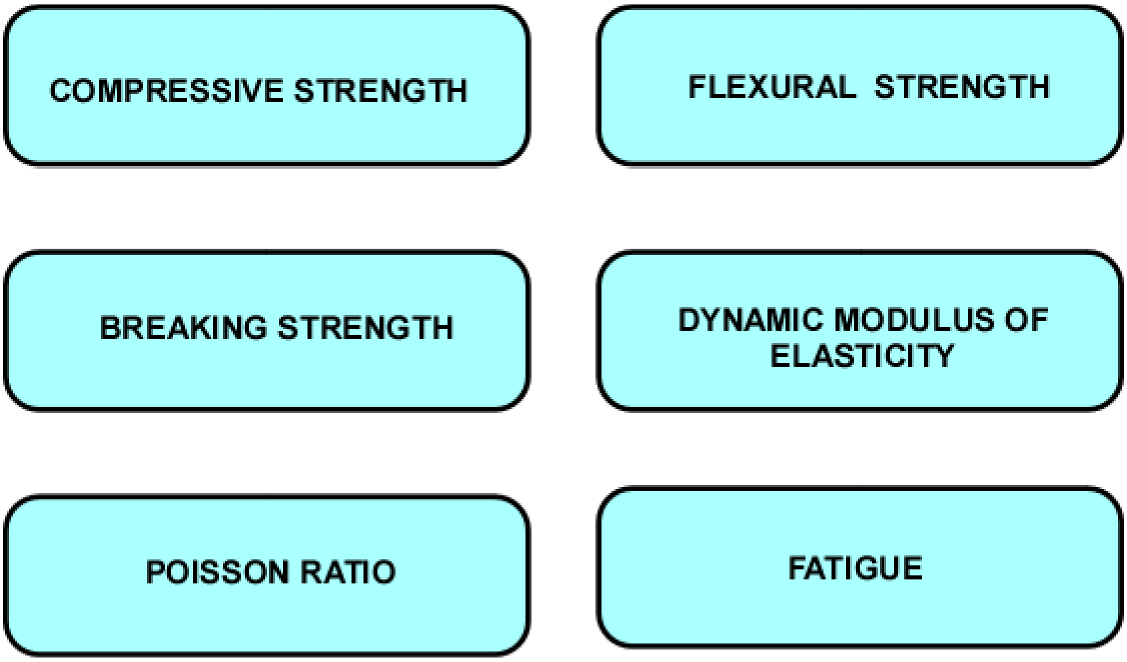


Figure 5.32 Determine most important physical material properties for road dimensioning.

When material properties have higher values compared to the traditional materials then a better pavement structure will be built. Before actual construction takes place the properties of each project must be examined and checked. The reason is that each sub-base is unique and there is always a possibility that the properties of the material deviate from the general recommendations discussed previously. If any of the properties show unacceptable values then the mixture composition needs to be changed. The methods used for the measurement of the different material properties are given next.

5.7.2 Comressive strength

Compressive strength is measured by applying a known pressure (or a loadin) to a sample speciment and observing the pressure needed to cause the failure of the specimen. Special testing equipment is needed. The rate at which pressure is applied is also controled.

A minimum value for compressive strength of 2 MPa is needed after 48 hours and 4,2 MPa after 28 days. These are higher values in comparison with the values obtainable with all traditional hydraulic materials with the exception of concrete.

Figure 5.33 Commpresive strength test.

At least 2 cubes must be made to determine the compressive strength.

- When the value for compressive strength is higher than specified then the use of less cement can be considered but will need to be verified by subsequent tests. This can result in a substantial saving.
- When the value for compressive strength is lower than specified then more cement needs to be used.

5.7.3 Dynamic elasticity modulus

The modulus of elasticity is the slope of the initial, linear-elastic part of the stress-strain diagram.

$$E = \frac{stress}{strain} = \frac{F/A}{x/L}$$

where

E = Young's modulus [Nm^{-2}]

F = applied load [N]

A = cross-sectional area [m^2]

x = extension [m]

L = original length [m]

For isotropic materials it is related to the bulk modulus K and to the shear modulus G by

$$E = 3(1 - 2\nu)K$$

$$E = 2(1 + \nu)G$$

where

ν = Poisson's ratio

K = bulk modulus [Nm^{-2}]

G = shear modulus [Nm^{-2}]

Commonly $\nu = 1/3$, and hence $E = K$, and $E = (8/3)G$.

The measurement of the Dynamic Modulus of Elasticity can be achieved by three or four point bending flexural tests (Figure 5.34).

The minimum value should be at least of 3.000 MPa after 48 hours. This is a higher value in comparison to all traditional materials with the exception of concrete (20.000 MPa) and asphalt (7.500 MPa).

At least 3 test samples must be made to determine the dynamic elasticity moduls.

- When a value higher than 3.000 MPa is less cement can be used but verification test is required. This can result in a substantial saving.
- When a value of less than 3.000 MPa is achieved then more cement and/or RoadCem must be used but verification test is required.

5.7.4 Breaking strain

The measurement of the Breaking Strain is also achieved by three or four point bending flexural tests (Figure 5.34).

The minimum acceptable value when the 3-point flexural test is used is 500 μm/m after 28 days. This is a higher value in comparison to all traditional material.

3 test samples must be made to determine the breaking strain. The test can be carried out simultaneously with determination of the dynamic elasticity module.

Figure 5.34 Three-point bending flexural test.

- When a value higher than 500 μm/m is achieved then it can be considered to use less RoadCem. Verification tests are requiered.
- When a value is lower than 500 μm/m is achieved it is advisable to use more RoadCem. Verification tests are requiered.

5.7.5 Poisson Ratio

Poisson ratio measurement is often of interest for design criterion when a material's mechanical properties are evaluated.

When a sample of material is stretched in one direction it tends to get thinner in the other two directions.

Poisson's ratio is the ratio of the relative contraction strain, or transverse strain normal to the applied load, to the relative extension strain, or axial strain in the direction of the applied load.

Poisson's Ratio can be expressed as

$$\upsilon = -\epsilon_t / \epsilon_l$$

where

υ = *Poisson's ratio*

ϵ_t = *transverse strain*

ϵ_l = *longitudinal or axial strain*

Strain can be expressed as

$$\epsilon = dl/L$$

where

dl = *change in length*

L = *initial length*

Typical value for concrete is 0.2 and for materials stabilized with Cement and RoadCem the typical values range between 0.2 and 0.3

The tensile test can provide two constants, Poisson's ratio and modulus of elasticity. The method involves lateral and transverse strain measurement simultaneously. Either strain gage or extensometers can be used for the strain measurements, but strain gages are preferred for their compact size. There are several limitations to Poisson determinations, but generally these are dictated by the material characteristics.

5.7.6 Fatigue

The measurement of fatigue is conducted during the fatigue test with a minimum value of 10^7 load applications with a strain of 80 μm/m achieved for a standard axle load of 100 kN.

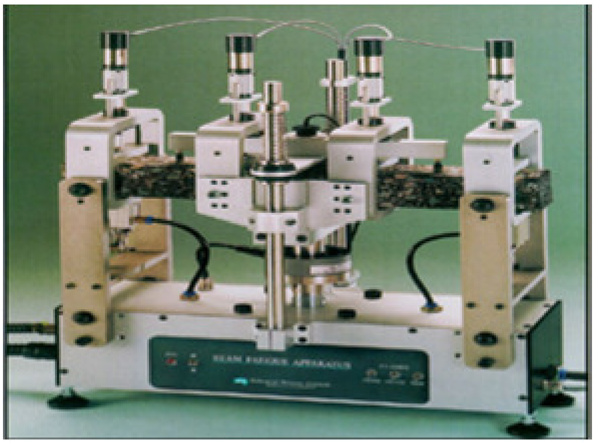


Figure 5.35 Fatique test.

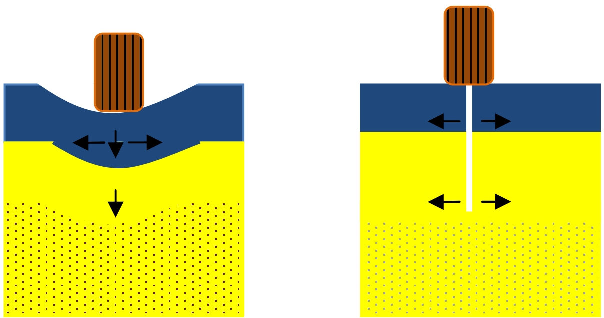
- When a value for the number of load applications before failure greater than 10^7 is obtained with a strain of 100 μm/m at a standard axle load of 100 kN one can consider the reduction of the dose of RoadCem. Verification tests are requiered.
- When a value for the number of load applications before failure small than 10^7 is obtained with a strain of 100 μm/m at a standard axle load of 100 kN, more RoadCem has to be used. . Verification tests are requiered.

The sample preparation procedure and the testing methods are given in the appropriate appendices at the end of the manual.

5.8 Procedure for checking that minimum requirements are met

The RoadCem Design Approach presented earlier requires that a check if the minimum design requirements are met is carried out. If the minimum design requirements mentioned in paragraph 5.2 to 5.7 are not met then the following pavement and foundation damage scenario(s) can occur:

- Deformation in the sub-base (1);
- Deformation in un bound foundation (2);
- Cracking on top of bound foundation (3);
- Instantaneous break in bound foundation (4);
- Fatigue damage in bound foundation (4).



Unbounded material *Bounded material*

Figure 5.36 Damage scenario that can occur in road construction

A part of the pavement structure design is the determination of stresses and strains within the structure itself under given design loads. In response to the loading the pavement structure will deform. Deformation can occur at the top of the layer and cracks will occur underneath the bound material. The stresses and strains that occur depend on the traffic load, the elasticity modulus of the materioals and the viscosity of the materials and the properties of the soil.

The stresses and strains are typically calculated using the multiple layer elasticity theory. Once tehse calculations are performed a comparison is made to the proporties of the materials used and an evaluation of the ability of the materials to withstand, without damage, the stressess and strains calculated is carried out. This kind of calculations are typically performed by specialised engineering offices, such as ARCADIS, using specialised calculation methods and software.

The calculation process is summarized in Figure 5.37:

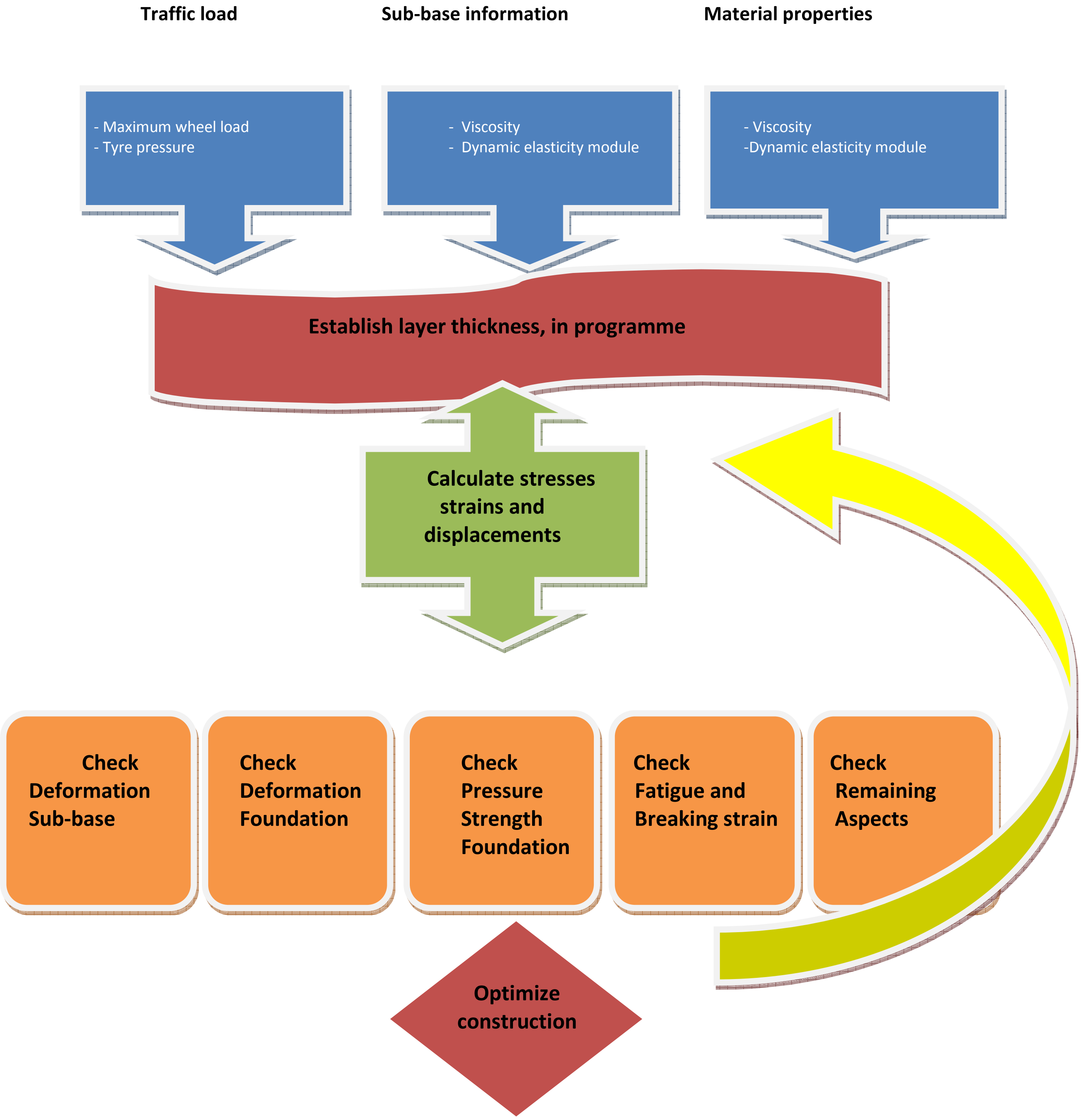


Figure 5.37 Procedure for Dimensioning pavement Structure

After a initial pavement design calculation has been made it is tested against the different failure mechanisms that can occur. This next sections explain, step-by-step, what must be done.

Determination due to shock in the sub-base

Permanent deformation can occur in the sub-base as a result of compaction that leads too deformation. These processes can happen independently or in combination. The criteria is developed to predict when the longitudinal plane (smooth or rough) has increased to IRI=3,5. The fatigue relation for a subsoil is modelled as follows:

$$\sum_{N=i} \log(N_i) = 0{,}5 \cdot \log(N_v) + 0{,}5 \cdot \log(N_l)$$

$$\log(N_f) = (-6{,}211 - 0{,}482 \cdot z - 4 \cdot \log(\varepsilon_f)) +$$

$$\log(N_e) = (-6{,}211 - 0{,}482 \cdot z - 4 \cdot \log(\varepsilon_e))$$

Formula 5.1 Determining shock in the sub-base

Where:

Z = For the z-score a reliability level of 70 % is accepted.

ε_f = Vertical shock above sub-base with fully loaded truck (50% of the total amount of trucks).

ε_l= Vertical shock above sub-base with empty loaded truck (50% of the total amount of trucks).

N_v= Permitted amount load repetitions based on sub-base shock.

RoadCem can prevent deformation from happening depending on the composition of the sub-base.

Deformation in unbound foundation

With unbound foundations permanent deformations must be prevented. The calculation of resistance against moldable deformation is shown in the formula 5.2. When the pressure ratio is smaller than 0,6 then the construction suffices compared to the permanent deformation of the unbound foundation.

$$R = \frac{\sigma_1 - \sigma_3}{\sigma_{1f} - \sigma_3}$$

Formula 5.2 Determining deformation in unbounded foundation.

R = Pressure ratio

σ_1= highest (mainly vertical) main pressure with fully loaded truck (kPa);

σ_3= least (mainly horizontal) main pressure, with fully loaded truck (kPa);

σ_{1f}= Maximum permitted main pressure for the foundation material is accepted at 1.700 kPa, this is the same as cement granulate.

Figure 5.38 Deformation in unbound foundation.

Cracking of upper edge for bound foundation

When using an emulsion layer on the foundation material the stress from the traffic load above can become so high that cracking occurs and ruts can develop. The formula 5.3 is a method of calculating the lifespan relative to this condition with approx. 10 mm rutting on the upper edge of the foundation.

$$\sum_{N_{CA}=i} \log(N_{CA})_i = 0{,}5 \cdot \log(N_{CA})_{full} + 0{,}5 \cdot \log(N_{CA})_{empty}$$

$$\log(N_{CA})_{full} = (0{,}894 - 0{,}55 \cdot z) \cdot (1 - \frac{\sigma_{v2(full)}}{(1{,}31 - 0{,}085 \cdot z) \cdot \sigma_d)})$$

$$\log(N_{CA})_{empty} = (0{,}894 - 0{,}55 \cdot z) \cdot (1 - \frac{\sigma_{v2(empty)}}{(1{,}31 - 0{,}085 \cdot z) \cdot \sigma_d)})$$

Formula 5.3 Crushing upper edge bounded foundation.

N_{CA} = Permissible number of load repetitions until continued cracking

σ_{v2full} = Maximum vertical stress in the upper edge of the foundation and bearing strength of the sub-base.

$\sigma_{v2empty}$ = Maximum vertical stress in the upper edge of the foundation with an empty truck, this value depends on the thickness and bearing strength of the foundation and bearing strength of the sub-base.

σ_d = Pressure strength of the foundation material; it is assumed that the minimum pressure strength is 2 MPa.

z = A reliability level for the z-score is 70%.

Fatigue - bound foundation

Repeated load application on a bound foundation can lead to cracks in the lower part of the construction. The cracks could carry on through the construction and appear on the surface. For a foundation material with RoadCem the fatigue ratio has not yet been determined, but knowing the properties of RoadCem with its special fibrous crystal structure is can be assumed. With bound foundation materials there are 2 fatigue ratios known:

- with sand cement (>8% cement), and
- AGREC (3,5% cement) foundations.

The ratio with sand cement is less favorable compared with AGREC. The percentage of cement in a construction with RoadCem is approx. 8% and based on this it comes close to that of a sand cement foundation. Yet it has been chosen to use the AGREC-fatigue ratio for RoadCem. This is because of the crystalline structure that RoadCem develops and the resulting improved fatigue resistance. This must be verified for each project. With standard construction the AGREC fatigue ratio is used as shown in formula 5.4.

$$\sum_{N_{CA}=i} \log(N_{fatfund,L})_i = 0{,}5 \cdot \log(N_{fatfund,L})_{full} + 0{,}5 \cdot \log(N_{fatfund,L})_{empty}$$

$$\log(N_{fatfund,L})_{full} = 21{,}37 - 7{,}72 \cdot \varepsilon_{(r,fund)\,full}$$

$$\log(N_{fatfund,L})_{empty} = 21{,}37 - 7{,}72 \cdot \varepsilon_{(r,fund)empty}$$

Formula 5.4 Fatigue bounded foundation (AGRAC).

$N_{fatfund,L}$ = Permissible number of load repetitions based on strain at the lower level of foundation

$\varepsilon_{(r,fund)full}$ =Horizontal strain at the lower level of unbound foundation with full truck load on the road construction.

$\varepsilon_{(r,fund)empty}$ =Horizontal strain at the lower level of unbound foundation with empty truck load on the road construction.

Figure 5.39 Fatigue Cracks in asphalt.

Breaking strain

The breaking strain is the strain that is created by a high load and whereby instantaneously a crack occurs. At wharfs where high loads regularly occur the breaking strain is an important property when dimensioning for a cement bound construction.

Check remaining aspects

As well as the mechanical properties other aspects can have an influence on the construction thickness, such as possible frost/thaw damage. In areas where frost does not occur (less than 4 days with temperatures below -4 °C) or the level of the capillary water is lower than 1 m no measures need to be taken. When there is chance of frost/ thaw damage then precautions are needed and the advise is to contact the engineers at PCT head office.

5.9 Surfacing

5.9.1 General

Once the pavement load bearing structure is in place it is advisable to apply some kind of surfacing finish to the road. Many different methods of surface finishing are in common use and discussing all of them is beyond the scope of this manual. What is presented in this manual is a brief review of some of the available options. The possible options that are discussed in the manual are:

- Concrete
- Bricks
- Asphalt
- Wearing layer
- Sand up
- Gravel layer
- Chip and spray, etc.

The decision on the most suitable option will be affected by requirementes of the client, the availability of suitable materials locally and the economic considerations. In principle a wide range of aggregate types and qualities can be used for different surfacing options. Each of various types of surfacing has different requirements as regards the necessary materials and equipment for placement.

5.9.2 ConcreCem Fine Aggregate (sand) Concrete Finish

This option is durable and strong. It has a good wearing resistance characteristics and is impermeable to water so any precipitation on the surface will have to be evacuated through an appropriate runoff collection system.

The surfacing layer is applied on top of the pavement structure (in situ material stabilized with RoadCem and Cement) Figure 5.40. The Concrete can be placed either manually or using specialised equipment as in Figure 5.41. The finished surface is shown in Figure 5.42.

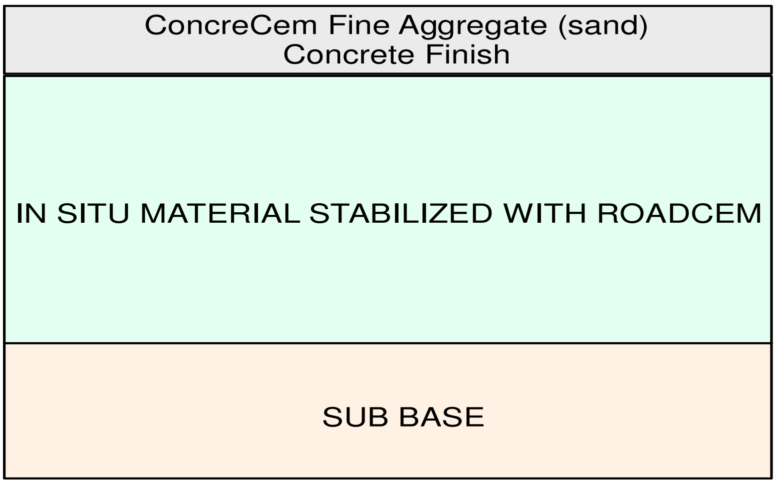


Figure 5.40 ConcreCem Fine Aggregate Surfacing Finish.

Figure 5.41 Placing of the ConcreCem Fine Aggregate(sand) Concrete.

Figure 5.42 The look of the ConcreCem Fine Aggregate(sand) Concrete Finish.

The mix specification for 1 m^3 of concrete for the ConcreCem Fine Aggregate(sand) Concrete finish is given in the Table 5.8.

Table 5.8 Mix design.

Material	MIX DESIGN
Sand, 0-5 mm, kg	1500
ConcreCem, kg	4.5
Cement CEMI 42.5N, kg	350 to 450
Water, L	270

The amount of water needs to be adjusted depending on the actual moisture content of the sand aggregate and the weather conditions.

The thickness of the the ConcreCem Fine Aggregate(sand) layer should not be less than 4 cm and can be as high as 8 to 10 cm.

5.9.3 ConcreCem Fine Aggregate (sand) Concrete +Quartz Sand Finish

Concrete is placed and than sprayed with fine quartz sand which is blended into the surface of concrete to give it more rougness for added skid resistance.

Same Mix design is used as prescribed in table 5.8, and 5 to 7 kg of 0-2 mm quartz sand is spread on top of the fresh concrete (Figure 5.43) and is then blended in using the rotary "Helicopter" polishing equipment to finish the treatment (Figure 5.43).

Figure 5.43 ConcreCem Fine Aggregate (sand) Concrete +Quartz Sand Finish.

Similar to the above is the Smmoth finish. The top 1cm of the construction is completed with a mixture of cement, ConcreCem and a granular material with a very fine grain size. Using the Smooth finisher machine to finish off the top neatly. An example is shown in figure 5.44.

Figure 5.44 Implementing Smooth finisher.

5.9.4 Brushed Finish

This option is suitable for situations where the load bearing layer is in situ soil stabilized with more than 160 kg/m³ of Cement and 1.6 kg/m³ of RoadCem .

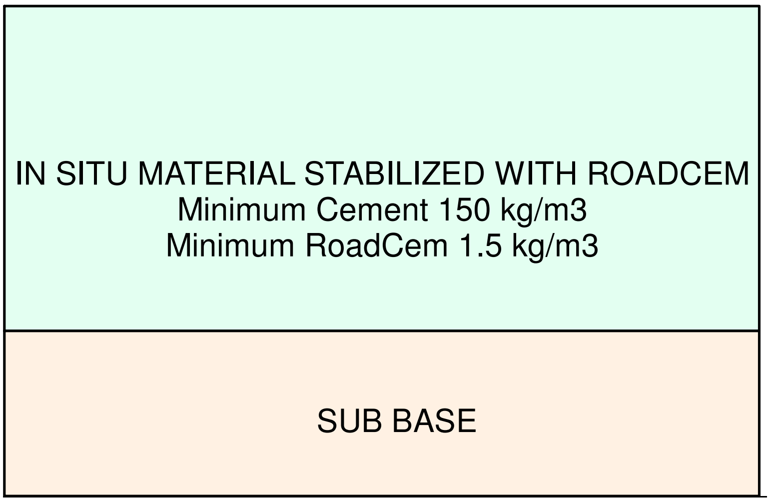


Figure 5.45 Brushed finish.

Figure 5.46 Mechanical Surface finishing brooms.

After stabilization is completed and compaction finished the surface of the stabilized layer is roughned using normal street sweeping mechanical brooms (Figure 5.46). This needs to be done within a few hours of stabilization.

The finish that can be achieved is shown in Figure 5.47.

Figure 5.47 Mechanical Broom Finish.

This type of finish is especially suitable for low intensity traffic areas. The surface layer is either impermeable or, extremely low permeability so appropriate run-off control measures have to be put in place. The surface is rather hard but depends also on the type of the soil which has been stabilized. Skid resistance is good to moderate. Wearing resistance under low intensity traffic is good.

5.9.5 Chip and Spray Finish

Chip and Spray Finish is a rather cost effective option even for high intensity traffic areas and is an effective and economic replacement for traditional asphalt finishing. Depending on the intenisty of expected trafic it can be applied in one two or three layers. It is most effective if it is applied within 24 to 48 hours following the completion of the soil stabilization with RoadCem. (Figure 5.48)

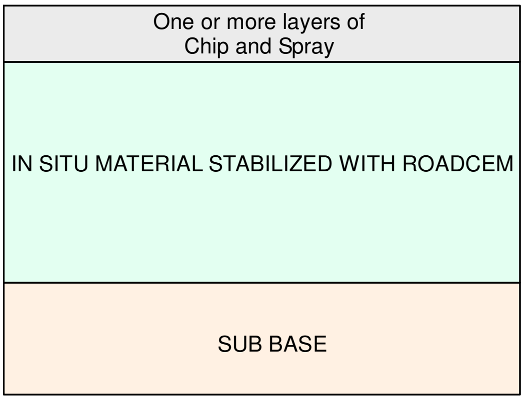


Figure 5.48 Chip and Spray Option.

On completion of stabilization with RoadCem and final compaction the surface of the road is primed with aquous cold bitumen spray (Figure 5.49).

Figure 5.49 Cold Aquaous Bitumen Priming.

Figure 5.50 Applying chiped stone.

Immidiately a layer of Chip Stone of appropriate size (5 to 13 mm depending on the desired rougness) is placed on top of the primed layer (Figure 5.50)

The surface is than compacted statically. If more than one layer is to be applied the procedure is repeated for each layer.

The finished road surface is shown in Figure 5.51.

Figure 5.51 Finished single layer Chip and Spray.

Alternatively a hot bitumen Chip and Spray can also be used. The procedure of application is the same except that hot bitumen spray equipment is needed. If applied within 24 hours of the stabilization priming is not necessary. One or more layers can be applied.

Typical application rates are:

- Chipped Stone from 20 to 40 kg per m2 per layer
- Bitumen from 5 to 15 litres per m2 per layer

Chip and spray options are very fast to construct, require minimum skill are durable and cost effective solution for surfacing of roads.

Figure 5.52 Hot Bitumen Chip and Spray.

5.9.6 Gravel and Gravel-Slurry Finish

Another cost effective option for the surfacing is of RoadCem stabilized pavements is the so called Gravel Finish. The appereance of the gravel finish is shown in Figure 5.53.

Figure 5.53 Gravel Finish.

This option involves surfacing operation as a part of the stabilization effort. Immediately after stabilized layer is compacted 2 to 3 cm of gravel 8 to 11 mm in nominal size is spread over the surface of the stabilized layer. This is followed with a number of static compaction runs until the desired finish is achieved (Figure 5.53).

The resulting surface is cured with water until hardening.

This surfacing option gives a surface with good skid resistance but sometimes wearing resistance is reduced due to lack of full integration of the gravel material into the stabilized layer. For law intensity traffic this should not be a problem but if traffic intensity is high than we recommended that following the compaction of gravel into the stabilized layer a self levelling slurry is made from:

- RoadCem (4 kg);
- Cement(1000 kg);
- Water (1000 kg).

This mixture is applied on top of the surface. Figure 5.54 gives an example. Curing with water is recomended frequentley following 6 hours of setting.

Figure 5.54 Gravel+RoadCem/Cement Slurry Finish

This Finish is a cost effective option even for high intensity traffic areas and is an effective and economic replacement for traditional asphalt finishing. Skid resistance is reduced because the finish is rather smooth. Wearing resistance of this option is good.

It is noted that the slurry as prepared above can also be used on top of the soil stabilized with RoadCem and Cement even without a gravel layer. However for this to be effective it requires that the stabilized soils contain minimum amount of clay and organic materials. Slurry only treatment is best suitable for sandy soils stabilized with RoadCem and Cement.

5.9.7 Other Surfacing Options

Other bituminous surfacing options such as Otta Seal and Asphalt Concrete (AC) can also be used, Table 5.9 gives general guidelines for required inputs to achieve good results.

Table 5.9 All types of sprayed surfacing, such as surface dressings, Otta seals and sand seals

	Required input for achievement of a good results *(Low Moderate High)*				
	Surface dressing	Otta seal	Sand seal	Slurry	AC 4)
Skills	Moderate	Moderate	Low	Moderate 3)	Un-suitable
Equipment, Spreading	Moderate	Moderate	Low	Low	Un-suitable
Equipment, Bitumen Applications 1)	Moderate	Moderate	Low	Low	Un-suitable
Materials quality	High	Moderate	Low 2)	Moderate/High	Un-suitable

1) A bitumen distributor is required for most sprayed seals. Hand sprayers are an alternative, especially when using emulsions, but spray rates need to be controlled. Mixing slurry in concrete mixers is preferred, even when laying by hand. Selfpropelled slurry machines increase efficiency but a much higher cost.

2) Coarse sand, sometimes available by screening, can increasae the material quality to “moderate” where sand seals are used alone as permanent seals. Where sand seals are used as cover seals, the material quality requirements can be reduced to “low”.

3) The selection and handling of bitumen emulsions, including proportioning and adjustment of consistency, increases the need for handling skills. Training is usually required.

4) Although included for comparison with other seal types, surfacing with AC is usually confined to areas with wet climates and/or steep terrain.

These type of sprayed surfaces all follow a similar construction procedure:

- Priming of the base (may sometimes be omitted).
- Base repair (chip and spray by hand using emulsion) to even out the occasional rut caused by a stone under the motor grader blade.
- Spraying of bituminous binder.
- Spreading of aggregate.

- Chip spreading requires uniform aggregate cover. A drag broom can assist this process on large areas.
- Rolling is preferably carried out with pneumatic rollers but can also be done by trafficking.
- Repeat steps 2 to 6, if a double layer is applied.
- An emulsion "fog spray" is sometimes applied to chip seals after they have been laid to enhance adhesion of the chippings.
- In slurry seals, crusher dust, bitumen emulsion, water and cement filler are premixed with either a specialized "mix and spread" machine or in a concrete mixer for spreading by hand with squeegees. Mixing by hand is possible but is not recommended.

Bricks and paving bloks can be used on a terrain for esthetical reasons or because very heavy loads are expected. With these loads it is possible that setting occurs. When applying bricks a thin sand layer must be laid under the stones. When this layer and the mortar between the bricks are mixed with RoadCem and cement then this results in a water impermeable construction. If a traditional joint and sand layer water seepage will occur in the construction and just like sand cement stabilization the water needs to drained from the construction using boreholes in the stabilization.

Figure 5.55 Applying paving bricks (automatically or manually).

Asphalt is often applied on the road and has the advantage that it is a stiff material and only minor deformations occur because of this. The disadvantage is that it is a viscous material and deforms with high temperatures and with relatively high static loads. When asphalt is applied on a RoadCem foundation of a certain thickness then the fatigue occurring below in the asphalt is the most important factor in the design. The thickness depends on the strength of the RoadCem foundation and the strength of the asphalt.

A sealing layer must be applied between the asphalt and RoadCem based pavement structure.

Figure 5.56 Applying asphalt layer.

Chip and spray and macadam options are also feasible method of surfacing. Some of the options are:

Close Graded Macadam Wearing Courses

The nature of these materials is that the aggregate is a through grading of a combination of all sizes of aggregate particles according to the largest size of the aggregate. The particles knit together to produce a tight aggregate mass held together by the bitumen binder (Figure 5.63). Wheel load is distributed thorough the layer by aggregate particle contact. It is an excellent lower cost material with mixtures for all types of site.

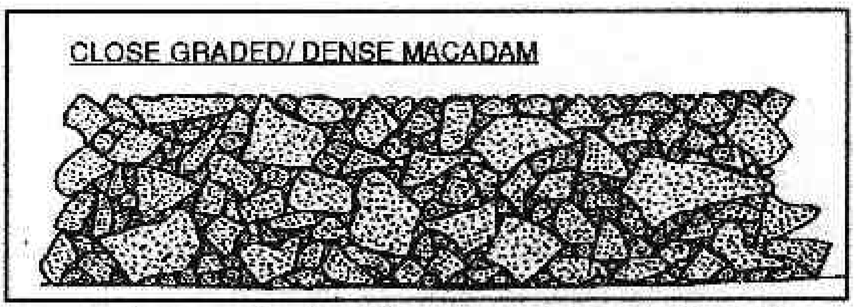
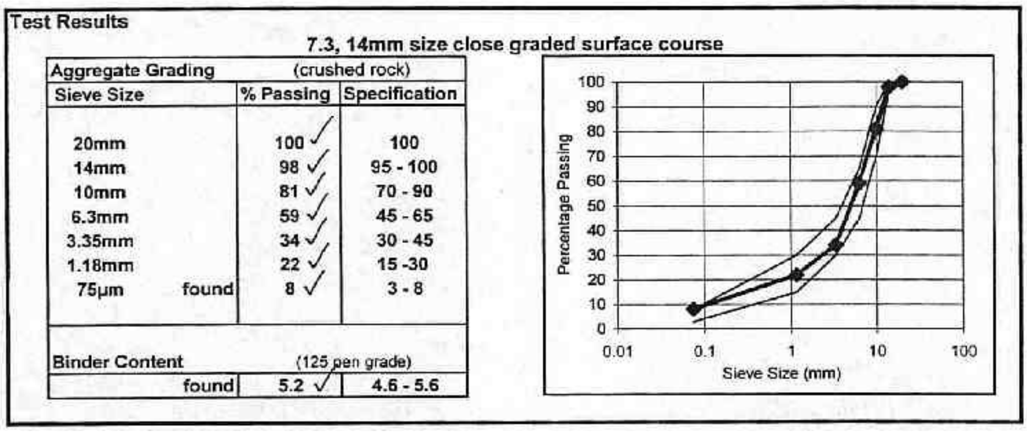


Figure 5.57 Close Graded Macadam Wearing Surfacing Layer.

Figure 5.64 is a typical result from a sample of 14mm. size close graded macadam, as specified in BS 4987: Part 1



Test Results

7.3, 14mm size close graded surface course

Aggregate Grading	(crushed rock)	
Sieve Size	% Passing	Specification
20mm	100 ✓	100
14mm	98 ✓	95 - 100
10mm	81 ✓	70 - 90
6.3mm	59 ✓	45 - 65
3.35mm	34 ✓	30 - 45
1.18mm	22 ✓	15 -30
75μm found	8 ✓	3 - 8
Binder Content	(125 pen grade)	
found	5.2 ✓	4.6 - 5.6

Figure 5.59 Sieve analysis

HOT ROLLED ASPHALT & PRECOATS

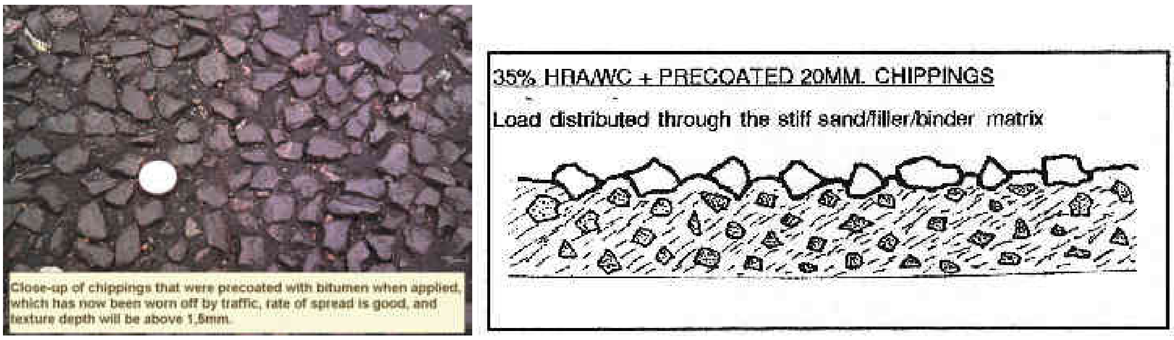


Figure 5.60 Texture of asphalt

This is the premium highway surfacing material that is used for many years and is responsible for a large percentage of the highway network being in such relatively good condition, even if it is covered by a surface dressing. The 35%/14mm HRA/WC is laid 50mm thick and not only provides a surface with good texture and a high PSV aggregate, it also imparts considerable strength to the existing pavement when applied as an overlay. It allows a low PSV (45 mm.) aggregate to be used in the matrix with the scarce and expensive high PSV aggregate only being used for the precoats. It is a very important factor when high quality, high PSV aggregate sources are becoming increasingly scarce.

The strength of the material is from the stiff (50.pen) binder, limestone filler, and sand matrix. There is no aggregate interlock to distribute load in the 30% and 35% aggregate content wearing courses

Figure 5.61 construction of asphalt

The photograph to the right shows a road surface that consists of a hot rolled asphalt wearing course and 20mm. precoats.

Porous Asphalt / Pervious Macadam

Porous asphalt is the same material that used to be called Pervious Macadam, a material that has been designed to be porous. Do not take another material i.e. stone mastic asphalt and make it porous by "dragging" it with the paver to a layer thickness less than it should be and hence creating voids in the matrix, that is not how a porous surface layer should be achieved.

Open graded macadams will also have a high degree of porosity. These materials should be laid on an impervious basecourse.

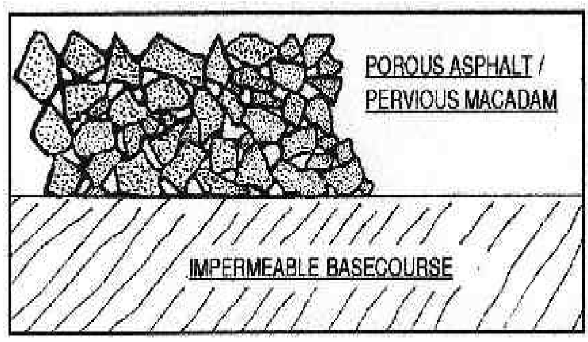


Figure 5.62 Pavement structure

It is this open structure that creates the surface texture and allows water to pass thought connecting voids thus reducing splash and spray, at least while the voids remain unclogged. This material, with a stiffer and perhaps modified binder, may be used to provide a free draining and brings on aqoustic isolation "quiet" surface. Porous surface course bituminous mixtures must be laid on a strong smooth and impervious base layer.

Porous asphalt is losing favour as a bituminous surfacing option. Although a material that may cause less surface noise to be generated and reduces spray, there have been problems in laying. Its life is much shorter than a hot rolled asphalt wearing course and there are problems with winter maintenance because porous asphalt needs salting at higher rates than impervious materials, as it is a "colder" surface.

These are just some examples of the surfacing options that one can consider. Each country and region may have other options that can be considered.

5.10 Priority Assurance and Quality Control

Quality assurance in road construction includes the total system within the construction site that ensures correct quality of the final road and associated structures. Besides conventional site control, quality assurance also includes the measures that contractors themselves apply for this purpose during operations.

Quality control includes laboratory and field testing of materials and construction. It forms part of the overall quality assurance system. It is applied in various ways, depending on the type of contract.

Conventional contract relations with a supervising body - often a consultant - carrying out control of the works is a common system used. Under these circumstances, end-product quality control is routinely included in elaborate systems and is applied with great effect on projects where roads are constructed. It is commonly considered necessary to establish full laboratory services on site for control of workmanship and material quality.

The inherent compromise for quality control and assurance will often require innovative solutions and focus on the overall quality assurance system to achieve optimal results.

Table 5.10 The Priority list for Quality Control when using RoadCem based road construction method

Priority	Layer	Comments
1	Bituminous surfacing	– Choice of equipment, choice of material tpe, visual assessment and measurement of application rates is of greatest importance. – Only basic laboratory equipment is essential for effective control during operation.
2	Surface finish of the base course	– Biscuit layers are the most common reason for an unacceptable product. A geological hammer/pick can be used to identify such flaws. – Visual assessment, plus choice of equipment and working method is of greatest importance. – Laboratory equipment is not essential for effective control during operation.
3	Material quality of the base course	– Laboratory tests in advance and after construction, combined with indicative tests or observations during construction, are essential.
4	Compaction control of the base course	– Method specifications, appropriate choice of method and equipment, visual assessment and proof rolling, in combination with regular testing for "calibration".
5	Subbase and earthworks	– Visual assessment and laboratory tests ahead of construction given improved confidence in material quality. – Method specifications, visual control, proof rolling and appropriate choice of method and equipment are sufficient for site control of workmanship.

6. Drainage

Like water we look for the easiest solution

6.1 General

Drainage is probably the most dominant factor affecting the performance of roads. When roads fail it is often because of inadequacies in drainage. This results in the ingress of water into the road structure, structural damage and costly repairs. In addition, surface water can form a road safety hazard by causing aquaplaning.

Unfortunately, many roads have evolved with inadequate initial engineering and drainage design. Even with properly engineered roads, on-site inspection is often necessary to correct any unforeseen conditions during construction. Such an approach is more cost-effective than maintaining or correcting deficiencies after the road has been in service for several years.

Two inter-related aspects of drainage require careful consideration during construction, namely:

- Internal drainage of the pavement which seeks to avoid the entrapment of water by allowing it to permeate through and drain out of the pavement structure.
- External drainage which seeks to divert water away from, and prevent its ingress into the pavement structure through measures such as the construction of sealed shoulders, side drains, etc.

6.2 Internal Drainage

6.2.1 General

Internal drainage involves measures to minimise moisture contents in the embankment and pavement layers and importantly to prevent unwanted movement of water within the pavement structure. Internal drainage is vital for the satisfactory performance of earthworks and pavement layers made of natural soils and gravel.

6.2.2 Permeability of pavement layers

Each layer in pavement and earthworks should be more permeable than the overlying layer in order to prevent any water entering the structure from being trapped. With RoadCem the road pavement design and construction ensures that this is always the case since it consist of one bound layer which is almost impermeable with extremely low water permeability. The sub base layer, under the RoadCem treated layer will almost always have a higher water permeability. But, it is always advisable to provide cross-fall in all earthworks and layer works for water to escape from the pavement structure and in doing so alleviate potential water retention problems. Under severe conditions, especially where there is risk of water seeping into the pavement structure, consideration should be given to installing subsurface drainage systems or, better still, to increase the height of the road in such areas.

6.2.3 Crown Height

Crown height is the vertical distance from the bottom of the side drain to the finished road level at centre line. It needs to be sufficiently great to allow proper internal drainage of the pavement layers. Economical ways to achieve sufficient crown height include the use of material from the side drain and road reserve, a common procedure where scrapers/motor graders are used for construction. Maintaining sufficient crown height through cuttings is of particular importance, owing to the unfavorable drainage conditions in such areas.

Figure 6.1 Drainage.

Figure 6.2 Damaged drainage.

This may result in a considerable increase in the quantity of earthworks. Alternatives, such as subsurface filter drains, should be considered as a last resort because of cost and maintenance implications. The traffic safety aspects of large crown heights should be taken into account by moving the side drain further away from the shoulder break point.

In areas where in situ soils are considered to be self-draining, such as in sandy areas and desert-type areas, priority should be given to providing good side support within a low embankment profile and shallow side slopes (typically 1:6 or 1:8) rather than a large crown height and relatively steep side slopes.

6.2.4 Seepage and subsurface drains

Unfortunately, inadequate surface and subsurface drainage are typical deficiencies associated with cut-and-fill pavement sections for roads, as shown in figure 6.3. Such deficiencies can affect the pavement by erosion, decreasing soil support or initiating creep or failure of the downhill fill or slope. They should be addressed during construction rather than waiting until failures occur because it is much more expensive to undertake remedial works.

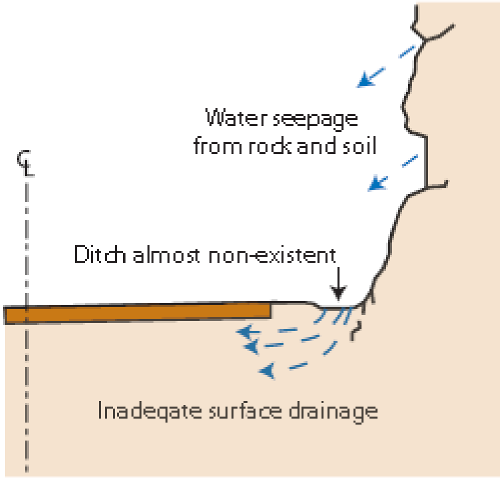


Figure 6.3 Inadeqate surface drainage.

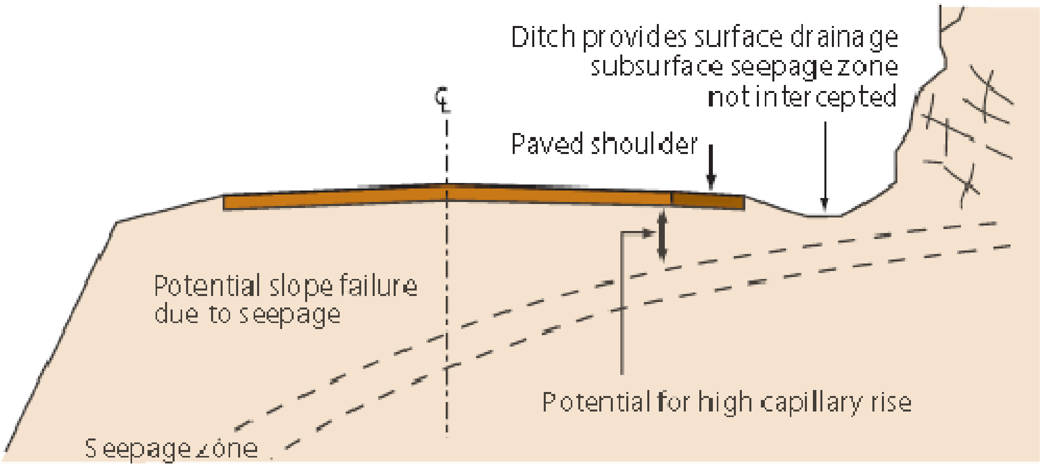


Figure 6.4 Typical Drainage deficiencies associated with cut and fill.

In the design of the vertical alignment of roads, it is advisable to try to avoid cutting into the ground to reduce the risk of encountering subsurface water. Thus, the “depressed pavement construction” shown in Figure 6.4 should be avoided except where soil moisture conditions are suitable or the drainage systems effectively eliminate water-related problems.

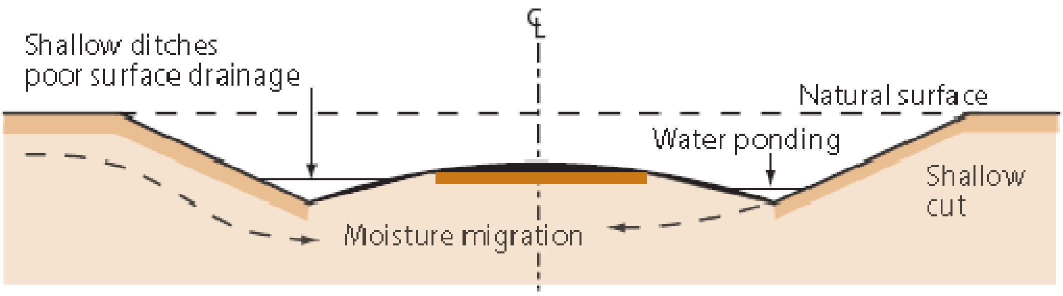


Figure 6.5 Potential drainage problems associated with depressed pavement construction.

Localised seepage can be corrected in various ways but seepage along pervious layers combined with changes in road elevation (grades) may require subsurface drains as well as ditches, as shown in Figure 6.6. Subsurface drains can be made of geotextiles wrapped around aggregate, with or without pipes installed, but various specialised systems are also marketed. Such drains have commonly been made out of aggregate surrounded by filter sand instead of geotextiles, depending on the grading of the in-situ soils.

As subsurface drainage systems usually incur relatively high installation costs and there is the risk of blocking of buried systems, alternative options are preferred.

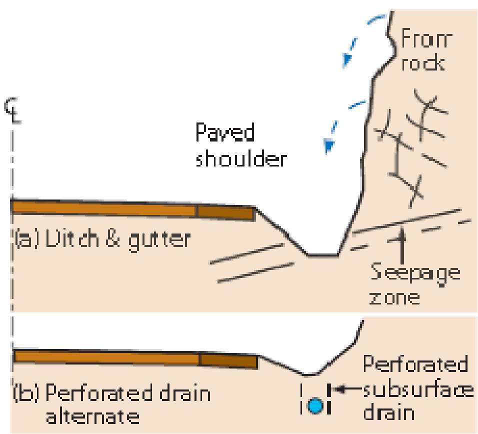


Figure 6.6 Beneficial interception of surface runoff and subsurface seepage.

Figure 6.7 Construction of filler in drain.

6.2.6 Shoulders

Construction of shoulders needs to be undertaken carefully if typical drainage problems are to be avoided. Preferably, the granular base should extend to the embankment slope with sufficient height above the ditch to prevent water intrusion. Trench, canal or “bathtub” construction, in which the pavement layers are confined between continuous impervious shoulders, should be avoided as this has the undesirable feature of trapping water at the pavement/ shoulder interface and inhibiting flow into the drainage ditch.

Shoulder materials should be selected which have a permeability similar to that of the base course, so that water does not get trapped within the pavement.

However, the material properties for unsealed shoulders may well be different from those required for the base for reasons of durability. Unsealed shoulders are similar to a gravel wearing course and require material with some plasticity, which is a property that might be considered less desirable for road base material.

A common problem is water infiltration into the base and sub base, which occurs for a number of reasons as, illustrated in Figure 6.8. These include:

- Rutting adjacent to the sealed surface.
- Build up of deposits of grass and debris.
- Poor joint between base and shoulder (more common when a paved shoulder has been added after initial construction).

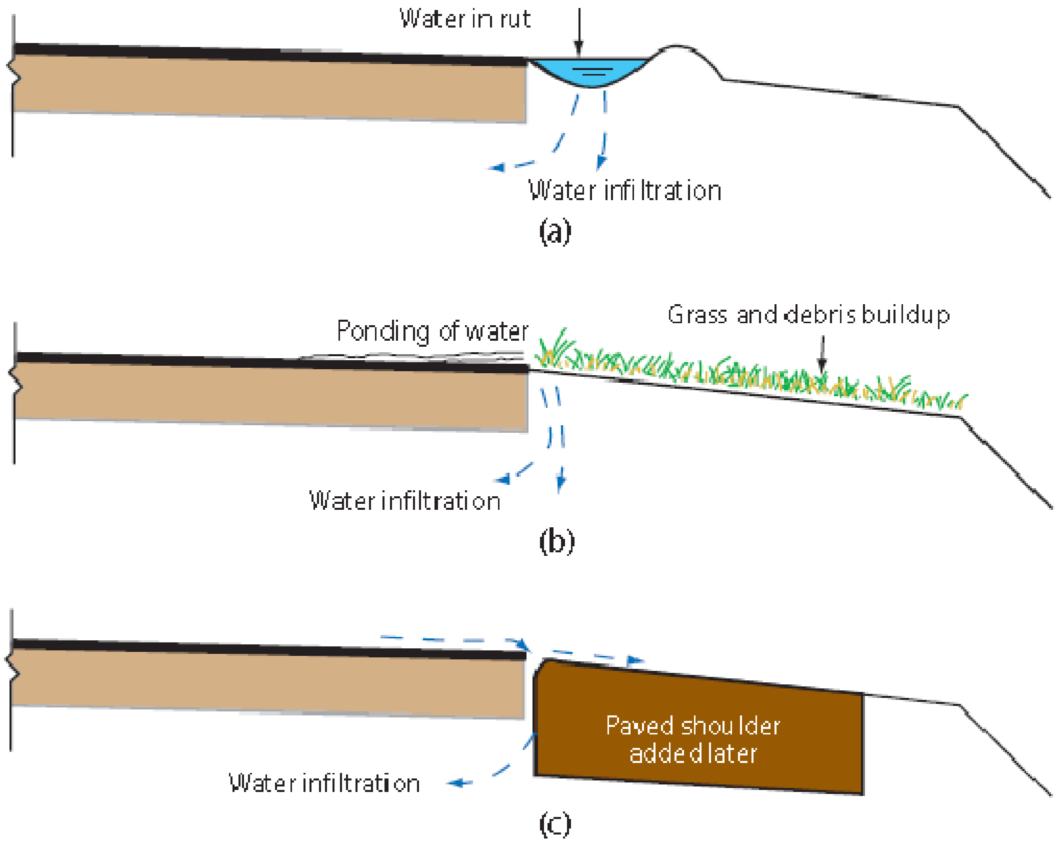


Figure 6.8 Typical drainage deficiencies associated with pavement sholder construction.

Ideally, as illustrated in Figure 6.9, the base and sub base layers should be extended outwards to form the shoulders, which should preferably be sealed.

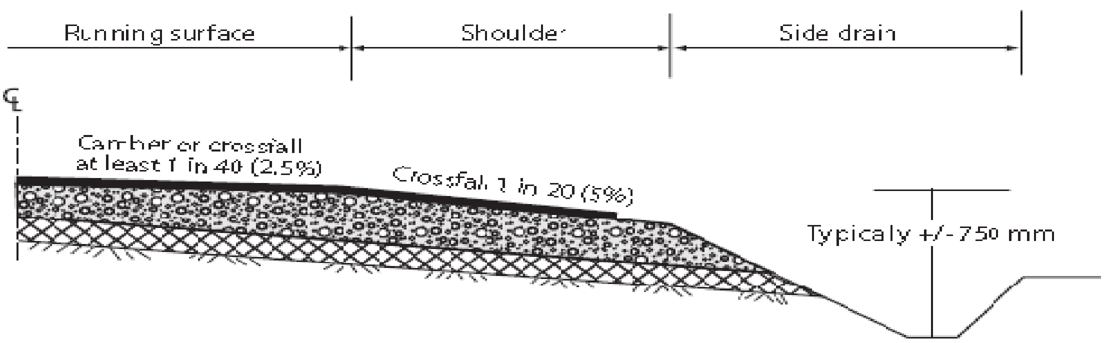


Figure 6.9 Ideal shoulder construction/drainage arrangements.

6.3 External Drainage

6.3.1 Introduction

External drainage involves methods of crossing of watercourses, measures to divert water away from the road and prevention of damage caused by erosion. In the construction of roads there is often wide scope for the use of various measures to improve external drainage, such as low-level structures, drifts etc. where 100% passability to traffic throughout the year may not be required.

It is not within the scope of this Section to provide a detailed description of all the various measures that make up a good drainage system. Conditions on site will vary tremendously in respect of in-situ soils, topography, vegetation, climate, human settlement patterns, environmental concerns, etc. The skills of site personnel and knowledge about local conditions are critical for successful installation of drains, catch-water drains, side drains, berms, channels, cut-off drains and crossings along the road .

Figure 6.10 Ground movement. *Figure 6.11 Flooding.*

6.4 Hydrology and Hydraulic Calculations

6.4.1 Introduction

The use of sophisticated methods to estimate run-off and for the calculation of the size of waterway structures is not always appropriate for road construction. In many of the developing countries because either the data and/or the resources required are not available. Thus, alternative methods, which also rely on visual observations and historical evidence from consultations with the local populations are often more appropriate. Furthermore, financial constraints also means that a compromise is often required between structures that provide all-weather access and those that can be constructed with the available resources.

6.4.2 Method

The capacity of drainage structures should ideally be calculated on the basis of local experience gathered over a long period of time and should be updated to cater for any recent changes in rainfall pattern and climate. Such information is often not readily available in many countries, prompting a need to develop standards for drainage design and calculations. In all cases it is advisable to combine calculations with observations on site, in addition to information from reliable local sources.

With the ever-increasing cost of maintenance, it is desirable to increase the size of drainage structures to a minimum of a 600 mm opening so that they can be easily maintained.

6.4.3 Return Period

The return period for a given flow of water is related to the estimated statistical risk of overtopping of drainage structures. It is part of the hydraulic calculations required for each type of structure and for each project on the basis of policy and anticipated consequences to the road or the public. The return period is therefore a critical parameter in the design of roads because it controls the level of risk in relation to cost of construction and the type of structure that is appropriate. As a broad guide, the following return periods can be considered for roads:

- Bridges: 20 – 50 years.
- Culverts: 5 – 10 years.
- Drifts or well-protected culverts: 0 – 5 years.

6.5 Drainage Structures

6.5.1 Introduction

This section gives some examples of the range of solutions available to designers and constructors of roads. The techniques shown are the results of innovative methods tried out and applied in many countries over a number of years. A basic requirement in the construction of structures for crossing water courses is to assess the need for protection of the structure against erosion. During the construction period as well as assessing the risk that structures that are not designed to withstand flooding will actually experience overtopping, so that additional protection measures can be taken. Construction of low, "sacrificial" points for overtopping should be considered where available resources do not allow for the provision of structures with adequate capacity.

6.5.2 Low-level structures

A low-level structure is designed to accept overtopping without damage, and is ideally suited for roads in locations where less than full all-weather passability is acceptable to the community. The two basic types have been used with success. Various alternative names are sometimes used to describe these structures.

- Drifts are designed to provide a firm driving surface in the riverbed, where traffic can pass when water levels are moderate.
- Vented drift sometimes named fords, causeways or Irish bridges, (larger structures are called low level bridges) allow water to pass through openings, but can withstand overtopping without damage. Openings in vented drifts should, like culverts, be made large enough, preferably not less than 0.9 m so that cleaning during future maintenance is made easier and the risk of blockage is minimized.

Figure 6.12 Low level drift.

Figure 6.13 Vented drift.

A common feature of all low level structures is that they require proper foundations and anchoring, as well as scour protection to the road prism.

Figure 6.14 Inadequate culvert.

Figure 6.15 Banks of pipe.

6.5.3 Culverts

Types: Culverts are constructed on roads using a variety of methods and materials. Examples include corrugated plastic pipes, steel pipes or arches, pre-cast or concrete pipes, boxes, arches or half arches ("shelverts"), reinforced concrete slabs resting on blockwork in a box culvert profile and wooden culverts in a box or circular profile.

Location

Wherever possible, culverts should be located in the original stream bed with the invert following the grade of the natural chanell.

SKEW CULVERTS

Water courses intercepting the road at an angle of skew less than 20 degrees can generally be accommodated by a culvert placed at right angles to the road centre line.

INLETS

To avoid silting, culvert inverts should be placed at a grade of not less than 1.25 % for pipes and 0.5 % for box culverts.

OUTLETS

The invert level at the outlet of a culvert should coincide with the ground level. At steep situations energy dispation structures should be provided to avoid erosion.

FOUNDATION

Ideally, culverts should be located on sound foundations such as rock. Soft, saturated and expansive clay soils may cause settlements or seasonal movements and should be stabilized with RoadCem.

Figure 6.16 Low level drift.

Figure 6.17 Vented drift.

Figure 6.18 Low level drift.

Figure 6.19 Vented drift.

Figure 6.20 Low level drift.

Figure 6.21 Vented drift.

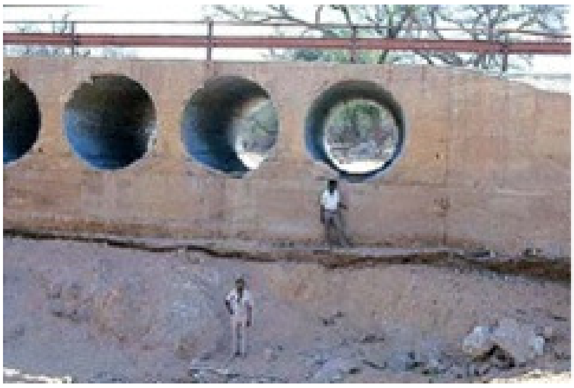


Figure 6.22 Low level drift.

6.6 Erosion

6.6.1 Introduction

Any disruption to the natural flow of water carries a risk of erosion that may lead to environmental, degradation, silting, damage to roads, damage to buildings and services, destruction of farming land and loss of fertile soil.

Thus, there is a responsibility to ensure that the construction of the drainage system for a road receives the same attention to good practice as the construction of other roads. Indeed, avoidance of erosion can be more critical in the case of roads because of the greater challenges faced in maintaining the drainage system in remote areas where these roads are often located.

6.6.2 Scour Checks

There are many examples of inexpensive and effective methods that are used to protect drainage channels and side drains by the use of scour checks that are easily constructed by labour-based methods. The scour checks can be made of wooden sticks, rocks, concrete or in situ material stabilized with RoadCem depending on the most economical source of materials. The frequency of scour checks needs to be properly adjusted according to slope gradient in order to prevent erosion between the checks causing damage to the system. The following table can be used as a guide:

Table 6.1 Gradient of the ditch

Gradient of the ditch	Scour check spacing
4% or less	Not required
5 %	20 m
8 %	10 m
10 %	5 m

6.6.3 Erosion of Culverts

Short culverts requiring high headwalls and wing walls are built to avoid erosion around both inlets and outlets, especially along the wing walls. Constructing culverts that are sufficiently long to reach the toe of the embankment will minimise necessary protection measures, future maintenance and the risk of damage to the embankment around the openings. It is necessary to carefully assess the additional cost of lengthening culverts against these benefits, especially in the case of roads that are often located in remote areas where regular maintenance is a challenge.

6.6.4 Slope Protection

If required, placing of topsoil and planting of vegetation on the slopes of embankments should take place in order to minimise erosion before indigenous vegetations can establish roots.

Planting of vegetation for protection of slopes against erosion can be an option.

Where grass or other vegetation is planted for protection of slopes, it is absolutely vital that professional advice to be obtained from a botanist. Failure to do this could lead to intrusion of non-indigenous species that could threaten the environment or cause damage to local farming. The slope can also be protected when using RoadCem and Cement.

6.7 Management and Maintenance Issues

Maintenance currently constitutes one of the major preoccupations of roads agencies in many countries. In the early stages of road development, most of the road expenditure is spent on construction. However, as these networks have become more developed, the expenditure required for adequate maintenance and rehabilitation has increased relative to that required for new construction.(Figure 6.24)

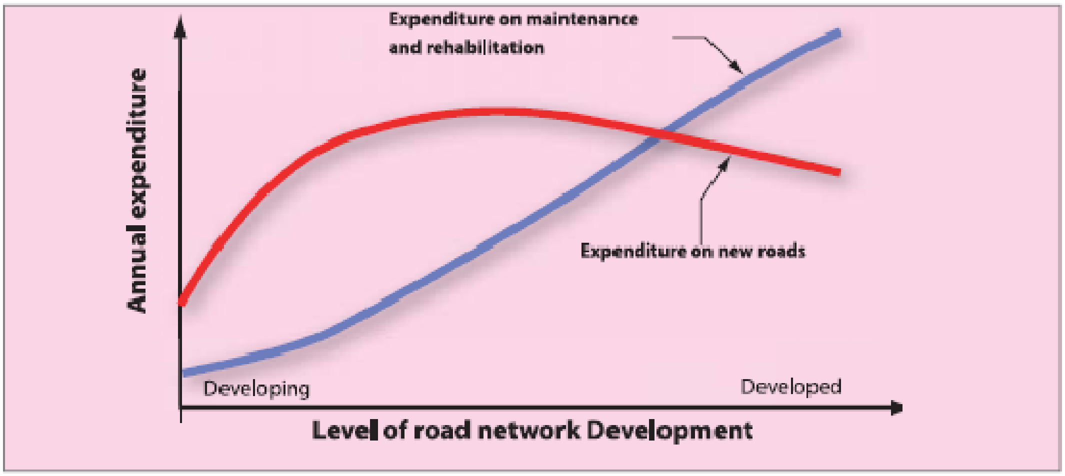


Figure 6.23 Historic path of road infrastructure investment.

With RoadCem it allows a reduction of investment on building,maintenance. It increase, the investment on the new roads further extending the road infrastructure.

Unfortunately, for a variety of reasons, including lack of adequate funding, provision of satisfactory, road maintenance still remains an elusive goal for a number of countries. As a result these countries have paid a high price in terms of deteriorating road networks, very high transport costs and the reluctance of donors to assist with the funding of new or rehabilitation projects. Fortunately, roads agencies are beginning to tackle the maintenance challenges in a more holistic manner to improve efficiency and effectiveness and to achieve sustainability.

Figure 6.24 Low level drift.

Figure 6.25 Vented drift.

The road system represents a major investment and is one of the largest public sector assets, with very high replacement costs. Indeed the asset value of the road system often exceeds the combined value of all the other surface transport systems. Therefore, it is extremely important that this asset be preserved through effective and efficient management. In the absence of this, the investment can be eroded quite quickly because roads that are not maintained deteriorate very rapidly.

Even for relatively low-trafficked road networks, reliable information has become essential for effective management. This has led to the development of management tools, including various types of road management systems, that assist roads agencies in allocating resources in a manner that achieves the best value for money. However, to be sustainable, such systems should be carefully chosen to match the available resources - both technical and financial - of the roads agency. Unfortunately, there are a number of examples of systems which have failed to work satisfactorily. In table 6.2 there is given a bief summary about aspect concening Road Safety, Road User Costs and Life Cycle Costs.

Table 6.2 Road safety.

Road Safety		
Issue/Problem	**Effect**	**Solution**
Vegetation growth	Impairs driver visibility	Ensure safty standards established and maintained
Potholes	Danger to motorists	Ensure safty standards established and maintained
Dirty, damaged or missing traffic signs	Increases likelihood of traffic accidents	Ensure safty standards established and maintained
Faint road markings	Increases likelihood of traffic accidents	Ensure safty standards established and maintained
Damaged bridges and guardrails	Increases likelihood of traffic accidents	Ensure safty standards established and maintained
Scoured highway shoulders	Impairs integrity of road pavement	Ensure safty standards established and maintained
Increases safety hazards to road users	Causes more road traffic accidents	Need for effective and timely road maintenance

Table 6.2 Road safety.

Road users costs		
Issue/Problem	**Effect**	**Solution**
Clear link established between pavement condition and vehicle operating costs and embodied in transport investment models (e.g. HDM-4).	An increase in surface roughness causes vehicle operating costs to increase significant additional costs incurred by road users when maintenance requirements are overlooked.	Identify, program and control maintenance operations
Rate of pavement deterioration is often not contained, causing surface roughness to increase at an accelerating rate	Additional costs to highway users	Use of an appropriate maintenance management system

Table 6.4 Road users costs.

Life Cycle Costs		
Issue/Problem	**Effect**	**Solution**
Feasibility and design strategies assume that (a) regular pavement strengthening will be carried out to arrest deterioration (b) care will be taken to deal with localized imperfections as they arise (e.g. crack sealing).	Failure to control deterioration results either in an earlier requirement for strengthening or substantially increased costs of reconstruction	Optimize investment by judiciously applying maintenance interventions to arrest rate of deterioration and to preserve structural integrity of each road link in the network
⇩	⇩	⇩
Assumptions often not realized in practive	Economic penalties incurred which result in a need for Premature reconstruction	Use of an appropriate pavement management system

7. Epiloque

TODAY'S SOLUTIONS ARE TOMORROWS QUESTIONS!

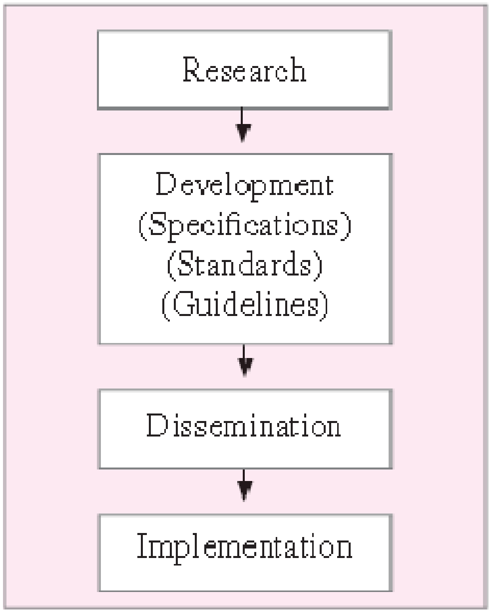
'ACCEPTANCE OF NEW TECHNIQUES REQUIRES OPEN MINDEDNESS AND A WILLINGNESS TO LEARN FROM PLANNERS AND ENGINEERS WHO MUST APPLY IT. IT ALSO REQUIRES THE POLITICAL WILL TO RESIST PRESSURE FROM VESTED INTERESTS AND MAKE THE BEST USE OF THE RESOURCES THAT THEY HAVE AT THEIR DISPOSAL'

7.1 General

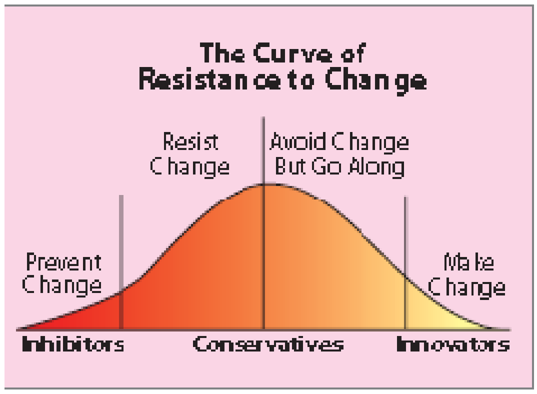
There has been a very strong motivation for preparing this Guideline on RoadCem used in Road Construction. In essence:

- Many aspects of road provision have stemmed from technology and research in Europe and the USA, in environments very different from those prevailing in the other regions where RoadCem based approach is surely more appropriate. Even in developed world RoadCem offers many advantages.
- Whilst changes have inevitably occurred in the recent past, much of the basic philosophy concerning road provision remains unchanged, as have many of the norms and standards to be found in guidance documents, which have not been revised for many years.
- A significant amount of research work spanning some 20 – 30 years has been carried out in different parts of the world by a number of specialist organizations, collaborating country agencies and, in some cases, by country agencies themselves.
- Much of the research has been aimed at new approaches to road provision including planning, appraisal, design, and use of local materials, surfacing techniques, construction methods and finance for maintenance.
- Where implemented, the results of this research have invariably been highly beneficial and cost-effective.
- Unfortunately, there is still a general tendency to use a conventional approach to provision of roads that is often perceived to be "safe". As a result, few of the results of relevant research have been put into practice and the potential benefits of so doing have not been gained.

Table 6.2 Road Safety, Road Users Costs and Life Cycle costs.



Moving technology from the research environment to an operating environment will involve considerable technology transfer effort and resources to overcome various obstacles to implementation.



"There is nothing more difficult to take in hand, more perilous to conduct or more uncertain in its success, than to take the introduction of a new order of things, because the innovator makes enemies of all those who prospered under the old order, and only lukewarm support from those who would prosper under the new".

Machiavelli, The Prince (1513).

Figure 7.1 Research versus implementation.

The benefits of this Manual will only be achieved if the approaches recommended are implemented. However, the path from research to implementation is a tortuous and time-consuming one. It has been estimated that, in engineering, in each of the steps in the pathway that begins in obtaining funding for research, through to implementation, the magnitude of difficulty increases by a factor of 2 to 8. These activities include carrying out the research, processing the results, developing standards, disseminating the information, right through to actual implementation (Figure 7.1). Thus, it can be quite difficult to get the results of engineering research put into practice, despite the evidence that very large savings can accrue where this has been done.

The implementation stage can be accelerated by understanding the process that is involved in technology transfer, identifying the likely obstacles and adopting a strategy that seeks to mitigate them. In broad terms there are five stages to the process of innovation:

Stage 1

Idea generator – the initial perceived need for developing theGuideline.

Stage 2

Technology generation, adaptation and transfer – which has been achieved by raising awareness of the results of research carried out with the use of RoadCem, the adaptation of appropriate standards and the knowledge shared in the development of the Guideline.

Stage 3
State and local roads agencies – the importance of “buy-in”, which can be achieved through the process of stakeholder involvement in the whole process.

Stage 4
Specifications and contracts – the modification of conventional specifications and contract types to suit local conditions; the important role of contractors in embracing the new approaches as embodied in project applications.

Stage 5
Benefits – the substantial potential benefits to be gained by implementing the recommendations in the Guideline.

The production of this Manual forms a major part of Stage 3 as well as contributing to parts of Stage 2 and 4. This chapter is concerned with the pathway from here to full acceptance and implementation. The various obstacles and associated problems that remain and suggestions for overcoming them are discussed below.

7.2 Political

Government Policy
The road transport sector cannot be properly planned without reference to overall government transport policy. For effective planning, governments need to take a comprehensive view of the whole transport sector, with road sector policy being designed to meet the wider social and economic goals of each country. It is important that the key messages from this Manual on the benefits to be derived from RoadCem based approach are included in the debate leading to the development of a policy document. The policy should cover such issues as poverty alleviation, employment creation, technology choice, etc. The outcome of this process will dictate the type of planning system that is most appropriate.

Political and Public Perceptions
The intense competition for scarce public funds makes it imperative that appropriate, cost-effective standards are adopted at all times in the provision of roads. This may well imply the use of lower, but nonetheless appropriate, standards on these roads. However, such standards can still provide a satisfactory level of service with no compromise on road safety.

It is important that the public and political authorities accept the standards adopted for roads. However, their perceptions as to what is an appropriate standard of pavement or surfacing can adversely affect technical decisions.

Very often such perceptions are conditioned by standards adopted in the developed world and with traditional materials; a lower, albeit more appropriate, standard based on new materials is often perceived to be “sub-standard” and, hence, unacceptable.

More effort needs to be expended on educating politicians and the general public as to the basis on which technical standards are determined so that they are more readily accepted. Ranking policy changes according to their political costs and benefits can help policy makers obtain support from politicians and the general public.

Axle Load Control

Inadequate axle load control remains arguably one of the most serious challenges faced by road authorities in many countries. As indicated in Chapter 5 of the Manual, pavement performance is critically influenced by traffic loading which, in turn, controls the life of the pavement.

RoadCem based approach results in roads which are normally constructed of lighter (thinner) pavements using naturally occurring materials that can be sensitive to the impact of overloading.

This makes them particularly susceptible to overloading which has an adverse and disproportionate effect on pavement life. Thus, overloading is not only an increased risk to the road, including bridges; it is also not justified on economic grounds. A more determined effort should be made to control overloading.

Effective control of overloading requires a strong political will which is sometimes not evident. The move towards new methods of overload control should be implemented by all countries as soon as possible.

Risk

The need to adopt more appropriate standards and specifications in the construction of road pavements has been clearly recognized for some time. However, whilst there are many examples of the successful adoption of such a strategy, few are well documented and, until relatively recently, the conditions necessary for successful performance were not adequately defined. Thus, there has been an understandable reluctance, particularly by consultants and donors, to utilize non-standard materials because of an undoubtedly greater perceived risk of problems or even failure.

Fortunately, the results of research undertaken over the past 20 years make it possible to utilize local resources with greater confidence.

Moreover, risks can be mitigated by ensuring that standards/specifications apply to local environments.

The perceived risks associated with the use of non-standard materials and non-traditional designs can now be sensibly managed and a larger proportion of un-surfaced roads can be economically surfaced without additional risk.

7.3 Social

More and more governments are promoting the use of labor-based methods as an alternative to the more traditional plant-based operations as a means of combating high unemployment levels. In this regard, road programs that maximize the use of surplus manpower that might exist in a rural community are more likely to engender a positive attitude to the future maintenance of the road than programs that are plant-based and require the import of a limited amount of skilled manpower.

Despite the above, negative perceptions still persist in some countries that such approaches are uneconomic, time consuming and sub-standard.

Where labour-based operations are indicated, government will need to make a clear policy commitment for change. This will call for special institutional arrangements, comprehensive planning as well as effective managerial and administrative systems and procedures.

7.4 Institutional

The institutional framework of roads sector organizations in many parts of the world critically affects all aspects of road provision. Historically, traditional approaches to the management and financing of road infrastructure have proved to be unsuccessful. Fortunately, the new institutional framework for management and financing of roads offers a promising alternative to traditional approaches and, where implemented, has begun to show positive results.

7.5 Technical

The consistent application of appropriate technical standards and design methods is critical if cost-effective, sustainable solutions are to be obtained. In the past, there was an understandable tendency to rigidly apply imported standards, specifications and geometric and pavement design methods as "best practice" simply because there was little alternative other than taking an unquantified risk in using untried materials and design methods. Transfer of these risks to the designer and the contractor offers advantages and reduces resistance to new approaches.

With the wealth of research and development work undertaken during the past three decades new "indigenous" standards, specifications and pavement design methods have now emerged in a number of innovative ways on the basis of quantified evidence. RoadCem is one of these new innovative methods which are giving very good results. Nonetheless, due sometimes to donor insistence or to lack of awareness of the existence of regional standards, there is still a tendency in some countries to use imported standards.

The time has come for government policy to stipulate that where regional standards, including specifications and design methods exist; they should be used in preference to imported standards.

7.6 Economic

The results of research have shown, quite unequivocally, that adoption of the methods described in this Guideline result in roads that are less expensive to build, are less expensive to maintain and reduce the costs of operating to both motorized and non-motorized transport during their service lives. Thus, both agency costs and total (life-cycle) costs are reduced. Furthermore, although economic assessments cannot readily take into account social benefits, if these are included, the benefits of following the principles advocated in the Guideline should be obvious. Nevertheless it is necessary to demonstrate this repeatedly and as clearly as possible for the benefit of administrators, economists and others in authority that should not be expected to be conversant with the engineering principles involved in road building and maintenance.

7.7 Financial

The main challenge is to secure sufficient funding both to maintain the existing network and to accommodate the extensions to the network that are deemed to be necessary for rural development and for the attainment of poverty reduction goals.

7.8 Environmental

The continued use of large amounts of gravel is not only causing serious environmental problems but is also unsustainable in the medium to long term. This provides a strong impetus for adopting the strategies that are promoted in the Guideline which seek to improve the "environmental" performance of the road transport sector. This can be achieved for example, through more extensive use of local materials, use of low-cost road surfaces, preservation of resources of high quality stone, cost and safety conscious design, consideration of non-motorized traffic, community participation in planning and many more.

7.9 From vision to practice

By its very nature this Manual is aimed at PowerCem Technology Partners and other stakeholders open to new and innovative ideas delivering on better infrastructure in a more efficient manner. The primary target audience are hower our distributors and their technology partners – governments, consultants, planners and designers – those in the position to foster and support change.

This manual describes **WHAT** RoadCem is and **HOW** it must be used. Seeing the good results achievable with the RoadCem based approach gives us enormous satisfaction and a feeling of achievement. The more this is used more people will feel the same. Because RoadCem is able to turn even waste materials such as sludge into strong building materials and pavement structures our vision of the sustainable future is convincing and appropriate. When this potential is brought correctly onto the market then there is an enormous advantage possible for both the customer and the provider.

I am convinced that together we can take further steps with the PowerCem based technology and that the contents of this Manual will be a helpful guide for you to do this.

Prof.dr.ir. P. Marjanovic

Appendix 1

Resources

F.M. Dekking e.a., **Probability and statistics for the 21the century part1 and part 2**, TUDelft, Delft, November 2002.

Prof. ir. A.A.J. Pols, dr. ir. R.J. Verhaeghe, **Plan en projectevaluatie deel 1 en deel 2**, TUDelft, Delft, May 2002.

Prof. ir. A.A.J. Pols, dr. ir. R.J. Verhaeghe, **Plan en projectevaluatie: Impact assessment methods,** TUDelft, Delft, January 2003.

CROW, **Nomenclatuur van weg en verkeer**, CROW-publicatie 156, Ede, July 2001.

A. Verruijt, **Grondmechanica**, Delft University press, Delft, January 1999.

ing. C.E.G. Egyed en ing. H.Visser, **Ophoogmaatregelen en bouwstoffen**: voor voorzieningen op slappe bodem, Delft Cluster, Delft, 2005.

CROW, **Ophogingen en ophoogmaterialen**: dimensionering en ontwerp, CROW-publicatie 121, Ede, December 1997.

CROW, **Secundaire bouwstoffen voor de wegenbouw**, CROW-publicatie 143, Ede, November 1999.

CROW, **schuimbeton voor wegen en terreinen**, CROW-publicatie 173, Ede, May 2002.

CROW, **Toepassingsrichtlijn voor EPS in wegenbouw**, CROW-publicatie 150, Ede, November 2000.

CROW, **Verticale drainage**, CROW-publicatie 77, Ede, November 1993.

CROW, **standaard RAW bepalingen 2005**, Ede, 2005.

DWW, **Handleiding Wegenbouw – Ontwerp onderbouw**, Delft, October 2004.

DWW, **Handleiding Wegenbouw – Ontwerp verharding**, Rijkswaterstaat DWW, Delft, December 1998.

Prof. dr. ir. A.A.A. Molenaar, **Structural design of pavements**, part 1: Stresses and Strains in Flexible pavements, TUDelft, January 2003.

Prof. dr. ir. A.A.A. Molenaar, **Structural design of pavements**, part 3: Design of flexible pavements, TUDelft, January 2003.

Prof. dr. ir. A.A.A. Molenaar, **Structural design of pavements**, part 4: Structural evaluation and strengthening of flexible pavements using deflection Measurements and visual condition surveys, TUDelft, January 2003.

C.A.P.M van Gurp, **Keuzemodel wegconstructies**: Achtergrondrapport CROW publicatie Keuzemodel wegconstructies, CROW, Ede, April 2005.

Spangenburg and Moser, **The story of America's roads**, Facts On File, New York, 1992.

Expert Group on Influencing Road Traffic Demand, **Influencing Road travel demand: You can't reach Kyoto by car**, OECD, 2000.

AASHO (1962). **The AASHO Road Test: Pavement Research**. HRB Special Report 61E. American Assoc. of State Highway Officials, Washington, D.C.

Abbey P (1999). **Storm Water Drainage Design Guidelines**. Land and Transport Division, Ministry of Environment and Transport, Mahé. A Pocket Guide to Road Design for Low-volume Roads, (1998). Ministry of Transport and Energy, Department of Roads, Harare.

Anderson M (1995). **Why Are Rural Roads So Important?** New World Transport '95 (Sterling Publications, London).

Archondo-Callao R (1999). **Roads Economic Decision Model (RED) for Economic Evaluation of Low-volume Roads**. Sub-Saharan Transport Policy Program Technical Note No. 18. World Bank, Africa Regional Office, Washington, D.C.

ARRB (1995). **Sealed Local Roads Manual** - Guidelines to Good Practice for the Construction, Maintenance and Rehabilitation of Pavements. ARRB Transport Research Ltd., South Vermont, Victoria.

Austroads (1992). **Pavement Design**. A Guide to the Structural Design of Road Pavements. Austroads Publication No. AP-17/92. Sydney.

Austroads (1995). **Sealed Local Roads Manual**. Guidelines to Good Practice for the Construction, Maintenance and Rehabilitation of Pavements. Sydney. Brink A B A (1979). Engineering Geology of Southern Africa (Volumes 1 - 4) (1979). Building Publications.

Austroads (1996). **Bitumen Sealing Safety Guide** (1996), Sydney. Stock S A and J de Veen (1996). Expanding Labor-based Methods for Road Works in Africa. SSATP Working Paper No. 22. The World Bank, Washington D.C.

Austroads (1998). **Guide to Stabilization in Roadwork's**. Austroads Publication No. AP-60/98, Sydney.

Behrens L C (1999). **Overview of Low-volume Roads: Keynote Address**. 7th Int. Conf. On Low-volume Roads. Transportation Research Record No. 1652. TRB, Washington.

Birgisson B and B E Ruth (2003). **Improving Performance Through Consideration of Terrain Conditions**. Proc. 8th Int. Conf. on Low volume Roads, Reno, Nevada, June 22 – 25, 2003.

Brown S F, S C Loach and M P O'Reilly (1987). **Repeated Loading of Fine Grained Soils**, University of Nottingham, Nottingham.

C P van der Merwe (1999). **Material and Pavement Structures for Low Volume Roads in Zimbabwe**. Unpublished Report, Harare. Standards Association of Australia (1986). Australian Standard 2341. Methods of Testing Bitumen's.

CAPSA (1989). **Cost Effective Low-volume Roads**. Workshop Session, 5th Conf. on Asphalt Pavements for Southern Africa, 1989.

Carnemark C, J Biderman and D Bovet (1976). **The Economic Analysis of Rural Road Projects**. World Bank Staff Working Paper No. 241, The World Bank, Washington, D.C.

Carney D (1998). **Implementing the Sustainable Rural Livelihoods Approach**. Sustainable Rural Livelihoods – What Contribution Can We Make? (ed Diana Carney). Papers presented at the Department for International Development's Natural Resources Adviser's Conference, London. July 1998.

Cavelle D C (1993). **Transport and Economic Performance**: A Survey of Developing Countries. World Bank Technical Paper 232. Africa. Technical Department Series, World Bank, Washington, D.C.

CEBTP (1980**). Practical Guide to Pavement Design for Tropical Countries**. The Ministry of Cooperation.

Collis L and R A Fox (1985). **Aggregates**. Geological Society, London.

Committee of State Road Authorities (1981**). TMH 5: Standard methods of testing road construction materials**. CSRA, Pretoria.

Committee of State Road Authorities (1985). **TRH 14: Guidelines for road construction materials**. CSRA, Pretoria. Committee of State Road Authorities (1991). TRH 16: Traffi c loading for pavement design and rehabilitation. CSRA, Pretoria.

Committee of State Road Authorities (1986). **Cementitious Stabilizers in Road Construction**. Draft TRH13. CSRA, Pretoria.

Committee of State Road Authorities (1986). TMH **1: Sampling methods for road construction materials**. CSRA, Pretoria.

Committee of State Road Authorities (1987). **Standard Specification for Road and Bridge Works.** CSRA, Pretoria.

Committee of State Road Authorities (1991). **Code of Practice for the design of highway bridges and culverts in South Africa**: Part 3. CSRA, Pretoria.

Demsey B, M I darter and S H Carpenter (1982). **Improving sub-drainage and shoulders of existing pavements** - State of the art. Federal Highway Administration Report FHWA/RD-81/077. Department of Transportation, Washington, D.C.

Committee of State Road Authorities (1997). **TRH 4: Structural Design of flexible pavements for inter-urban and rural roads**. CSRA, Pretoria.

Committee of State Road Authorities (1998). Draft **TRH3: Surface Seals for Rural and Urban Roads,** CSRA, Pretoria. Transport Research Laboratory (2000) Overseas Road Note 3. A Guide to Surface Dressing in Tropical and Sub-Tropical Climates. Overseas Centre, TRL, Crowthorne, Berkshire. (2nd edition).

Construction Industry Research and Information Association (1988). **Laterite in Road Construction Pavements**. Special Publication 47. CIRIA, Westminister, London.

Croney D and P Croney (1991). **The Design and Performance of Road Pavements**. McGraw-Hill Inst.

Crossley P C and S D Ellis (1996). **A Handbook of Rural Transport Vehicles in Developing Countries**. Silsoe College, Cranfield University.

Government of Ghana (2001). **Development of a Feeder Road Prioritisation Method. Dept. of Feeder Roads. Vol I** Working Documents: Vol. II Support Documents.

CSIR (1981). **The Mechanistic Design Method Used to Evaluate the Pavement Structures in the Catalogue of the Draft TRH 4 1980**. Technical Report RP/2/81. NITRR, CSIR, Pretoria.

Department of Transport (1992). Towards **Appropriate Standards for Rural Roads.** Discussion document. Project Report PR 92/466/001, Pretoria.

Department of Transport (1993**). Guidelines for Upgrading Low-volume Roads**. Project Report PR 92/466/002, Pretoria.

Development Bank of Southern Africa (1993). **Interim Guidelines for Labour Based Construction** Projects. Johannesburg.

DFID (2001). **Appraisal of Investments in Improved Rural Access: Economists Guide**. Department for International Development, London.

Division of Roads and Transport Technology (1990). **The Design, Construction and Maintenance of Low-volume Rural Roads and Bridges in Developing Areas.** CSIR, Pretoria.

Division of Roads and Transport Technology (1996). **Appropriate Use of Locally Available Materials in Concrete, Bituminous Surfacing and Layer Works for Roads in Rural Areas.** Project Report RR 93/263. CSIR, Pretoria.

DORM (1997). **Mongolian Road Maintenance Manual**. Department of Roads, Ulaan Baatar.

Dyer C (1982)**. Road Construction Technology in South Africa**, Juta & Ltd, Cape Town and Johannesburg.

Edmonds G A (1979). **Appropriate Technology for Low-volume Roads. 2nd Int. Conf. on Low-volume Roads**. Transportation Research Record No. 702. TRB, Washington.

Edmonds G A and J J de Veen (1993).Technology Choice for the Construction and Maintenance of Roads in Developing Countries. ILO, Geneva.

Gerke R J (1987). **Subsurface drainage of road structures**. Special Report No. 35. Australian Road Research Board, Sydney.

Emery S J (1992): The **Prediction of Moisture Content in Untreated Pavement Layers and Application to Design in southern Africa.** CSIR

Emery S J, S van Huyssteen and G D van Zyl (1991). **Appropriate Standards for Effective Bituminous Surfacing: Final report**, CSIR Transportek, Pretoria.

European Communities - Commission (1996). **Towards sustainable transport infrastructure: A sectoral approach in practice.** Office for Official Publications of the European Communities, Luxembourg.

Fouracre P (2001). **Rural Transport Survey Techniques. Rural Transport Knowledge Base**, Rural Travel and Transport Program. TRL Limited, Crowthorne.

Gichaga F J and N A Parker (1988). **Essentials of Highway Engineering.** Macmillan Publishers Limited, London.

Gourley C S and P A K Greening (1999). **Environmental Damage From Extraction Of Road Building Materials**: Results And Recommendations From Studies In Southern Africa. TRL Unpublished Report PR/ OSC/169/99, Crowthorne.

Gourley C S and P A K Greening (1999). **Performance of Low-volume Sealed Roads: Results and Recommendations from Studies in Southern Africa**. Project Report PR/OSC/167/99. TRL. November, 1999.

Gourley C S and P A K Greening (2001). **Cost-Effective Designs for Low-volume Sealed Roads in Tropical and Sub-Tropical Countries**. TRL Unpublished Report PR/OSC/167/99, Crowthorne.

Gourley C S and P A K Greening. (1999). **Performance of Low-volume Sealed Roads: Results and Recommendations from Studies in Southern Africa.** TRL Published Report PR/OSC/167/99. Crowthorne.

Gourley C S, and P A K Greening (1999). **Collaborative Research Program on Highway Engineering in the SADC Region**. Transport Research Laboratory, DFID.

Gourley C S, T Toole T, and R C Petts, (2001). **Improving Local Resource Utilization in Roadwork's in Developing and Emerging Countries**. 14th IRF World Congress, International Road Federation, Paris, June 2001.

Grace H and D G Toll (1987). **Recent Investigations into the Use of Plastic Laterites as Bases for Bituminous-Surfaced Low-volume Roads**. Proc. Fourth Int. Conf. on Low-volume Roads, Ithaca.

Gyamfi P and G Ruan, (1996). **Road Maintenance by Contract: Dissemination of good practice in Latin America and the Caribbean region.** Regional Studies Program, Report No.44, The World Bank, Washington, D.C.

Handy R L and D E Fox (1987). **K-Tests for Subgrade and Base Evaluation.** ATC Proceedings, 3 - 7 August 1987, Pretoria.

Semmelink C J (1991). **The Use of the DRTT K-Mould for Determining the Elastic Modules of Untreated Road-building Materials.** ATC Research Forum, CSIR, Pretoria.

Heggie I and P Vickers (1998). **Commercial Management and Financing of Roads.** World Bank Technical Paper No. 409, The World Bank, Washington, D.C.

Heggie I G (1972). **Economic Evaluation of Engineering Projects: A Comprehensive Approach to Planning Transport Facilities.** Proceedings of the UK Institution of Civil Engineers. Paper 7500S, London.

Heggie I G (1995). **Management and Financing of Roads: An Agenda for Reform.** World Bank Technical Paper 275 Africa Technical Series. World Bank, Washington, D.C.

Hewitt N C, T Mutowembwa, and T Toole (1998). **The Zimbabwe Road Deterioration Study. Secondary and Feeder Roads Development Program (SFRDP) Workshop**, Harare, Zimbabwe, June 1998. PA 3396/98, Transport Research Laboratory, Crowthorne.

Hine J L and S Ellis (2001). **Agricultural Marketing and Access to Transport Services. Rural Transport Knowledge Database**. TRL Limited. Crowthorne.

Howe J D G F (1972). **A Review of Rural Traffic-Counting Methods in Developing Countries**. RRL Report LR 427. Road Research Laboratory, Crowthorne.

Howe J D G F (1997). **Least-Cost Planning Methodologies in Rural Transport. Working Paper T&RE 19. International Institute for Infrastructural, Hydraulic and Environmental Engineering**, Delft.

Howe J D G F (1998): Impact of Rural Roads on Poverty Alleviation in Developing Countries. Third International Workshop on Secondary Rural Roads, 19-21 May 1998, Jozefow. IHE Working paper T&RE-21.

Howe J D G F and P Richards (1984). **Rural Roads and Poverty Alleviation**. Intermediate Technology Publications Ltd., London.

ILO ASIST (1998). **The Labor-Based Technology Source Book**. A Catalogue of Key Publications. International Labor Organization, Advisory Support, Information Services and Training, Nairobi.

Ingles O G and J B Metcalf (1972). **Soil Stabilization Principles and Practice**. Butterworths, Sydney.

Intech Associates (2001). **Low-cost Road Surfacing (LCS) Project**. Rationale for the Compilation of International Guidelines for Low-cost Sustainable Road Surfacing. LCS Working Paper No.1.

International Labor Organization (ILO) (1996). **Integrated Rural Accessibility** Planning in Lao PDR. August 1996.

Jennings J E and K Knight (1975). **A guide to the construction on or with materials exhibiting** additional settlement due to "collapse "of grain structure. Proc. Of the 6th African Regional Conference on Soil Mechanics and Foundation Engineering. Durban, September 1975.

Johansen J M and P K Senstad (1992). **Effects of Tire Pressures on Flexible Pavement Structures** – A Literature Survey. Publication No. 62. Norwegian Road Research Laboratory, Oslo.

Katala J and T Toole (2000). **Road Management Systems: The Development of the Road Mentor System in Tanzania**. Fourth Annual Transportation Conference. 23rd – 25th November, 2000, Dar es Salaam.

Kerali H, R Robinson and W D O Paterson (1996). **The New Highway Development And Management Tools (HDM-4)**. 75th TRB Conference, Washington D.C.

Kleyn E G (1982). **Aspects of Pavement Evaluation and Design as Determined with the Aid of the Dynamic Cone Penetrometer (DCP).** M.Eng. Thesis, University of Pretoria, Pretoria.

Kleyn E G and G D van Zyl (1988). **Application of the DCP to Light Pavement Design.** First Int. Symposium on Penetration Testing, Orlando.

Koch J A, F Moavenzadeh and K S Chew (1979**). A Methodology for Evaluation of Rural Roads in the Context of Development.** In Proceedings of Transportation Research Record 702; Low-volume Roads: Second International Conference, 1979. Transportation Research Board.

Kumar A and P Kumar (1999**). User-friendly Model for Planning Rural Roads. Transportation Research Record 1652**, Transportation Research Board, Washington, D.C.

Lab. Report 6/72, Ministry of Roads and Road Traffic, Salisbury. McLennan A K (1986). **Towards a Strategy for the Use of Marginal and Naturally** Occurring Materials in Pavements. ARRB Symposium, Bundaberg. Queensland, March 1986.

Lantran J M and C Morse (1995). **Development of the Private Sector (Module 6).** Framework and Competition and Procurement and Contract Management. Proceedings of The Highway Policy Seminar for the Countries of the Former Soviet Union, Moscow, 15 - 19 May 1995. The World Bank, Washington, D.C.

Larcher P (Ed) (1998). **Labor-based Road Construction**. Intermediate Technology Publications, London.

Larcher P and D Miles (2000). **Roads & Realities: How to promote road contracting in developing countries**. IDE, Loughborough University, Leicestershire.

Mayer A and G K Kayira (1997). **Addressing Unemployment Problems Through Expanding Labour-Based Public Works Program. Botswana Development Issues No. 1**, Friedrich Ebert Stiftung, October 1997.

Larcher P and D Miles (2000). **Roads and Realities: How to Promote Road Contracting in Developing Countries.** Institute of Development Engineering, Loughborough University.

Lay M G (1985). **Source Book of Australian Roads. ARRB**. 3rd Ed., Sydney.

Lay M G (1991). **Handbook of Road Technology,** Gordon and Breach Science Publishers, Reading.

Lebo K and D Schelling (200x). **Design and Appraisal of Rural Road Infrastructure**: Ensuring Basic Access for Rural Communities. World Bank Technical paper No. 496. The World Bank, Washington, D.C.

Lebo, J and D Schelling (2000). **The Design and Appraisal of Rural Transport** Infrastructure. Draft Technical Paper. The World Bank, Washington, D.C.

Lees R and A Tostensen (1982). **Regional Cooperation in Southern Africa**: The Case of the Southern African Development Coordination Conference (SADCC). Review of African Political Economy. No. 23, Gaborone.

Lionjanga A V L (1999). **Environmental Problems Facing Road Authorities** in Africa. PIARC XIX World Road Congress, Marrakech, 22-28 September, 1991.

Little I M D and M F G Scott (1976). **Using Shadow Prices**. Heinemann Educational Books.

Malmberg-Calvo C (1997). The **Institutional and Financial Framework of Rural Transport Infrastructure.** SSATP Working Paper No. 17, Sub-Saharan African Transport Program. The World Bank, Washington D.C.

Mandaza I and A Tostensen (1994) **Southern Africa in Search of a Common Future**: From the Conference to a Community. Printing and Publishing Company of Botswana, Gaborone.

Martin T C (2001). **Is Local Road Maintenance Meeting the Community's Needs**. Proceedings of the Institution of Civil Engineers. Municipal Engineer 145, Issue 2., Institution of Civil Engineers, London.

McLennan A K (1986). **Towards a Strategy for the use of Marginal and Naturally Occurring Materials in Pavements.** 24th ARRB Regional Symposium, Bundaberg, Queensland.

McRobert J, Styles E, Giummarra G, McArthur M, and Sheridan G (2001). **Environmental Practices Manual for Rural Sealed and Unsealed Roads**. ARRB Transport Research Ltd., Melbourne.

Metcalf J B (1976). **Pavement Materials –The Use of the California Bearing Ratio Test in Controlling Quality**. ARR No. 48, ARRB, Victoria.

Metcalf J B (1991). **Use of Naturally Occurring but non-Standard Materials in Low-cost Road Construction, Geotechnical and Geological Engineering**, 9.

Miles D (Ed.) (1996). **Towards Guidelines for Labor-Based Contracting.** A framework document. MART Working Paper No. 1. Institute of Development Engineering, Loughborough University, Leicestershire.

Miles D W J (1996). **Promoting Small Contractors** in Lesotho: Privatization in Practice. Proceedings of the Institution of Civil Engineers (Civil Engineering), 114, August, pp124-129, London.

MOTE (1999). **Secondary and Feeder Road Development Program (SFRDP**): Phase 2. Final Report. Ministry of Transport and Energy Department of State Roads.

Millard R S (1979). **The Craft of Highway Engineering**. 2nd Int. Conf. On Low volume Roads. Transportation Research Record No. 702. TRB, Washington.

Millard R S (1993). **Road Building in the Tropics**. TRL State of the Art Review 9. Transport Research Laboratory, Dept. of Transport. National Transport Commission (1986). Road Drainage Manual. Chief Directorate: National Roads, Pretoria.

Ministry of Works, Tanzania (1999). **Pavement and Materials Design** Manual, Dar es Salaam.

Ministry of Works, Transport and Communication. (1999). **White Paper on Labor Based Works Policy**. Windhoek.

Ministry of Works, Transport and Communications, Botswana (1982). **Roads Design Manual, Roads Department**, Gaborone.

Mitchell M F, E C P Petzer and N Van der Walt N (1979). **The Optimum use of Natural Materials for Lightly Trafficked Roads in Developing Regions.** Transp. Res. Record 702. Washington, D.C.

Mitchell R L, C P van der Merwe and H K Geel (1975). **Standardized Flexible Pavement Design for Rural Roads with Light to Medium** Traffic, Ministry of Roads and Road Traffic, Rhodesia Government.

Morton B S (2001). **The Foam ability of Tar and the Engineering Properties of Foamed Tar Mixes**. M. Eng. Dissertation. University of Pretoria.

Motswagole K J (2000). **Evaluation of the CSIR Quality Control Test Kit, Final Research Report. Department of Roads,** Ministry of Transport, Harare, ILO/ASIST, Africa.

National Association of Australian State Road Authorities. (1984). **Moisture Movements in Pavements and Subgrades**. NAASRA, Sydney.

NEPAD (2002). **Main Report: Short-term Action Plan Infrastructure**. NEPAD Secretariat, Midrand.

Netterberg F (1979). **Salt Damage to Roads: An Interim Guide to its Diagnosis and Repair**. Institution of Municipal Engineers of South Africa, NITRR, CSIR.

Netterberg F (1993). **Low-cost Local Road Materials in southern Africa**. Geotechnical and Geological Engineering. CSIR, Pretoria.

Netterberg F and P Paige-Green (1984). **Carbonation of Lime and Cement Stabilised Layers in Road Construction**. NITRR Report RS/3/84, CSIR, Pretoria.

Netterberg F and P Paige-Green (1988): **Pavement Materials for Low-volume Roads in Southern Africa:** A review. Proceedings ATC Conference, Vol. 2B - Appropriate Materials and Methods. Pretoria.

Netterberg F and P Paige-Green (1998). **Pavement Materials for Lowvolume Roads in Southern Africa**: A Review. Annual Transport Convention, S.443, Vol. 2D, Pretoria. July, 1988.

Netterberg F. (1985): **Pedocretes.** RR430 NITRR, Pretoria. Brink A A B and A A R Williams (1964): Soil Engineering Mapping for Roads in South Africa. CSIR Research Report 227, NIRR Bulletin 6, Pretoria.

Nilsson C (1993). **Labor-based Contracting**. ILO ASIST Bulletin, Harare. Rolt JR, C S Gourley and J P Hayes (2002). Rational drainage of road pavements. PR/INT/244/2002. Transport Research Laboratory, DFID.

Norwegian Public Roads Administration (1999). **A Guide to the Use of Otta Seals**. Road Technology Department (NRRL), Publication No. 93, Oslo. August, 1999.

Norwegian Public roads Administration. (1995). **Impact Assessment of Road Projects**. Norwegian Public Roads Administration, Oslo.

Obika B, R J Freer-Hewish, M Woodbridge and D Newill (1995). **Prevention of Salt Damage to Thin Bituminous Surfacing:** Design Guidelines. Proc. Sixth Int. Conf. on Low-volume Roads, Minneapolis, Minnesota, June 25-29, 1995.

Oglesky H O (1990). **Dilemmas in the Administration, Planning, Design, Construction and Maintenance of Low-volume Roads**. Transportation Research Special Report 160, TRB, Washington.

UNESCO (1967). **Low-Cost Roads: Design, Construction and Maintenance**. The Butterworth Group, London. SATCC (1998). SADC Protocol on Transport, Communications and Meteorology. Maputo.

Olivier J H W O (1990). **Models to Predict the Hardening Rate and Distress Viscosity** Level in Sprayed Seals. ARRB, Report No. 182.

Overby C (1982). **Material and Pavement Design for Sealed Low volume Roads in Botswana** 1974-81. NRRL Report 1042. Norwegian Public Roads Administration, Oslo.

Overby C (1990). **Monitoring of Sealed Low-Volume Roads in Botswana 1980 - 1989**. NRRL Report 1478. Norwegian Public Roads Administration, Oslo.

Overseas Development Administration (ODA). (1996): **The Manual of Environmental Appraisal.**

Paige-Green P (1994). **Recommendations for the use of Marginal Base Course Materials in Low-volume Roads in South Africa,** CSIR Transportek, Pretoria.

Parker N A (1997). **The Socio-Economics of Paving Low-volume Roads. Keynote Paper**, 1.o Simpóso International de Pavimentacão de Rodovias de Baixo Volume de Tráfego, Rio de Janeiro, 5 a 10 de Outubro de 1997.

Parsley L L and R Robinson (1982). **The TRRL Road Investment Model for Developing Countries**. TRL Report LR 1057, Crowthorne.

Paterson W D O (1987). **Road Deterioration and Maintenance Effects, Models for Planning and Management.** John Hopkins University Press for the World Bank, Baltimore, 1987.

Petts R C (1997). **Agricultural Tractors in Roadwork's. Annual Roads Convention**, Dar es Salaam.

PIARC (2000). **HDM-4. Highway Development and Management Series**. The World Road Association (PIARC), Paris.

Pinard M I (1998). **Innovative Compaction Techniques for Improving the Bearing Capacity of Roads and Airfields.** Proc. 5th Int. Conf. on the Bearing Capacity of Roads and Airfields. Trondheim.

Pinard M I and Kaombwe, S M A (2001). **Pilot Survey of Country Stakeholders Views of the RMI Vision, Strategy and Indicators of Progress In Implementation and Impact**. Report to World Bank, Transport 1, RMI Africa Region. The World Bank, Washington, D.C.

Pinard M I and S Ookeditse (1988). **Evaluation of High Energy Impact Compaction Techniques for Minimising Construction Water Requirements in Semi-Arid Regions**. Fourteenth ARRB Conference, Canberra. 26 August - 2 September,1988.

Reeves I N (1989). **Modified Texas Triaxial Test for Non-Standard Paving Materials. Workshop on Pavements in Dry Climates,** Materials Branch, Main Roads, Brisbane.

Research Report 644, **DRTT Bulletin 20**, CSIR, Pretoria. Mitchell R L and M Ahronovitz (1972). The Laying of Test Sections to Measure the Phenomenon of Hydrogenesis at Victoria Falls Airport.

Riverson J D N, J Gavira and S Thriscutt. (1991). **Rural Roads in Sub-Saharan Africa - Lessons from World Bank experience.** World Bank Technical Paper No. 141, Africa Technical Department Series. Washington, D.C.

Roads Department, Botswana (2001). **Planning and Environmental Impact Assessment of Road Infrastructure**. Guideline No.5. Roads Department, Ministry of Works, Transport and Communications, Gaborone.

Roads Department, Ministry of Works, Transport and Communications (2001). **The Prevention and Repair of Salt Damage to Roads and Runways**. Guideline No. 6.

Roads Department, Ministry of Works, Transport and Communications, Botswana. 2000: **Methods and Procedures for Prospecting for Road Construction Materials**. Guideline No. 3, Gaborone.

Robinson P (1998). **Maintenance by Contract: Is it Delivering Value for Money?** Proceedings of the National Workshop, Melbourne, Australia, November 2000. ARRB Transport Research.

Robinson R (1988). **A View of Road Maintenance, Management and Economics**. TRL Research Report RR 145. Transport Research Laboratory, Crowthorne.

Robinson R (1999). **A New Approach for Quantifying Economic and Social Benefits for Low-volume Roads in Developing Countries**. In: Impact Assessment and Project Appraisal, Volume 17, Number 2, June 1999, pages 147 - 155. Beach Tree Publishing, Guildford.

Robinson R (1999): **A New Approach to Quantifying Economic and Social Benefits for Low-volume Roads in Developing Countries**. Impact Assessment and Project Appraisal, Volume 17, No.2, London. June 1999.

SABITA Manual 10 (1992). **Appropriate Standards for Bituminous Surfacing for Low-volume Roads**. South African Bitumen and Tar Association, Cape Town.

SABITA Manual 11 (1994). **Labor-enhanced construction for bituminous surfacing**.

SABITA Manual 12 (1995). **Methods and procedures Labor-enhanced construction for bituminous surfacing**.

SABITA Manual 2 (1992). **Bituminous products for road construction**.

SABITA Manual 7 (SURF+) (1993**). Economic Warrants for Surfacing Roads**.

Sampson L R and F Netterberg (1984). **A Cone Penetrometer Method for Measuring the Liquid Limits of South African soils**. Proc. 8th African Reg. Conf. on Soil mechanics and Foundation Engineering, Harare.

SATCC (1999). Model Legislative Provisions. **Road Network Management and Financing**, Maputo.

Schroeder W L and S E Dickinson (1996). **Soil in Construction**. Prentice Hall. Roughton International in association with University of Birmingham

Schwartz K (1985). Collapsible **Soils. Problems Soils in South Africa - State of the Art.** The Civil Engineer in South Africa. Johannesburg, July 1985.

South African Roads Board: (1993). **Cost-Benefit Analysis Of Rural Road Projects: Program CB Roads, User Manual version 4.1**, South African Department of Transport, Chief Directorate: National Roads, Pretoria.

Southern Africa Consulting Group (SAGP) (1998). **Transport and Communications Integration Study for Southern Africa. Review Final Report. Vol. 1:** Summary and Main Report. Maputo, 31 March, 1998.

Southern Africa Transport and Communications Commission (1998). **Code of Practice for the Design of Road Pavements (draft**). SATCC, Maputo.

Southern African Bitumen and Tar Association (SABITA) and Council for Scientific and Industrial Research (CSIR). (1989). **Economic Warrants for Surfacing Roads: Manual 7**. CSIR, Pretoria.

Stevenson S R (1994). **Environmental Impact Assessment of Transportation Projects in Africa**. All- Africa Engineers' Conference on the Role of the Engineer in Sustainable Development, Nairobi.

Still D A (1992). **The Case for the Selective Use of Labor-based Construction in Civil Engineering**. Proc. Conf. On Appropriate Technology for the Third World, 8 to10 June, 1992. Windhoek.

Stock,E and J de Veen (1996). **Expanding labor-based Methods for Road Works in Africa**. World Bank Technical Paper No. 347. Washington, D.C.

Talvitie A (1996). **International experiences in restructuring the road sector.** Paper to annual meeting of the Transportation Research Board, January 1996. Washington, D.C.

TANROADS (2000). **Road Performance Agreement with MOW and Roads Fund Board**. Tanzanian National Roads Agency. Dar es Salaam.

TANROADS (2001). **Description and Classification of Road Maintenance Activities**. Tanzania National Roads Agency. Dar es Salaam. Transport Research Laboratory (1985). Maintenance Techniques for District Engineers. Overseas Road Note 2. TRL. Crowthorne.

The Institution of Civil Engineers, UK (1982). **Highway Investment in Developing Countries**. Proceedings of the Conference 'Criteria for Planning Highway Investment in Developing Countries', Café Royal Conference Centre, London, 17 – 18 May 1982.

The World Bank (1996). **Sustainable Transport**: Priorities for Policy Reform. The International Bank for Reconstruction and Development, Washington, D.C.

Tideman J (1990**). Environmental Impact Assessment**: A Process for Effective Management of Resources. Highway Engineering in Australia - December 1990, Sydney.

Toole T and D Newill (1987). **Strategy for assessing marginal quality materials for use in bituminous** roads in the tropics. Proc. Seminar H, PTRC Transport and Planning Summer Annual Meeting, University of Bath, London.

Transport and Road Research Laboratory (1992). **Overseas Road Note 9: A Design Manual for Small Bridges**. TRRL, Crowthorne

Transport Research Board/National Research Council (1995). Assessing **Worldwide Low-volume Roads: Problems, Needs and Impacts.** Transport Research Circular No. 446. Washington. May, 1995.

Transport Research Laboratory (1988). **A Guide to Road Project Appraisal. Overseas Road Note 5**, TRL.

Transport Research Laboratory (1993). **Overseas Road Note 31. A Guide to the Structural Design of Bitumen-Surfaced Roads in Tropical and sub-Tropical Climates (1993):** TRL, Crowthorne, Berkshire. (4th edition).

Transport Research Laboratory (2001). **Management of Rural Road Networks. Overseas Road Note 20**. TRL, Crowthorne.

Transport Research Laboratory, Ross Silcock Partnership and Overseas Development Administration (1991). **Towards Safer Roads in Developing Countries – A Guide for Planners and Engineers**. TRL, Crowthorne.

Transportation Research Board (1979). **Low-volume Roads: Second International Conference. Transportation Research Record 702. National Academy of Sciences**, Washington, D.C. August, 1979.

Tsunokawa K and C Hoban (ed). (1997). **Roads and the Environment: A Handbook**. World Bank Technical Paper 376. Washington, D.C.

United Nations Economic Commission for Latin America and the Caribbean (1993). **Roads: A New Approach for Road Network Management and Conservation**. UN-ECLAC, Santiago.

University of Nottingham (2000). **Guidelines on Materials and Borrow Pit Management for Low-Cost Roads**. DFID.

Van der Tak H G and A Ray (1971). **The Economic Benefits of Road Transport Projects.** World Bank Staff Occasional paper No. 13, The World Bank, Washington, D.C

Van Zyl , N J W and C R Freeme (1984). **Determination of Damage Done to Roads by Heavy Vehicles.** Proc. Annual Transport Convention, Pretoria.

Visser A T, J H Maree and G P Marais (1983). **Implications of Light Bituminous Surface Treatments on** Gravel Roads. 3rd Int. Conf. On Low volume Roads, Transp. Res. Board, Washington D.C., 1983.

Walker R N, W D O Paterson, C R Freeme and C P Marais (1977). **The South African Mechanistic Design Procedure.** Proc. 4th Int. Conf. on the Structural Design of Asphalt Pavements, Ann Arbor, Michigan, August 1977.

Weinert H H (1974). **A Climatic Index of Weathering and its Application to Road Construction**. Geotechnique, Vol. 24, No.4, pp475-488.

Weinhert H H (1980). **The Natural Road Construction Materials of Southern Africa**. Pretoria: Academica.

Weston D J (1980). Expansive **soil treatment for southern Africa.** Proc.4th International Conference on Expansive Solis, Denver.

Wolff H, S J Emery, G D van Zyl and P Paige-Green (1995). **Design Catalogue for Low-volume Roads Developed for South African Conditions.** Proc. Sixth Int. Conf. on Low-volume Roads, Minneapolis, Minnesota, June 25-29, 1995.

Wooltorton F L D (1954). **The Scientific Basis of Road Design**. Edward Arnold Ltd.

World Bank. (1999). **Managing the Social Dimension of Transport**. The Role of Social Assessment. World Bank, Social Assessment Thematic Team, Washington, D.C.

Yoder E J and M W Witczak (1975). **Principles of Pavement Design**, Wiley, New York.

Appendix 2

Conversion tables

Length

	km	m	mm	mile	yard	ft	in	10^{-3} in
km	1	1000	10^{6}	0.6214	1094	3281	3.937×10^{4}	3.937×10^{7}
m	10^{-3}	1	1000	6.214×10^{-4}	1.0936	3.281	39.370	3.937×10^{4}
mm	10^{-6}	10^{-3}	1	6.214×10^{-7}	1.094×10^{-3}	3.281×10^{-3}	3.937×10^{-2}	39.37
mile	1.6094	1609.4	1.609×10^{6}	1	1760	5280	63360	$6.336 X 10^{7}$
yard	9.144×10^{4}	0.9144	914.41	5.682×10^{-4}	1	3	36	36000
ft	3.048×10^{-4}	0.3048	304.8	1.894×10^{-4}	0.3333	1	12	12000
in	2.54×10^{-5}	0.0254	25.4	1.578×10^{-5}	2.778×10^{-2}	8.333×10^{-2}	1	1000
10^{-3}	2.54×10^{-8}	2.54×10^{-5}	0.0254	1.578×10^{-8}	2.778×10^{-5}	8.333×10^{-5}	10^{-3}	1

Chart B.2.1 Conversion table length.

Area

	km^2	m^2	cm^2	mm^2	sq.mile	acre	yd^2	ft^2	in^2
km^2	1	10^{-6}	10^{10}	10^{12}	0.38612	247.11	1.196×10^{6}	1.076×10^{7}	1.550×10^{9}
m^2	10^{-6}	1	10^{4}	10^{6}	3.86×10^{-7}	2.471×10^{-4}	1.1960	10.764	1550
cm^2	10^{-10}	10^{-4}	1	100	3.86×10^{-11}	2.471×10^{-8}	1.196×10^{-4}	1.076×10^{-3}	0.1550
mm^2	10^{-12}	10^{-6}	10^{-2}	1	3.86×10^{-13}	2.47×10^{-10}	1.196×10^{-6}	1.076×10^{-5}	1.550×10^{-3}
sq. mile	2.590	2.59×10^{6}	2.59×10^{10}	2.59×10^{12}	1	639.96	3.097×10^{6}	2.788×10^{7}	4.01×10^{8}
acre	4.047×10^{-3}	4047	4.047×10^{7}	4.047×10^{9}	1.563×10^{-3}	1	4840	43560	6.273×10^{6}
yd^2	8.36×10^{-7}	0.8361	8361	8.36×10^{5}	3.228×10^{-7}	2.066×10^{-4}	1	9	1296
ft^2	9.29×10^{-8}	9.29×10^{-2}	929	92900	3.587×10^{-8}	2.296×10^{-5}	0.1111	1	144
in^2	6.45×10^{-10}	6.45×10^{-4}	6.4516	645.16	2.491×10^{-10}	1.594×10^{-7}	7.716×10^{-4}	6.944×10^{-3}	1

Chart B.2.2 Conversion table surfaces.

Volume								
	m^3	dm^3 (litre)	cm^3 (ml)	yd^3	ft^3	in^3	UK gallon	US gallon
m^3	1	10^{-3}	10^{6}	1.3079	35.311	6102	219.97	264.17
dm^3 (litre)	10^{-3}	1	10^{3}	1.308×10^{-3}	3.531×10^{-2}	61.02	0.2200	0.2642
cm^3 (ml)	10^{-6}	10^{-3}	1	1.308×10^{-6}	3.531×10^{-5}	6.102×10^{-2}	2.199×10^{-4}	2.642×10^{-4}
yd^3	0.7646	746.6	7.646×10^{5}	1	27	46650	168.19	201.99
ft^3	2.832×10^{-2}	28.32	2.832×10^{-4}	3.704×10^{-2}	1	1728	6.229	7.481
in^3	1.639×10^{-5}	1.639×10^{-2}	16.387	2.144×10^{-5}	5.787×10^{-4}	1	3.605×10^{-3}	4.329×10^{-3}
UK gallon	4.546×10^{-3}	4.546	4.546×10^{3}	5.946×10^{-3}	0.1605	277.42	1	1.2008
US gallon	3.785×10^{-3}	3.785	3.785×10^{3}	4.951×10^{-3}	0.1337	231	0.8327	1

Chart B.2.3 Conversion table volume.

Mass								
	Tonne (Mg)	kg	g	UK Ton	US Ton	cwt	lb	oz
Tonne (Mg)	1	1000	10^{6}	0.9842	1.1011	19.66	2.205×10^{3}	3.527×10^{4}
kg	10^{-3}	1	1000	9.842×10^{-4}	1.101×10^{-3}	1.966×10^{-2}	2.2046	35.274
g	10^{-6}	10^{-3}	1	9.842×10^{-7}	1.101×10^{-6}	1.966×10^{-5}	2.204×10^{-3}	3.527×10^{-2}
UK Ton	1.016	1016	1.016×10^{6}	1	1.12	20	2240	35840
US Ton	0.9081	908.1	9.081×10^{5}	0.8928	1	17.856	2000	32000
cwt	5.085×10^{-2}	50.85	5.085×10^{4}	0.05	0.0560	1	112	1792
lb	4.536×10^{-4}	0.4536	453.6	4.46×10^{-4}	5×10^{-4}	8.92×10^{-3}	1	16
oz	2.835×10^{-5}	2.835×10^{-2}	28.349	2.79×10^{-5}	3.125×10^{-5}	5.580×10^{-4}	6.25×10^{-2}	1

Chart B.2.4 Conversion table mass.

Density						
	Tonne/m^3 Mg/m^3 MPa	kg/m^3	lb/in^3	UK ton/yd^3	US ton/yd^3	lb/ft^3
Tonne/m^3 Mg/m^3 MPa	1	1000	0.03613	0.75247	0.8428	62.43
kg/m^3	10^{-3}	1	$3.613x10^{-5}$	$7.525x10^{-4}$	$8.428x10^{-4}$	$6.243x10^{-2}$
lb/in^3	27.680	27680	1	20.828	23.328	$1.728x10^{3}$
UK ton/yd^3	1.3289	$1.328x10^{3}$	$4.801x10^{-2}$	1	1.12	82.955
US ton/yd^3	1.1865	$1.186x10^{3}$	$4.287x10^{-2}$	0.8929	1	74.074
lb/ft^3	$1602x10^{-2}$	16.019	$5.787x10^{-4}$	$1.205x10^{-2}$	$1.35x10^{-2}$	1

Chart B.2.5 Conversion table density.

Force and Weight						
	MN	kN	N	kgf	tonf	lbf
MN	1	1000	10^{6}	$1.0196x10^{5}$	100.4	$2.248x10^{5}$
kN	10^{-3}	1	10^{3}	101.96	0.1004	224.82
N	10^{-6}	10^{-3}	1	0.10196	$1.004x10^{-4}$	0.2248
kgf	$9.807x10^{-6}$	$9.807x10^{-3}$	9.807	1	$9.842x10^{-4}$	2.2048
tonf	$9.964x10^{-3}$	9.964	9964	1016	1	2240
lbf	$4.448x10^{-6}$	$4.448x10^{-3}$	4.448	0.45455	$4.464x10^{-4}$	1

Chart B.2.6 Conversion table power and weight.

Pressure, stress and modulus of elasticity											
	MN/m^3 MPa	kN/m^2 kPa	kp kgf/cm^3	bar	atm	m H_2O	ft H_2O	mm Hg	Ton/ft^2	psi lbf/in^2	lbf/ft^2
MN/m^3 MPa	1	1000	10.197	10	9.869	102.2	355.2	7500.6	9.320	145.04	20886
kN/m^2 kPa	0.001	1	$1.019x10^{-2}$	0.0100	$9.87x10^{-3}$	0.1022	0.3352	7.5006	0.0093	0.14504	20.886
kp kgf/cm^3	$9.807x10^{-2}$	98.07	1	0.9807	0.9678	10.017	32.866	735.56	0.9139	14.223	2048.1
bar	0.100	100	1.0197	1	0.9869	10.215	33.515	750.06	0.9320	14.504	2088.6
atm	0.1013	101.33	1.0332	1.0132	1	10.351	33.959	760.02	0.9444	14.696	2116.2
m H_2O	$9.788x10^{-3}$	9.7885	$9.983x10^{-2}$	$9.879x10^{-2}$	$9.661x10^{-2}$	1	3.2808	73.424	$9.124x10^{-2}$	1.4198	204.45
ft H_2O	$2.983x10^{-3}$	2.9835	$3.043x10^{-2}$	$2.984x10^{-2}$	$2.945x10^{-2}$	0.3048	1	22.377	$2.781x10^{-2}$	0.43275	62.316
mm Hg	$1.333x10^{-4}$	0.1333	$1.3595x10^{-3}$	$1.333x10^{-3}$	$1.315x10^{-3}$	$1.362x10^{-2}$	$4.469x10^{-2}$	1	$1.243x10^{-3}$	$1.934x10^{-2}$	2.7846
Ton/ft^2	0.1073	107.3	1.0942	1.0730	1.0589	10.960	35.960	804.78	1	15.562	2240
psi lbf/in^2	$6.895x10^{-3}$	6.895	$7.031x10^{-2}$	$6.895x10^{-2}$	$6.805x10^{-2}$	0.7043	2.3108	51.714	$6.426x10^{-2}$	1	144
lbf/ft^2	$4.788x10^{-5}$	$4.788x10^{-2}$	$4.883x10^{-4}$	$4.788x10^{-4}$	$4.725x10^{-4}$	$4.891x10^{-4}$	$1.605x10^{-2}$	0.3591	$4.464x10^{-4}$	$6.944x10^{-3}$	1

Chart B.2.7 Conversion table power and elasticity.

Permeability						
	m/s	cm/s	m/year	Darcy	ft/yr	ft/day
m/s	1	100	$3.156x10^7$	$1.04x10^5$	$1.035x10^8$	$2.835x10^5$
cm/s	0.01	1	$3.156x10^5$	$1.04x10^3$	$1.035x10^6$	$2.834x10^3$
m/year	$3.169x10^{-8}$	$3.169x10^{-6}$	1	$1.04x10^3$	3.281	$8.982x10^{-3}$
Darcy	$9.66x10^{-6}$	$9.66x10^{-4}$	304	1	1000	2.74
ft/yr	$9.658x10^{-9}$	$9.659x10^{-7}$	0.3048	10^{-3}	1	$2.738x10^{-3}$
ft/day	$3.527x10^{-6}$	$3.527x10^{-4}$	111.33	0.365	365.25	1

Chart B.2.8 Conversion table permeability

Multiplying Prefixes		
Prefix symbol	Name	Multiplying factor
G	giga	1.000.000.000 = 10^9
M	mega	1.000.000 = 10^6
k	kilo	1.000 = m^3
h	hecto*	100 = m^2
da	deca*	10
d	deci*	10^{-1} = 0,1
c	centi*	10^{-2} = 0,01
m	milli	10^{-3} = 0,001
µ	micro	10^{-6} = 0,000.001
n	nano	10^{-9} = 0,000.000.01
** not recommended in SI*		

Chart B.2.9 Units

Appendix 3

Tables of contents Laboratory testing Manual 2000

CML test method, reference number	Name of test	Reference to test methods
Tests on Soils and Gravels		
1.1	Moisture Content	BS1377:Part 2:1990
1.2	Liquid Limit (Cone Penetrometer)	BS1377:Part 2:1990
1.3	Plastic Limit & Plasticity Index	BS1377:Part 2:1990
1.4	Linear Shrinkage	BS1377:Part 2:1990
1.5	Particle Density Determination - Pyknometer	BS1377:Part 2:1990
1.6	Bulk Density for undisturbed samples	BS1377:Part 2:1990
1.7	Particle Size Distribution – Wet sieving	BS1377:Part 2:1990
1.8	Particle Size Distribution – Hydrometer Method	BS1377:Part 2:1990
1.9	Compaction Test – BS Light and BS Heavy	BS1377:Part 4:1990
1.10	CBR Test – One point method	BS1377:Part 4:1990
1.11	CBR Test – Three point method	BS1377:Part 4:1990 and TMH1:method A8:1986
1.12	Consolidation Test – Oedometer	BS1377:Part 5:1990
1.13	Triaxial Test	BS1377:Part 7:1990
1.14	Shear Box Test	BS1377:Part 7:1990
1.15	Permeability Test – Constant Head	BS1377:Part 5:1990
1.16	Organic Content – Ignition Loss Method	BS1377:Part 3:1990 and NPRA 014 test 14.445
1.17	Crumb Test	BS1377:Part 5:1990
1.18	pH Value (pH meter)	BS1377:Part 3:1990
1.19	Preparation of Stabilized Samples for UCS	TMH1:method A14:1986 and BS1924:Part2:1990
1.20	Compaction Test – Stabilized Materials	TMH1:method A14:1986 and BS1924:Part2:1990
1.21	UCS of Stabilized Materials	TMH1:method A14:1986
1.22	Initial Consumption of Lime – ICL	BS1924:Part 2:1990
Tests on Aggregates and Concrete		
2.1	Moisture Content of Aggregates	BS812Part 109:1990
2.2	Relative Density and Water Absorption	BS812Part 2:1975
2.3	Sieve Test on Aggregates	BS812Part 103.1:1985
2.4	Flakiness Index (FI) and Average Least Dimension (ALD)	BS812Section 105.1:1989
2.5	Elongation Index	BS812Section 105.2:1990
2.6	Aggregate Crushing Value (ACV)	BS812Part 110:1990
2.7	Ten Percent Fines Value (TFV)	BS812Part 111:1990
2.8	Aggregate Impact Value (AIV)	BS812Part 112:1990
2.9	Los Angeles Abrasion Test (LAA)	ASTM C535-89
2.10	Sodium Soundness Test (SSS)	ASTM C88-90
2.11	Slump Test	BS1881:Part 102:1983
2.12	Making of Concrete Test Cubes	BS1881:Part 108:1983
2.13	Concrete Cube Strength	BS1881:Part 116:1983
Tests on Asphalt and Bituminous Materials		
3.1	Pre-conditioning of Bitumen Samples Prior to Mixing or Testing	NPRA 014 test 14.511
3.2	Density of Bituminous Binders	ASTM D70-97
3.3	Flash and Fire Point by Cleveland Open Cup	ASTM D92-90
3.4	Thin-Film Oven Test (TFOT)	ASTM D1754-87
3.5	Penetration of Bituminous Materials	ASTM D5-86
3.6	Softening Point Test	ASTM D36-70
3.7	Ductility	ASTM D113-86
3.8	Viscosity Determination using the Brookfield Thermosel Apparatus	ASTM D4402-91
3.9	Density and Water Absorption of Aggregates Retrieved on a 4.75mm Sieve	ASTM C127-88
3.10	Density and Water Absorption of Aggregates Passing the 4.75mm Sieve	ASTM C128-88
3.11	Calibration of Glass Pycnometers (0.5- 1 Liter)	NPRA 014 test 14.5922
3.12	Mixing of Test Specimens; Hot Bituminous Mixes	NPRA 014 test 14.5532
3.13	Determination of Maximum Theoretical Density of Asphalt Mixes and Absorption of Binder into Aggregates	ASTM D2041-95 and D4469-85
3.14	Bulk Density of Saturated Surface Dry Asphalt Mix Samples	ASTM D2726-96
3.15	Bulk Density of Paraffin-Coated Asphalt Mix Samples	ASTM D1188-89
3.16	Bulk Density of Asphalt Mix Samples, Caliper Measurements	NPRA 014 test 14.5622
3.17	Calculation of Void Content in Bituminous Mixes	ASTM D3203 and AASHTO pp19-39
3.18	Marshall Test	ASTM D1559-89
3.19	Marshall Mix Design	ASTM D1559-89
3.20	Refusal Density Mix Design	TR: Overseas Road Note 31, app. D:1990
3.21	Indirect Tensile Strength Test	ASTM D3967 and NPRA 014 test 14.554
3.22	Determination of Binder Content and Aggregate Grading by Extraction	ASTM D2171-88, method B
3.23	Effect of Water on Bituminous Coated Aggregates, Boiling Test	ASTM D3625-96

Appendix 4

Tables of contents Field testing Manual 2003

Appendix 5

Glossary of terms

	English	Francais	Deutsch
A	aggregate	granulat	Zuschlagstoff, Gesteinsmaterial
	aggressiveness	agressivité	Aggressivität
	aligator cracking	faïençage	Netzrisse, Elefantenhaut
	analysis	analyse	Untersuchung
	analytical model	modèle analytique	analytisches (Rechen)Modell
	articulated lorry	camion articulé	LKW – Zug
	asphalt	asphalte	Asphalt
	asphalt (2^{nd} sense, US) asphalt binder (US) asphalt cement (US)	bitume	Bitumen
	asphalt concrete	béton bitumineux	Asphaltbeton
	asphalt mixture	enrobé asphaltique, materiau bitumineux	Asphaltmischgut
	asphalt pavement	revêtement bitumineux	Asphaltdecke, bituminöser Oberbau
	assessment of pavement condition	évaluation de l'état du revêtement (d'une chaussée)	Oberbau-Zustandserfassung
	axle	essieu	Achse
	axle load	charge par essieu	Achslast
	axle spacing	distance entre essieux	Achsabstand
B	base course (US)	couche de base	obere Tragschicht
	bearing capacity	portance	Tragfähigkeit
	bedrock	bedrock	Felsuntergrund
	bend	courbe, virage	Kurve
	berm(e)	berme	Berme
	binder	liant	Bindemittel
	bindercontent	teneur en liant	Bindemittelgehalt
	binder course	couche de liaison	Binderschicht
	bitumen	bitume	Bitumen
	bituminous binder	liant bitumineux	Bitumen, bituminöses Bindemittel
	bituminous layer	couche bitumineuse	bituminöse Schicht
	bottleneck	goulot d'étranglement	Engstelle, Engpass
C	calibration factor capping layer	coefficient de calage couche de forme	Anpassungsfaktor verbesserter Unterbau
	carriageway	chaussée	Fahrbahn
	canalisation (of traffic)	canalisation (des véhicules)	Kanalisierung (des Verkehrs)
	cement	ciment	Zement
	cement-bound material	matériau traité au liant	hydraulisch gebundenes

	hydraulique	Material
central reserve	terre-plein central	Mittelstreifen
clay	argile	Ton
cohesion	cohésion	Kohäsion
coarse aggregate	granulat grossier	Grobkorn
commercial vehicle	véhicule commerciale	Nutzfahrzeug
compaction	compactage	Verdichtung
concrete	béton	Beton
concrete pavement	chaussée en béton	Betondecke
construction traffic	trafic de chantier	Baustellenverkehr
core	carotte	Bohrkern
course	couche	Schicht
crack longitudinal crack reflection crack transverse crack	fissure fissure longitudinale remontée de fissure fissure transversale	Riß Längsriß Reflektionsriß Querriß
cracking	fissuration	Rißbildung
structural cracking	fissuration structurelle	tragfähigkeitsbedingte
surface cracking	fissuration superficielle	oberflächliche
crazing	faïençage	feine Netzrisse
cross roads	carrefour	Kreuzung
cross section, cross profile	profil en travers	Querschnitt, Querprofil
crossfall	pente transversale/dévers	Querneigung
crown of a carriageway	plateforme	Straßenkrone
curb	bordure (de trottoir)	Bordstein
cycle path (track)	piste cyclable	Radweg
D debonding	décollement d'interface	Verlust der Schichthaftung
deflection	déflexion	Einsenkung
deformation elastic plastic viscous	déformation elastique plastique visqueux	Verformung elastische plastische viskose
delamination	délamination	Abplatzen, Ablösen einer Schicht
density	masse volumique	Dichte
design	conception, dimensionnement	Entwurf, Bemessung
design criterie	critère de dimensionnement	Bemessungskriterien
design life	durée de vie	Bemessungslebensdauer, Nutzungsdauer

	design mix	mélange théorique, formule d' enrobage	Eignungsprüfungsrezeptur
	design period	période de dimensionnement	Bemessungsperiode
	design traffic	trafic escompté, trafic de dimensionnement	Bemessungsverkehr
	deterioration	dégradation	Schädigung, Schadensentwicklung
	distress pavement distress	dégradation dégradation de chaussée	Schaden Oberbauschaden
	ditch	fossé	Graben
	ditch at top of slope	cunette de crête de talus	oberer Abfanggraben
	ditch at foot of slope	fossé de pied de talus	unterer Abfanggraben
	drainage	drainage, évacuation des eaux	Entwässerung
	dual carriageway	route à double voie	zweistreifige Straße
	durability	durabilité	Dauerhaftigkeit
	dynamic load	charge dynamique	dynamische Belastung
E	elastic stiffness	rigidité élastique	elastische Steifigkeit
	embankment	remblai	Damm
	empirical model	modèle empirique	empirisches Verfahren
	equivalent standard axle load	essieu standard équivalent	äquivalente Standardachslast
	eveness	uni	Ebenheit
F	fatigue	fatigue	Ermüdung
	filler	filler (fines)	Füller
	flexible pavement	chaussée souple	flexibler Oberbau (ungebundene und Asphaltschichten)
	footway	trottoir, chemin piétonnier	Fussweg, Gehweg
	forecasting short term long term	prévision à court term à long term	Vorhersage Kurzzeit- Langzeit-
	formation (level)	plate-forme	Unterbauplanum
	foundation	fondation	Gründung
	freight transport	transport de marchandises	Güterverkehr
	friction course	couche de roulement, couche d'usure	Rauhbelag, Deckschicht
	frost-susceptibility	gélivité	Frostempfindlichkeit
	full depth asphalt construction	structure bitumineuse épaisse	Vollasphaltoberbau
G	global index	indice global	globaler (Zustands)wert

	granular layer	couche granulaire	ungebundene Schicht
	granular material	granulat	Gesteinsmaterial
	gross vehicle mass	masse totale du véhicule	Fahrzeuggesamtmasse
	gross vehicle weight	poids total du véhicule	Fahrzeuggesamtgewicht
	gussasphalt	asphalt coulé	Gußasphalt
H	hard shoulder for emergency stop	bande d'arrêt d'urgence	Standstreifen, befestigter Seitenstreifen
	heavy vehicle	poids lourd	Schwerfahrzeug, Lastkraftwagen
	highway	route	Straße, Fernstraße
I	improvement of soil	sol traité, sol amélioré	Bodenverbesserung
	improved subgrade	fondation traitée, fondation améliorée	verbesserter Untergrund
	interface rough interface smoth interface	interface interface collée interface glissante	Grenzfläche rauhe Grenzfläche glatte Grenzfläche
	intersection	carrefour routier, intersection	Kreuzung
J	junction	carrefour	Knotenpunkt
	joint	joint	Fuge
K	kerb	bordure	Bordstein
L	layer	couche	Lage
	levelling course	couche de reprofilage	Ausgleichsschicht
	long-term performance	comportement à long terme	Langzeit-Gebrauchsverhalten
	lorry (UK), truck (US)	camion, poids lourd	Lastkraftwagen, LKW
	lorry with trailer	camion avec remorque	LKW mit Anhänger
	lorry with semi-trailer	camion avec semi-remorque	LKW mit Sattelanhänger, Sattelzug
	load	charge	Last, Beladung
	longitudinal profile	profil longitudinal, profil en long	Längsprofil
M	macrotexture	macrotexture	Makrotextur, Grobrauheit
	maintenance	entretien	Erhaltung
	mastic asphalt	mastic, mastic d' asphalte	Asphaltmastix
	mechanistic model	modèle mechanique	mechanistisches (Rechen)Modell
	median (US)	terre-plein central	Mittelstreifen
	microtexture	microtexture	Mikrotextur, Feinrauheit
	mix	mélange	Gemisch
	mix design	formulation	Eignungsprüfung, Rezeptentwurf
	mix-in-place	mélange en place	Baumischverfahren

	mix-in-plant	mélange en centrale	Zentralmischverfahren
	modulus	module	Modul
	modulus of elasticity resilient modulus	module d'elasticité module reversible	Elastizitätsmodul Verformungsmodul (Untergrundmodul)
	moisture	humidité	Feuchtigkeit
	moisture content	teneur en eau	Wassergehalt
	motorway	autoroute	Autobahn
O	overlay	recouvrement, couche de renforcement	Hocheinbau, Verstärkungs- schicht
P	particle size distribution	granularité, distribution granules, distribution granulometrique	Korngrößenverteilung
	passenger car	véhicule léger, V.L.	Personenkraftwagen, PKW
	pave	recouvrir, revêtir	befestigen
	pavement	chaussée	Fahrbahn
	pavement flexible pavement flexible composite pavement rigid pavement pavement deterioration	revétement chaussée souple chaussée semi-rigide, chaussée mixte chaussée rigide revêtement rigide dégradation de chaussée, du revêtement	Oberbau flexibler (bituminöser) Oberbau bit. Oberbau mit zementstab. Tragschicht starrer Oberbau Verschlechterung des Oberbau-zustandes, Oberbauschädigung
	pavement design	dimensionnement de chaussée	(Straßen-) Oberbaubemessung
	pavement failure	rupture de chaussée, dégât de chaussée	Oberbauschaden
	pedestrian	piéton	Fussgänger
	performance	comportement, tenue	Gebrauchsverhalten
	performance factor	facteur de comportement	Verhaltenskenngröße (Schadensart)
	performance model	modèle de comportement	Verhaltensmodell
	plant-mixed	mélange en centrale	Zentralmischverfahren
	porous asphalt	enrobé drainant, enrobé poreux	Drainasphalt, offenporiger Asphalt
	pot hole	nid de poule	Schlagloch
	precracking	pré-fissuration	gezielte Rißbildung
Q	quality	qualité	Qualität

	quarry	carrière	Steinbruch
R	raveling	arrachement	Kornverlust, Kornausbruch
	reconstruction	reconstruction	Erneuerung
	regulating course	couche de reprofilage	Ausgleichsschicht
	rehabilitation	rehabilitation	Instandsetzung
	response model	modèle de comportement	Beanspruchungsmodell
	resurfacing	rechargement, renouvellement du surface, resurfaçage	Deckschichterneuerung
	rigid layer	couche rigide	starre Schicht
	rigid pavement	chaussée rigide	starrer Oberbau (Beton), Betonstraße
	road trunk road toll road road base (UK) road construction	route route à grand circulation route à péage couche de base construction routière	Straße Hauptverkehrsstraße Mautstraße obere Tragschicht Straßenbau
	road surface	surface de chaussée	Straßenoberfläche, Fahrbahn
	roller	rouleau, cylindre	Walze
	rut	orniére	Spurrinne
	rutting	orniérage	Spurrinnenbildung
	roughness	rugosité	Rauhheit, rauhe Stelle
	roughness	uni	Ebenheit
S	safety fence (guardrail)	glissière de sécurité	Schutzplanke (A: Leitschiene, CH:Leitschranke
	screed	régle (de finisseur)	Bohle, Einbaubohle (Fertiger)
	semi-rigid pavement	chaussée semi-rigide	halbstarrer Oberbau (zement- stabilisierte und Asphaltschichten)
	serviceability	viabilité	Befahrbarkeit
	shoulder	accotement	Bankett
	shoulder	bas-côté	Randstreifen
	single axle	essieu simple	Einzelachse
	skid resistance	adhérence	Griffigkeit
	slab	dalle	Platte
	slope	talus, pente	Böschung
	soil non-cohesive soil stabilized soil soil cement	sol sol non cohésif sol stabilisé sol ciment, sol stabilisé au ciment	Boden nichtbindiger Boden verfestigter Boden mit Bindemittel (Zement) verfestigter Boden

	soil mechanics	mécanique des sols	Bodenmechanik
	specification	specification	Vorschrift, technische Beschreibung
	standard axle	essieu standard	Standardachse
	stiffness	rigidité	Steifigkeit
	stiffness modulus	module de rigidité	Steifigkeitsmodul
	strain	allongement, déformation relative	Dehnung
	strength	résistance	Festigkeit
	strengthening, reinforcement	renforcement	Verstärkung
	stress	contrainte	Spannung
	stripping	désenrobage	Ablösen(ung)
	studded tyres	pneus à clous	Spikesreifen
	subbase	couche de fondation	untere Tragschicht, Frostschutzschicht
	subgrade	sol de fondation, sol support	Untergrund, Unterbau
	surface dressing	enduit superficiel	bituminöse Oberflächen-behandlung
	surfacing	couche de surface	Decke
T	tack coat	couche d'accrochage	bituminöser Haftanstrich, Vorspritzung
	tandem axle	essieu tandem	Tandem- (Doppel)achse
	tensile test	essai de traction	Zugprüfung
	test	essai	Prüfung, Versuch
	total land requirement	emprise	Straßengrund
	traffic flow	flux de trafic	Verkehrsfluß
	traffic lane	voie de circulation	Fahrstreifen
	traffic volume	volume de trafic	Verkehrsstärke
	transverse distribution	distribution transversale	Querverteilung (des Verkehrs)
	transverse profile	profil en travers	Querprofil
	tridem axle	essieu tridem	Dreifachachse
	truck (US)	camion, poids lourd	Lastkraftwagen, LKW
	tyre, tire	pneu	Reifen
	single tire	roue simple	Einzelreifen
	twin tire	roues jumelées	Zwillingsreifen
U	unbound material	matériau non traité, matériau non lié	ungebundenes Material
	unevenness	défaut d'uni	Unebenheit

	transverse	transversal	Quer-
	longitudinal	longitudinal	Längs-
V	voids content	teneur en vides	Hohlraumgehalt
W	wear	usure	Abnützung, Abrieb
	wearing course	couche de roulement	Deckschichte
	weight	poids, charge	Gewicht
	weigh-in-motion (W.I.M)	pesage en marche	Wiegen während der Fahrt
	wheel	roue	Rad
	wheel assembly	roue jumelée	Zwillingsrad
	wheel base	écartement des roues	Radstand
	wheel load	charge par roue	Radlast
	wheel path	frayée, bande de roulement	Radspur
	widening	elargissement	Verbreiterung

Parts of the road | Elements de chaussée | Teile der Straße

total land requirement	emprise	Straßengrund
crown of a carriageway	plate-forme	Straßenkrone
pavement	chaussée	Fahrbahn
traffic lane	voie de circulation	Fahrstreifen
hard shoulder for emergency stop	bande d'arrêt urgence	befestigter Seitenstreifen Standstreifen
shoulder	accotement	Bankett
ditch	fossé	Graben
berm(e)	berme	Berme
central reserve median (US)	terre-plein central (TPC)	Mittelstreifen
slope	talus, pente	Böschung
cycle path (track)	piste cyclable	Radweg
ditch at top of	cunette de	Oberer
slope	crête de talus	Abfanggraben
ditch at foot of	fossé de pied	Unterer
slope	de talus	Abfanggraben
safety fence	glissière de sécurité	Schutzplanke

Structure of the pavement   Structure de la chausseé   Aufbau der Straße

pavement	revêtement (2e sens)	Oberbau
road foundation	corps de la chaussée	Tragschichten (Oberbau ohne Decke)
subgrade	sol de fondation	Unterbau
road surface	surface de la chaussée couche de surface	Fahrbahnoberfläche Decke
surface layer, wearing course	couche de roulement	Deckschichte
binder course	couche de liaison	Binderschicht
road base (UK) base course (US)	couche de base	(obere) Tragschicht
subbase	couche de fondation	untere Tragschicht, Frostschutzschicht
capping layer	couche de forme	verbesserter Unterbau
natural ground	terrain naturel	Untergrund
formation(level)	forme	Planum (Unterbau-)

Appendix 6

Comparison Traditional and RoadCem constructions

1. Introduction

This appendix gives a relative comparison of pavement structure designed using a traditional pavement structure design approach with a pavement structure designed using the RoadCem pavement structure design. The given pavement structures are intended to have equivalent performance with the RoadCem based structure typically requiring less maintenance than the traditionally designed pavement structure.

The examples given are for different soil types and different traffic loads and traffic intensity conditions.

Section 2 of the appendix summariswes the basic design criteria used for all the cases. Section 3 refers to a comparison for unbound (crushed concrete) and bound (BRAC) material and a RoadCem based solution for the case of clay soil, with a bearing capacity of 50 MPa. Section 4 refers to a comparison cases where sandy soils are present. Section 5 refers for heavy duty situations such as exist in harbour terminals.

2. Design Criteria

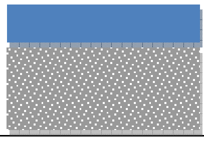
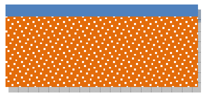
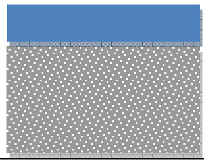
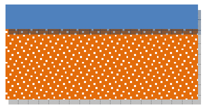
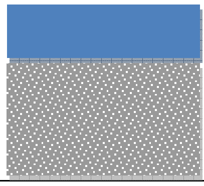
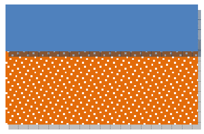
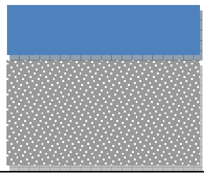
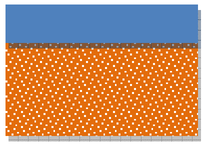
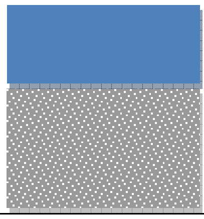
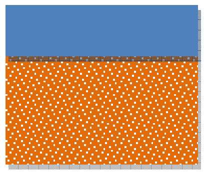
Before the comparison is made between a traditional construction and a PowerCem method it is necessary to determine the design criteria. The design criteria used for the examples given in this appendix are summarised below:

- Bearing strength of the sub-base- the dynamic elasticity modulus, for pavement structures on clay soils the design bearing capacity is 50 MPa, and pavement structures on sandy soils the design bearing capacity is 100 MPa.
- Groundwater level is more than 1 meter below the surface of the pavement.
- Soil structure is homogenous
- Capillarity of the soil and settling behaviour is taken into account for the clay soils.
- Behaviour of the frost/thaw cycle - the examples given assume no frost heave action occurs. In cases where this is not the case additional analysis is needed.
- Maximum load expected on the pavement is the axle load of 100 kN for the roads and for the heavy duty pavement(port terminals) the maximum axle load is 275 kN.
- Axle load configuration(s) of the different vehicles -For the roads and heavy duty pavements four standard wheels are assumed. For the roads it is assumed that the vehicles are double single wheel configurations and for the heavy duty pavements a reach stacker configuration is used.
- Number of axle load repetitions per load are given in the relevant tables.
- Structural lifespan of the pavement is 20 years.
- Tire pressure of the vehicles is 1000 kPa.

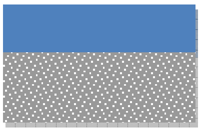
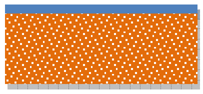
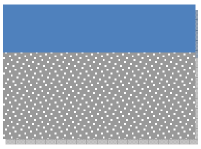
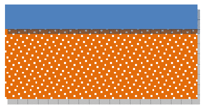
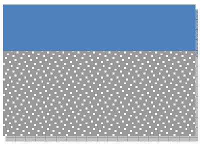
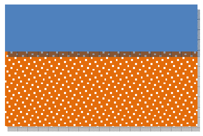
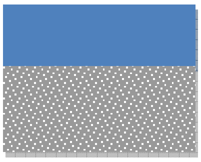
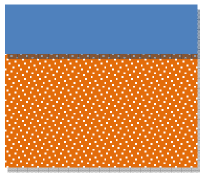
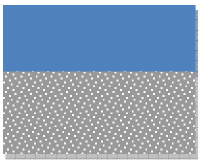
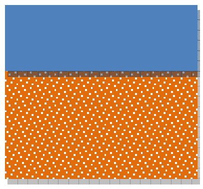
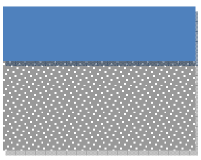
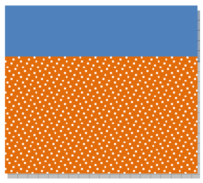
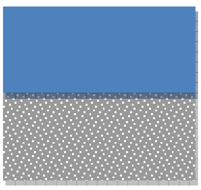
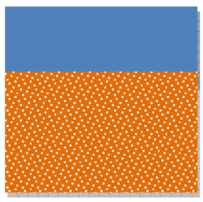
- Weather expectations during construction of the pavement is 15ºC and dry conditions;
- Optimal moisture content for compaction is assumed.
- Required construction equipment is available.
- In-situ material is used (sand or clay).
- Costs for the different materials are location and project specific.
- The required doses of RoadCem are dependent on the soil type and are taken into account. Designs with clay soils assume a value of 3.000 MPa elastic modulus for the RoadCem stabilized layers a the value for viscosity 0,2. For sandy soils the appropriate values assumed are 8.000 MPa for elastic modulus 0.2 for the viscosity.

3. Pavent structures on clay soils with bearing capacity of 50 MPa.

COMPARISON FOR A CONCRETE GRANULAR MATERIAL AND ROADCEM MIXED WITH CLAY.

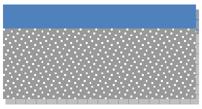
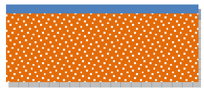
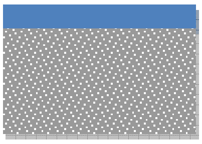
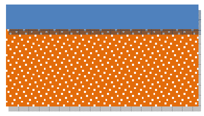
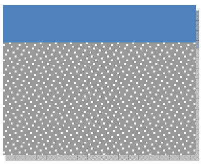
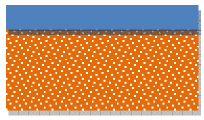
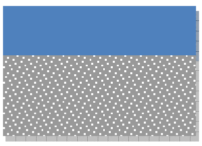
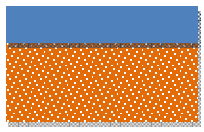
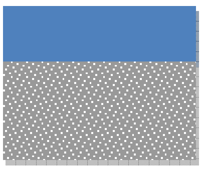
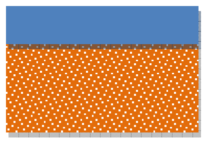
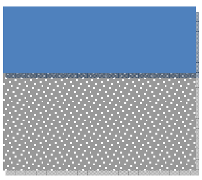
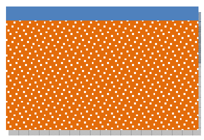
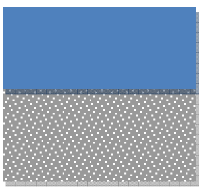
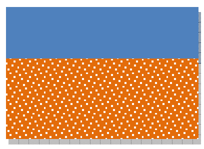
Traffic Load	Traditional construction		RoadCem construction	
2 Trucks a day	80 mm asphalt 300 mm Concrete granular mat.		20 mm chip and spray 200 mm RoadCem layer	
20 Trucks a day	80 mm asphalt 400 mm Concrete granular mat.		40 mm chip asphalt 200 mm RoadCem layer	
60 Trucks a day	100 mm asphalt 400 mm Concrete granular mat.		80 mm asphalt 250 mm RoadCem layer	
250 Trucks a day	140 mm asphalt 400 mm Concrete granular mat.		120 mm asphalt 300 mm RoadCem layer	
700 Trucks a day	190 mm asphalt 400 mm Concrete granular mat.		140 mm asphalt 350 mm RoadCem layer	

Comparison with a bounded BRAC material and RoadCem mixed with clay.

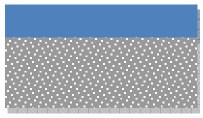
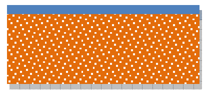
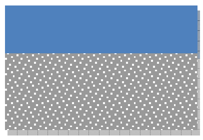
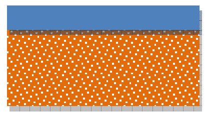
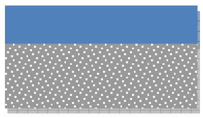
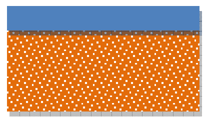
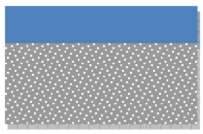
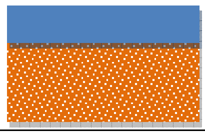
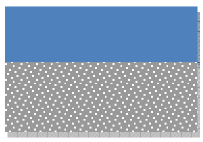
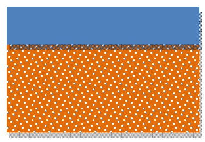
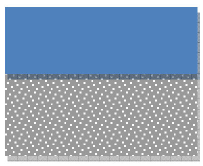
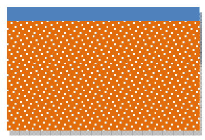
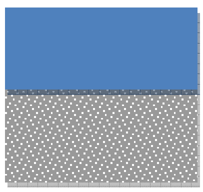
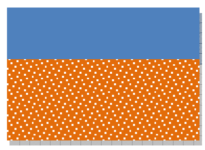
Traffic Load	Traditional construction		RoadCem construction	
2 Trucks a day	100 mm asphalt 250mm BRAC.		20 mm chip and spray 200 mm RoadCem layer	
20 Trucks a day	120 mm asphalt 250 mm BRAC.		40 mm chip asphalt 200 mm RoadCem layer	
60 Trucks a day	120 mm asphalt 250mm BRAC.		80 mm asphalt 250 mm RoadCem layer	
250 Trucks a day	140 mm asphalt 250mm BRAC.		120 mm asphalt 300 mm RoadCem layer	
700 Trucks a day	170 mm asphalt 250mm BRAC.		140 mm asphalt 300 mm RoadCem layer	
1.800 Trucks a day	200 mm asphalt 250mm BRAC.		160 mm asphalt 300 mm RoadCem layer	
4.500 Trucks a day	230 mm asphalt 250mm BRAC.		180 mm asphalt 300 mm RoadCem layer	

4. Pavement structures on sandy soils with bearing capacity of 100 MPa.

COMPARISON WITH A CONCRETE GRANULAR MATERIAL AND ROADCEM MIXED WITH SAND.

Traffic Load	Traditional construction		RoadCem construction	
2 Trucks a day	80 mm asphalt 200 mm Concrete granular mat.		20 mm chip and spray 200 mm RoadCem layer	
20 Trucks a day	80 mm asphalt 200 mm Concrete granular mat.		40 mm asphalt 200 mm RoadCem layer	
60 Trucks a day	100 mm asphalt 200 mm Concrete granular mat.		40 mm asphalt 250 mm RoadCem layer	
250 Trucks a day	140 mm asphalt 300 mm Concrete granular mat.		80 mm asphalt 250 mm RoadCem layer	
700 Trucks a day	180 mm asphalt 300 mm Concrete granular mat.		120 mm asphalt 250 mm RoadCem layer	
1.800 Trucks a day	220 mm asphalt 300 mm Concrete granular mat.		140 mm asphalt 250 mm RoadCem layer	
4.500 Trucks a day	260 mm asphalt 300 mm Concrete granular mat.		180 mm asphalt 250 mm RoadCem layer	

Comparison with a bounded BRAC material and RoadCem mixed with sand.

Traffic Load	Traditional construction		RoadCem construction	
2 Trucks a day	100 mm asphalt 250 mm BRAC.		20 mm chip and spray 200 mm RoadCem layer	
20 Trucks a day	120 mm asphalt 250 mm BRAC.		40 mm asphalt 200 mm RoadCem layer	
60 Trucks a day	120 mm asphalt 250 mm BRAC.		40 mm asphalt 250 mm RoadCem layer	
250 Trucks a day	120 mm asphalt 250 mm BRAC.		80 mm asphalt 250 mm RoadCem layer	
700 Trucks a day	150 mm asphalt 300 mm BRAC.		120 mm asphalt 250 mm RoadCem layer	
1.800 Trucks a day	180 mm asphalt 250 mm BRAC		140 mm asphalt 250 mm RoadCem layer	
4.500 Trucks a day	210 mm asphalt 250 mm BRAC.		180 mm asphalt 250 mm RoadCem layer	

5. Heavy duty pavements

General

In harbours and harbour terminal large wheel loads can occur by the heavy lifting equipment typically used in these facilities. Different pavement structure is therefore necessary to support these loads.

For these pavements mostly a sand cement stabilization foundation is used. In the example that is prescribed in this chapter there is give a traditional construction that is used in the harbor of Rotterdam. Next to this traditional construction a similar construction with RoadCem is calculated.

Design Criteria.

For the design criteria, the same criteria are applicable for the harbor except for the wheel load and the soil type is well graded sand.

The wheel load and the frequents of a typical harbor terminal is given in table B.6.1

Table B.6.1 Wheel load and frequency during the life span of 20 years.

Wheel load kN	N_i	Wheel load kN	N_i
275	444	195	10667
270	444	190	10222
265	444	185	10667
260	1333	180	14222
255	0	175	10222
250	6667	170	9778
245	10667	165	8000
240	22222	160	7556
235	36000	155	4444
230	44000	150	4889
225	31556	145	4444
220	28000	140	97778
215	22667	135	0
210	22222	130	0
205	12444	125	0
200	12444		

The actual designs were verified using flexible pavement design software package BISAR.

Two examples of the calculations carried out is given below. When the Cumulative damage factor, (CDF), is lower than 1 then the the design is assumed not to fulfil the design criteria and the structural demand.

Example 1. Traditional construction

Construction

- 190 mm asphalt.
- 500 mm sand cement stabilization
- Sand.

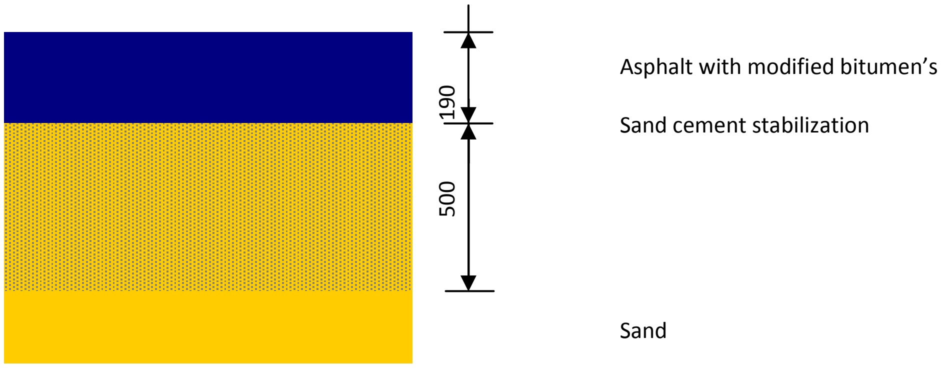


Figure B.6.1 Traditional construction.

Calculation

BISAR was used to calculate the strains are calculated within the design pavement structure and a given loading scenario. When the layers are thinner than the thicknesses given in figure B 6.1 than the CDF factor will be higher than 1 and the construction is not strong enough to have a life span of 20 years.

Wheel load kN	Strain µm/m	AGV %	N_i	n_i	Damage factor N_i/n_i
275	89	0,1	444	56624	0,008
270	88	0,1	444	71992	0,006
265	86	0,1	444	91532	0,005
260	85	0,3	1333	116374	0,011
255	83	0	0	147960	0,000
250	82	1,5	6667	188117	0,035
245	80	2,4	10667	239174	0,045
240	79	5	22222	304089	0,073
235	78	8,1	36000	386621	0,093
230	76	9,9	44000	491554	0,090
225	75	7,1	31556	624967	0,050
220	73	6,3	28000	794590	0,035
215	72	5,1	22667	1010249	0,022
210	70	5	22222	1284441	0,017
205	69	2,8	12444	1633052	0,008
200	67	2,8	12444	2132492	0,006
195	66	2,4	10667	2784678	0,004
190	64	2,3	10222	3636323	0,003
185	63	2,4	10667	4748430	0,002
180	61	3,2	14222	6200654	0,002
175	59	2,3	10222	8097016	0,001
170	58	2,2	9778	10573347	0,001
165	56	1,8	8000	13807021	0,001
160	55	1,7	7556	18029658	0,000
155	53	1	4444	23543715	0,000
150	52	1,1	4889	30744151	0,000
145	50	1	4444	40146714	0,000
140	48	22	97778	52424887	0,002
135	47	0	0	68458125	0,000
130	45	0	0	89394850	0,000
125	43,6	0	0	116734708	0,000
Cumulative Damage Factor, (Sum)					**0,522**

The CDF factor < 1, so this construction is feasible.

RoadCem Construction

Construction

- 150 mm asphalt.
- 300 mm sand cement stabilization with RoadCem.
- Sand.

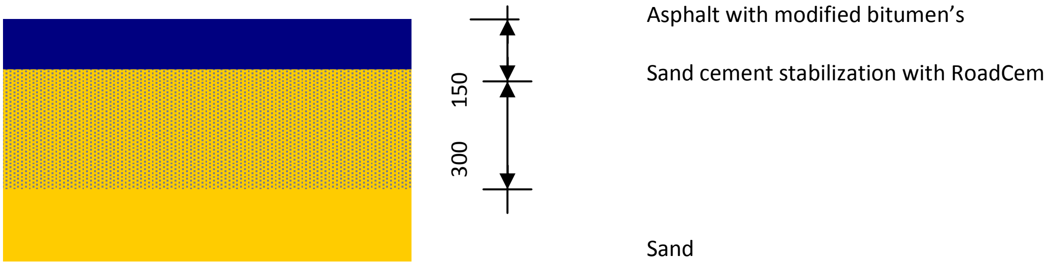


Figure B.6.2 RoadCem construction

Calculation

Wheel load kN	Strain ·m/m	AGV %	N_i	n_i	N_i/n_i
275	130	0,1	444	112294	0,004
270	128,2	0,1	444	125056	0,004
265	126,4	0,1	444	139480	0,003
260	124,6	0,3	1333	155812	0,009
255	122,8	0	0	174337	0,000
250	121	1,5	6667	195388	0,034
245	119,2	2,4	10667	219355	0,049
240	117,4	5	22222	246696	0,090
235	115,6	8,1	36000	277949	0,130
230	113,8	9,9	44000	313749	0,140
225	112	7,1	31556	354844	0,089
220	109,9	6,3	28000	476632	0,059
215	107,8	5,1	22667	554806	0,041
210	105,7	5	22222	647773	0,034
205	103,6	2,8	12444	758721	0,016
200	101,5	2,8	12444	891614	0,014
195	99,4	2,4	10667	1051402	0,010
190	97,3	2,3	10222	1244293	0,008
185	95,2	2,4	10667	1478116	0,007
180	93,1	3,2	14222	1762789	0,008
175	91	2,3	10222	1762789	0,006
170	88,8	2,2	9778	2129374	0,005
165	86,6	1,8	8000	2584413	0,003
160	84,4	1,7	7556	3152364	0,002
155	82,2	1	4444	3865357	0,001
150	80	1,1	4889	4765904	0,001
145	77,8	1	4444	5910681	0,001
140	75,6	22	97778	7375844	0,013
135	73,4	0	0	9264595	0,000
130	71,2	0	0	11718026	0,000
125	69	0	0	14930867	0,000
Cumulative Damage Factor, (Sum)					**0,781**

The CDF factor < 1, so this construction is feasible.

Conclusion

Both design meet the design criteria and structural requirements. The RoadCem based design uses less material and in effect can deliver an equivalent performance at the approximate cost saving of approximately 30- 70 percent depending on the local cost of materials!

Appendix 7
Reference List

Country:	Colombia-San Jose del Guaviare, at the Department of Guaviare	
Year:	1999	
Notes:	Construction: Non paved road 130 mm Stabilized base 1.5 K/m³ RoadCem* 150 Kg/m³ Cement	
Project Nr.	RC.19990102.CO.0003 – Guaviare_department	

Country:	Colombia- Taxi way Kilo Street at Dorado Airport	
Year:	2000	
Notes:	Construction: 0.15 m Asphalt 0.35 m Stabilized base 1.7 K/m³ RoadCem* 170 Kg/m³ Cement	
Project Nr.	RC.20000101.CO.0004 – Taxi_way Guaymaral_Airport	

Country:	Colombia-Tres esquinns-Caqueta-Air force	
Year:	2000	
Notes:	Construction: 0.30 m Stabilized base 1.7 Kg/m³ RoadCem 170 Kg/m³ Cement	
Project Nr.	RC.20010101.CO.0007 – Air Force Tres Esq	

Country:	Colombia-Taxiway Guaymarac airport	
Year:	2000	
Notes:	Construction: 0.07 m Asphalt 0.15 m Stabilized base 1.4 Kg/m^3 RoadCem 140 Kg/m^3 Cement	
Project Nr.	RC.20000101.CO.0004 – Taxi_Guaymaral_Airport	

Country:	England-Great Yarmouth	
Year:	2002	
Notes:	Construction: 0.15 m Asphalt 0.20 m Demolition rubble 0.25 m Stabilized base 1.4 Kg/m^3 RoadCem 140 Kg/m^3 Cement	
Project Nr.	RC.20020301.GB.0008 – Powerbetter – Great Yarmouth 2002	

Country:	Colombia-Puerto Leras-Cruce de Puerto Rico	
Year:	2000-2001	
Notes:	Construction: 15 K m 0.05 m Asphalt 0.15 cm Stabilized base 1.2 K/m^3 RoadCem 120 Kg/m^3 Cement	
Project Nr.	RC.20020501.CO.0009 – Highway_Puerto_lleras	

Country:	Colombia– highway Morales – Puerto Bolivar at the department of Bolívar	
Year:	2004	
Notes:	Construction: 0.05 cm Asphalt 0.15 cm Stabilized base 1.2 K/m^3 RoadCem 120 Kg/m^3 Cement	
Project Nr.	RC.20040101.CO.0015 – Bolivar_highway	

Country:	Netherlands	
Year:	2004	
Notes:	Industrial Road at Rotterdam	
Project Nr.	RC.20040401.NL.0016 – Stoomdepot Rotterdam	

Country:	Netherlands	
Year:	2005	
Notes:	–	
Project Nr.	RC.20050504.NL.0033 – Moerdijk	

Country:	Croatia	
Year:	2005	
Notes:	Construction: 0.25 cm Stabilized base 1.2 Kg/m^3 RoadCem 160 Kg/m^3 Cement	
Project Nr.	RC.20050901.HR.0036 – Forrest road	

Country:	Colombia	
Year:	2006	
Notes:	Construction: 0.16 m Concrete layer 0.25 m Stabilized base 0.20 cm of filler with granular material bellow the stab base 1.2 Kg/m^3 RoadCem 120 Kg/m^3 Cement	
Project Nr.	RC.20060801.CO.0044 – Gas station exit Bogota	

Country:	Mexico	
Year:	2006	
Notes:	–	
Project Nr.	RC.20060801.MX.0045 – Tuxpan Highway	

Country:	Vietnam	
Year:	2006	
Notes:	One layer of chippings Bitumenspray 0.18 m Stabilized base 1.3 Kg/m^3 RoadCem 140 Kg/m^3 Cement	
Project Nr.	RC.20061101.VN.0047 – Mekong Delta	

Country:	South Africa	
Year:	2006	
Notes:	Secondary Road	
Project Nr.	RC.20061101.ZA.0048 – Danie Theron – Fochville	

Country:	Canada	
Year:	2006	
Notes:	–	
Project Nr.	RC.20070301.CA.0051 – Conoco Philips	

Country:	South Africa	
Year:	2007	
Notes:	–	
Project Nr.	RC.20070301.ZA.0053 – Koster Road	

Country:	Germany	
Year:	2007	
Notes:	CITY ROAD FREIBERG CITY	
Project Nr.	RC.20070501.DE.0055 – LSTW – Drei Bruders	

Country:	Canada	
Year:	2007	
Notes:	SHELL OIL DRILLING PLATFORM	
Project Nr.	RC.20070700.CA.0056 – Shell – Pad 14	

Country:	Canada
Year:	2007
Notes:	– 
Project Nr.	RC.20070800.CA.0057- Calgary – City project 80th Ave

Country:	South Africa
Year:	2007
Notes:	Entrance Platinum Mine Rustenburg 
Project Nr.	RC.20071006.ZA.0066 – Rustenburg – Impala Platimum-III

Country:	South Africa
Year:	2007
Notes:	Highway 
Project Nr.	RC.20070901.ZA.0060 – Tzaneen RSA

Country:	Mexico	
Year:	2007	
Notes:	0,30 m Stabilized base 1.4 kg /m3 RoadCem	
Project Nr.	RC.20071001.MX.0061 – Calle La Roca – Reynosa	

Country:	Canada	
Year:	2007	
Notes:	Yard	
Project Nr.	RC.20071101.CA.0067 – Nilex	

Country:	South Africa	
Year:	2007	
Notes:	Secondary road	
Project Nr.	RC.20071107.ZA.0073 – N14 Delareyville	

Country:	Canada	
Year:	2007	
Notes:	–	
Project Nr.	RC.20071201.CA.0075 – Burnco	

Country:	South Africa	
Year:	2007	
Notes:	Secondary road	
Project Nr.	RC.20071203.ZA.0078 – Aquarius Mine Road Project	

Country:	South Africa	
Year:	2007	
Notes:	Secondary road without asphalt	
Project Nr.	RC.20071204.ZA.0079 – Mogaly City – Muldersdrift	

Country:	South Africa	
Year:	2007	
Notes:	Secondary road	
Project Nr.	RC.20071205.ZA.0080 – N14 Delareyville	

Country:	Australia	
Year:	2008	
Notes:	Construction: 0.25 m Stabilized base 1.6 Kg/m³ RoadCem 160 Kg/m³ Cement	
Project Nr.	RC.20080101.AU.0100 – NCI	

Country	South Africa	
Year	2008	
Notes	Intersection	
RC.20080605.SA.0143 – Project Protea South		

Country:	Mexico	
Year:	2008	
Notes:	Parking lot General Motors Local soil turned into a flexible monolithically construction without joints of 100 mm covered by chip and spray	
Project Nr.	RC.20080203.MX.0106- GM - Queretaro - 630.000 m2	

Colofon

Report	RoadCem, the Road to the future
Datum	**September 1st, 2008**
Authors	**P de La Roij** **R de La Roij** **C.E.G. Egyed** **P. Marjanovic**
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PowerCem Technologies B.V.
Plaza 24
4782 SK MOERDIJK
The Netherlands
tel.: +31-168-409440
www.powercem.com