

SOUTH AFRICAN PAVEMENT ENGINEERING MANUAL

Chapter 6

Road Prism and Pavement Investigations



**AN INITIATIVE OF THE SOUTH
AFRICAN NATIONAL ROADS AGENCY SOC LTD**

Date of Issue: October 2014

Second Edition

South African Pavement Engineering Manual
Chapter 6: Road Prism and Pavement Investigations

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Chapter 6

Road Prism and Pavement Investigations



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BACKGROUND

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SCOPE

The South African Pavement Engineering Manual (SAPEM) is a reference manual for all aspects of pavement engineering. SAPEM is a best practice guide. There are many relevant manuals and guidelines available for pavement engineering, which SAPEM does not replace. Rather, SAPEM provides details on these references, and where necessary, provides guidelines on their appropriate use. Where a topic is adequately covered in another guideline, the reference is provided. SAPEM strives to provide explanations of the basic concepts and terminology used in pavement engineering, and provides background information to the concepts and theories commonly used. SAPEM is appropriate for use at National, Provincial and Municipal level, as well as in the Metros. SAPEM is a valuable education and training tool, and is recommended reading for all entry level engineers, technologists and technicians involved in the pavement engineering industry. SAPEM is also useful for practising engineers who would like to access the latest appropriate reference guideline.

SAPEM consists of 14 chapters covering all aspects of pavement engineering. A brief description of each chapter is given below to provide the context for this chapter, Chapter 6.

Chapter 1: Introduction discusses the application of this SAPEM manual, and the institutional responsibilities, statutory requirements, basic principles of roads, the road design life cycle, and planning and time scheduling for pavement engineering projects. A glossary of terms and abbreviations used in all the SAPEM chapters is included in Appendix A. A list of the major references and guidelines for pavement engineering is given in Appendix B.

Chapter 2: Pavement Composition and Behaviour includes typical pavement structures, material characteristics and pavement types, including both flexible and rigid pavements, and surfacings. Typical materials and pavement behaviour are explained. The development of pavement distress, and the functional performance of pavements are discussed. As an introduction, and background for reference with other chapters, the basic principles of mechanics of materials and material science are outlined.

Chapter 3: Materials Testing presents the tests used for all material types used in pavement structures. The tests are briefly described, and reference is made to the test number and where to obtain the full test method. Where possible and applicable, interesting observations or experiences with the tests are mentioned. Chapters 3 and 4 are complementary.

Chapter 4: Standards follows the same format as Chapter 3, but discusses the standards used for the various tests. This includes applicable limits (minimum and maximum values) for test results. Material classification systems are given, as are guidelines on mix and materials composition.

Chapter 5: Laboratory Management covers laboratory quality management, testing personnel, test methods, and the testing environment and equipment. Quality assurance issues, and health, safety and the environment are also discussed.

Chapter 6: Road Prism and Pavement Investigation discusses all aspects of the road prism and the road pavement investigations. The chapter includes the legal and environmental requirements for land access, and the opening of quarries and borrow pits within the road prism. Guidelines for the accommodation of traffic for investigations are given. The road prism investigations include field investigation and sampling methods, and potential problem areas and soils. The road pavement investigations include discussions on the investigation stages, and field testing and sampling (both intrusively and non-intrusively), and the interpretation of the pavement investigations. The phases of investigations are provided, and testing and reporting guidelines given. Chapters 6 and 7 are complementary.

Chapter 7: Geotechnical Investigations and Design Considerations covers the investigations into fills, cuts, structures and tunnels, and includes discussion on geophysical methods, drilling and probing, and stability assessments. Guidelines for the reporting of the investigations are provided.

Chapter 8: Material Sources provides information for sourcing materials from project quarries and borrow pits, commercial materials sources and alternative sources. The legal and environmental requirements for sourcing materials are given. Alternative sources of potential pavement materials are discussed, including recycled pavement materials, construction and demolition waste, slag, fly ash and mine waste.

Chapter 9: Materials Utilisation and Design discusses materials in the roadbed, earthworks (including cuts and fills) and all the pavement layers, including soils and gravels, crushed stones, cementitious materials, primes, stone pre-coating fluids and tack coats, bituminous binders, bitumen stabilized materials, asphalt, spray seals and micro

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surfacing, concrete, proprietary and certified products and block paving. The mix designs of all materials are discussed.

Chapter 10: Pavement Design presents the philosophy of pavement design, methods of estimating design traffic and the pavement design process. Methods of structural capacity estimation for flexible, rigid and concrete block pavements are discussed.

Chapter 11: Documentation and Tendering covers the different forms of contracts typical for road pavement projects; the design, contract and tender documentation; the tender process; and the contract documentation from the tender award to the close-out of the Works.

Chapter 12: Construction Equipment and Method Guidelines presents the nature and requirements of construction equipment and different methods of construction. The construction of trial sections is also discussed. Chapters 12 and 13 are complementary, with Chapter 12 covering the proactive components of road construction, i.e., the method of construction. Chapter 13 covers the reactive components, i.e., checking the construction is done correctly.

Chapter 13: Quality Management includes acceptance control processes, and quality plans. All the pavement layers and the road prism are discussed. The documentation involved in quality management is also discussed, and where applicable, provided.

Chapter 14: Post-Construction incorporates the monitoring of pavements during the service life, the causes and mechanisms of distress, and the concepts of maintenance, rehabilitation and reconstruction.

FEEDBACK

SAPeM is a “living document”. The first edition was made available in electronic format in January 2013, and a second edition in October 2014. Feedback from all interested parties in industry is appreciated, as this will keep SAPeM relevant.

To provide feedback on SAPeM, please email sapem@nra.co.za.

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1. INTRODUCTION

Road prism and road pavement investigations are essential activities carried out prior to construction, to determine the in situ materials and groundwater conditions. This chapter focuses on centre line soil surveys of the roadbed as well as pavement rehabilitation assessments. The investigations described in this chapter primarily involve shallow test pitting, but also include pits and auger holes up to 3 metres deep, to determine the depth of expansive clays and other problem soils.

Chapter 7 covers specialised and deeper geotechnical investigations such as those required for deep cuts, embankments, structures and tunnels. Such investigations normally involve rotary core drilling and related testing. They often follow after centre line surveys, using the information obtained from test pits to assist in planning.

Chapter 6 and Chapter 7 are complementary, and, in many cases, the same information could be included in both chapters. However, to limit duplicating information, topics are only included in one chapter. Therefore, both chapters should be referred to for geotechnical investigations.

Road prism and pavement investigations must be sufficiently comprehensive to enable the identification of features that may affect the construction or in situ performance of planned works. They must be carried out with proper planning and foresight by professional and experienced persons or institutions.

Some typical problems that may arise due to inadequate investigations of the **roadbed** include:

- Unforeseen areas over which the **roadbed is unsuitable** as a support for the pavement.
- Weak areas on top of which the pavement layers cannot be compacted.
- Unforeseen areas with shallow, hard rock that require special attention in respect of the pavement and drainage construction.

Some typical problems that may arise due to inadequate pavement rehabilitation assessments include:

- **Weak areas** that are not catered for sufficiently in the rehabilitation design.
- **Overdesign** of rehabilitation measures over stronger areas.
- The **undetected occurrence of poor quality materials**, which are unsuitable for use in the pavement layer for which they are destined.

This chapter is intended to provide guidance to prevent these occurrences.

1.1 Definitions

The following terminology is frequently used in this chapter:

- **Road reserve.** The proclaimed area reserved for a road, typically from fence to fence.
- **Road prism.** The portion of cross section of the road that is shaped for the road. It includes cuts and fills, as well as side drains and the roadbed.
- **Roadbed.** The natural in situ material on which the embankment, or in the absence of any embankment, any pavement layers exist, or are to be constructed.
- **Road pavement** comprises the combination of individually constructed layers designed to carry the structural loading and to provide the desired performance characteristics. It includes the selected subgrade layer(s), subbase layer(s), base and surfacing or wearing course. It may include some fill or in situ layers where these have adequate material properties.
- **Subgrade** describes the completed earthworks within the road prism on which the pavement layers are constructed. The subgrade can include in situ material of the roadbed or fill material.
- **Materials depth** describes the thickness or depth below the final road level of the road pavement where the material characteristics have a significant effect on the road pavement behaviour, and the minimum depth within which the material CBR value should be $\geq 3\%$ at the in situ density. Below this depth, the strength and density of the materials are assumed to have a negligible effect on the road pavement's performance.



Chapters 6 and 7

Chapter 6 and Chapter 7 are complementary, and, in many cases, the same information could be included in both chapters. However, to limit duplicating information, topics are only included in one chapter. Therefore, both chapters should be referred to for geotechnical investigations.

1.2 Scope

This chapter includes:

- Required **Competencies** for road prism investigations and pavement assessments.
- An **overview of legislation** covering legal and environmental requirements pertinent to the planning and execution of road prism and road pavement investigations.
- **Traffic accommodation** whilst conducting the road prism and road pavement investigations.
- **Road prism investigations**
- **Problem roadbed materials**
- **Road pavement assessments**
- **Materials testing for investigations**
- Guidelines for the **reporting on the findings** of the investigations and the resulting recommendations.

The appendices contain the following:

- Appendix A: **Soil Profiling** of Test Pits and Auger Holes
- Appendix B: **Rock Profiling** of Cores, Test Pits or Quarry Faces
- Appendix C: Examples of **Special Roadbed Treatment** Types



Greenfields Projects

A greenfields project is where no facility exists and a new facility will be provided.

2. REQUIRED COMPETENCIES

Where consulting engineering companies have been appointed for works, most road authorities require that such firms have in their employment, or shall procure, the services of a professionally registered engineer(s) who specialises in materials and pavement engineering. In this manual, this engineer is referred to as the materials engineer or pavement engineer. This engineer should be sufficiently knowledgeable and well versed in materials investigation and design activities to take leadership and responsibility of these activities. It is expected that such a person will be up to date with the particular requirements of the various client(s) regarding all aspects pertinent to this field and similarly to new developments. This engineer's responsibilities include:

- **Planning** of various investigations and tailoring them to the specific project.
- **Manage** the various participants in the project.
- **Appropriate geotechnical or related complex investigations are carried out** where required, as set out in Chapter 7 of this manual.
- The provisions of this **manual and best practice are followed** by the various participants, who may be in house staff or independent service providers appointed to carry out one or more of the activities. For example, specialist civil materials laboratories and their materials investigation and testing staff.
- **Planning the investigation and testing programme** to ensure high levels of confidence in the outputs, and that the sampling and testing programme is commensurate with the consequential risks.
- **Assessment of material quality and interpretation of information** and test data from the investigations.
- **Selection and design** of materials, treatments and other related engineering activities to suit the reigning environment and to meet the performance requirements.
- **Assessment of options** and making recommendations on the most suitable or appropriate option.
- **Compilation** of the necessary design reports, drawings and project documents.
- **Work in close liaison** with other members of the design team to deliver an adequate and economical design. For example, geometric and structural designers.

In most cases, the individuals involved in such an investigation are registered with the relevant statutory councils and appropriate specialist branches of institutions, and have experience commensurate with the complexities of the particular project. Table 1 gives the typical registration and affiliation requirements.

Table 1. Registration and Affiliation Requirements

Discipline	Registering Authority	Affiliation
Geotechnical engineer	ECSA ¹	SAICE ³ Geotechnical Division or Construction Division
Materials or pavement engineer	ECSA	SAICE Transportation Division or Geotechnical Division
Engineering geologist	SACNASP ²	SAIEG ⁴
Geohydrologist	SACNASP	SA Groundwater Association
Engineering technologist	ECSA	SAICE Geotechnical Division or Construction Division
Engineering technician	ECSA	SAICE Geotechnical Division or Construction Division

Note

1. ECSA is the Engineering Council of South Africa
2. SACNASP is the South African Council for Natural Science Professions
3. SAICE is the South African Institute of Civil Engineers
4. SAIEG is the South African Institution for Engineering and Environmental Geologists

As the visual and physical assessment of materials forming part of an existing pavement is equally as important as the sampling and testing and related results, it is essential that the materials engineer attend the excavation of each test pit in an existing pavement. The logging of test pits should only be carried out by personnel that have the requisite training and experience.

3. LEGAL AND ENVIRONMENTAL REQUIREMENTS

This section provides the information required by practitioners on Legal and Environmental requirements, which govern the process of materials investigations for road construction. Chapter 8, Materials Sources, covers the sourcing of materials from borrow pits and quarries, and the associated environmental and legal requirements in much more detail.

Road authorities undertake surface mining operations to provide essential gravel and rock material for road construction and maintenance. Gravel, rock and processed/crushed rock are essential materials for road building purposes. The gravel and rock are obtained from:

- Excavations within the **road reserve**, which is the preference.
- Excavations of **borrow pits and/or quarries** outside the road reserve. Materials for borrow pits are usually excavated by mechanical means, whereas quarries require drilling and blasting to excavate the materials.
- **Commercial sources** (if financially viable).

During the design stage of a project, consulting engineers investigate the availability of rock and gravel materials in close proximity to the project. Should commercial sources not be readily available, or be financially unviable for the project, investigations are undertaken to obtain rock/gravel in close proximity to the project. Should suitable gravel or rock material be found, the necessary application procedures in terms of the Mineral and Petroleum Resources Development Act (MPRDA), No. 28 of 2002, as administered by the Department of Mineral Resources (DMR), are applicable, prior to mining the material.

Obtaining materials from sources, other than from within the road reserve, is covered in detail in Chapter 8.

3.1 Permit Exemptions

SANRAL and the provincial-road authorities are exempt from the provisions of sections 16, 20, 22 and 27 of the MPRDA (application of a prospecting right, permission to remove and dispose of minerals, application of a mining right and application of a mining permit) in terms of section 106. Therefore, no application needs to be submitted to the DMR for prospecting, reconnaissance, mining permit or mining right. However, according to the provisions of Section 106(2) of the Act, prior to the extraction of any material from a proposed borrow pit or quarry, the road authority is still be required to prepare and submit an EMP or EMPProg to DME for their approval. See Chapter 8 for more details.

Should materials be sourced from within the road reserve, and be required for further processing, such as crushing, for use within the pavement, then a mining right may be required and the processes outlined in Chapter 8 must be followed. Where materials from the road are not processed and are used in fills or higher pavement layers, no mining rights need to be obtained. However, the necessary environmental approvals must be obtained to develop the cut and embankment.

3.2 Entry Upon Land

Most road authorities have legislation (National), regulations (National), ordinances (Provincial) or by-laws (Municipal) that facilitate the entry onto land for the purposes of assessing road centre lines and related borrow pit investigations. For example, the South African National Roads Agency Limited and National Roads Act (Act 7 of 1998) makes provision (Clause 43) for a member or employee of the Agency, or other person authorised in writing, to enter onto land with the necessary workers, machines and equipment to carry out, on or below the surface, any investigation, survey or any other act, with the written permission of the owner.

Where such entry has been refused, the act makes provision for the Agency to apply to the High Court in that area of jurisdiction for the issuing of a court order. The Court will authorise entry upon that



Chapter 8: Materials Sources

Chapter 8, covers the sourcing of materials from borrow pits and quarries, and the associated environmental and legal requirements in detail.



Exemptions

SANRAL and the provincial road authorities are exempt from applying to the DMR for prospecting, reconnaissance, mining permit or mining right. However, they are not exempt from all the environmental requirements for opening borrow pits or quarries.



Entry Upon Land

Written permission from the owner of the land is required before land can be entered for any investigations. If permission is not forthcoming, a High Court order must be obtained.

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land if satisfied that entry is necessary and justifiable in the circumstances. Such entry will normally exclude any dwelling or building used for residential purposes and will specify the purpose of entry, the acts to be carried out and how they will be performed.

Therefore, all necessary authorisations must be obtained prior to embarking upon any investigations requiring entry upon privately owned land, and all other requirements and conditions must be met.

3.3 Compensation for Damages

The Road Authority must repair or pay for any damage arising from any act performed by it or on its behalf.

3.4 Acquisition of Materials and/or Land

Where materials such as rock, stone, gravel, sand or clay are required for works or other purposes connected with a public road, the Agency or Road Authority is obliged to pay compensation to the land owner. Where the Minister or MEC is satisfied that the Agency or Road Authority is unable to acquire the land, or such use of materials as it may require, by agreement with the landowner or the holder of the relevant right, expropriation of such land or portion thereof may be considered in exceptional circumstances. This is covered in more detail in Chapter 8.



EIA Regulations

The National Department of Environment Affairs is in the process of amending the EIA Regulations, 2006. It is anticipated that the environmental studies associated with borrow pits/quarries will be included in the new regulations to be promulgated.



Abbreviations Used

DEA	Department of Environmental Affairs
DMR	Department of Mineral Resources
EAP	Environmental Assessment Practitioner
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EMProg	Environmental Management Programme
MPRDA	Mineral and Petroleum Resources Development Act, 2002 (Act No. 28 of 2002) (MPRDA)

4. TRAFFIC ACCOMMODATION FOR INVESTIGATIONS

Pavement investigations on existing roads or investigations in the road reserve of an existing road are disruptive to normal traffic flow, albeit a temporary disruption. The road user needs to be informed of this temporary condition, which is potentially more dangerous than the many other longer term hazards along a road. The best way of informing the road user is with a sequence of temporary signs along the traffic control zone or area. Typical traffic control zone scenarios, with sign layouts for different conditions, are described in the South African Roads Traffic Signs Manual, Volume 2, Chapter 13, Roadworks Signing (SADC, 1993), the cover of which is shown in Figure 1.

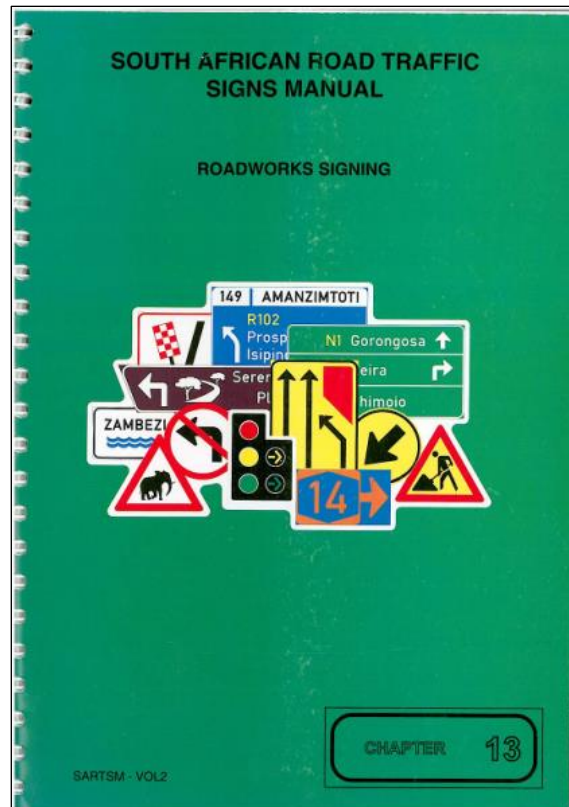


Figure 1. Road Traffic Signs Manual

This section only deals with the accommodation of traffic for investigations on, or adjacent to single, dual carriageway and urban roads. Road prism investigations for new (greenfield) projects normally require limited traffic accommodation measures.

The primary reason for temporary traffic accommodation is the ultimate safety of the road user and the workers in the work zone. It is therefore very important to thoroughly plan the pavement, or any other investigation, in the road reserve.

4.1 Planning the Investigations

In planning the investigation, cognisance should be taken of the following:

- **Pre-determine the number and position of testing positions**, test pits or slot excavations required. The traffic accommodation layout should coincide with the number and position of test pits or slot excavations, which in turn is determined from the pavement condition survey.
- A **traffic accommodation layout proposal** needs to be prepared in terms of Chapter 13 of SARTSM, for discussion with the road authorities.
- No test pit or slot excavation within the road prism may be left open **overnight**. This includes test pits on the side slopes of cuts and embankments, and in side drains.
- Supplying, erecting and moving/removing the traffic accommodation **temporary signage** must be planned and arranged in advance. This may be the responsibility of the consulting engineers appointed for the works, the

investigation laboratory or the routine road maintenance contractor. The routine road maintenance contractor is normally best equipped for this task. Irrespective of who supplies the temporary signage, the responsibility for the traffic accommodation remains with the appointed consultants, or with the organisation itself if the works are carried out in-house.

- All persons entering/working in the work zone shall wear **bright, highly visible clothing** and approved safety jackets.
- Suitable signs, equipment and all the materials required to properly **excavate and backfill the excavations** after profiling and sampling shall be available before closing the road/area to traffic, to keep traffic disruptions to a minimum.
- **Local Law Enforcement Officers** need to be contacted in advance, and provided with the proposed traffic accommodation layout plans.
- The Road Authorities, Route Managers and Local Law Enforcement Authorities need to be provided with the **proposed working plan**, i.e., method statement detailing dates, working hours, durations and locations. Days and times that are less disruptive for traffic need to be selected, i.e., avoid peak hours.
- Where **long term investigations**, such as geotechnical investigations, are planned, temporary (< 9 hours) or even longer, shoulder and/or lane closures may be needed to control traffic movements around the working areas. Such works are generally treated as special cases and each requires a method statement regarding traffic accommodation for prior approval by the relevant authority.
- All activities need to be planned and executed to be **environmentally sensitive**. For example:
 - Only reheat or mix materials in designated areas.
 - Ensure that excess excavation material, asphalt or emulsion, or any other treated materials, are disposed of in approved sites and not in the road reserve or on private property.
 - Materials, plant or equipment are not placed on walkways or sidewalks.

4.2 Providing Traffic Accommodation

In providing traffic accommodation for investigations on both rural single and dual carriageway roads and urban roads, the following must be adhered to:

- The traffic accommodation is **properly planned and organised**.
- Contact the **local law enforcement officers** for assistance with lane closures. On high volume trafficked roads, the local law enforcement officers are expected to assist with lane closures.
- Ensure that the **temporary traffic signs** are erected in terms of the approved layout plan as per SARTSM requirements. The SARTSM **layout plans** may need to be modified for the specific site conditions. Alternatively, use the Safety Measures at Roadworks Short Term Work Zones issued by the City of Cape Town (2003), or such guidelines as may be specified by the relevant road authority.
- Check that the longitudinal, lateral and vertical temporary sign layouts take cognisance of the road alignment with regard to **sight distance and visibility**.
- Use only **flag persons** that have sufficient training. The flags used and clothing worn must comply with SARTSM requirements.
- People working in the working zone should never work with their **backs to the traffic**.
- In rural areas, all **excavations within the road prism** may not be left open during the night. Unattended excavations left open during the day must also be properly demarcated. In urban areas, no excavations may be left unattended and all must be **backfilled the same day**. Where this is not possible, they should be covered with suitable steel plates or strong timber, such as scaffolding planks, to prevent persons or animals falling in.
- **Backfilling requirements** require that the resulting surface be smooth and carry traffic equal to that being carried by the existing pavement and at the same level of service. Use only material from the excavation or materials of better quality for backfilling. In backfilling **test pits**, materials from each individual road pavement layer may be used in the same position and should be compacted to the required density. Shortfalls in material must be made up with materials of similar type and/or better quality. Some authorities specify the use of new materials for the **backfilling of base layers**. The backfilling should be done according to the requirements in Section 7.4.4.
- The work zone must be **barricaded** off if there is a danger of injury to pedestrians, particularly in urban areas.
- For single carriageways, if the traffic volumes are **less than 500 vehicles per hour**, use STOP/RV-GO controls with radio operation for lane closures. The operators need to be adequately trained beforehand. If the traffic volumes **exceed 500 vehicles per hour**, the cost of the traffic signals could be prohibitively expensive, and the



Leaving Test Pits Open

No test pits or slot excavations may be left open overnight. This includes areas in cuts, fills and side drains.

possibility of doing to work over a weekend or a night time should be investigated.

- Where test pits and slots are **excavated on surfaced roads**, the surfacing needs to be reinstated with either hot or cold mix asphalt, see Section 7.4.4 for details. A light application of bituminous emulsion is useful to ensure the placed asphalt is watertight.
- To prevent early deformation, ensure all **newly placed hot mix asphalt** has reached ambient temperature before opening to traffic. High air temperatures extend cooling off times.
- Accommodating traffic on **surfaced shoulders**, which have not carried traffic for years, may result in shoulder pavement failures.
- All temporary signage must be removed and/or closed if **zero activity** is taking place. Do not confuse the road user!

When carrying out inspections, or marking defects on the road surface of high volume traffic roads, it is recommended that vehicles with appropriate signage are used to guide the traffic. An example is given in Figure 2.



Signage

Do not confuse the Road User!



Figure 2. Example of Visible Signage on Construction Vehicle

5. ROAD PRISM INVESTIGATIONS

The investigations described in this section are pertinent to both “greenfields” or new road projects, as well as projects involving the widening of existing road cuts and embankments.

The need for a new road (greenfields project) typically arises from strategic, social or economic considerations. The project generally proceeds through feasibility, route location, preliminary design and detailed design stages, before approvals and decisions are made whether to proceed with construction. A systematic phased or staged approach, tailored to meet the requirements of each stage, is therefore required. Road prism investigations, in most circumstances comprise:

- **Desk study** and **site reconnaissance**
- **Preliminary** site investigation
- **Detailed** site investigation



Road Prism Investigations

Road prism investigations are part of the family of activities that together encompass the materials investigation and design phase of a new or widened road.

Table 2 illustrates the linkage between the staged investigations and the stages normally followed in the provision of a new road, or the widening of an existing road.

Table 2. Road Prism Investigation Stages

Stage	Generally Includes	Provides Input To
1. Desk Study and Site Reconnaissance	• Assembly of all available site relevant information. • Soils engineering map and terrain evaluation reports. • Aerial and ortho photographs. • Site reconnaissance and reports on observations. • Interpretation of information collected, compilation of needs assessment for preliminary site investigation.	Route location
2. Preliminary Site Investigation	• Establish materials, geological and geohydrological characteristics, which affect the geometric and preliminary materials design. • Limited test pitting, drilling of boreholes, sampling and in situ and laboratory testing. • Interpretation of information collected, needs assessment for the detailed site investigation.	Preliminary Materials Report, which precedes the Basic Planning Report
3. Detailed Site Investigation	• Extensive field investigations with test pitting sampling, in situ and laboratory testing • Where problem areas are identified, specialist execution of sophisticated investigation and testing may be required. • Drilling of boreholes and the evaluation and design of project specific geotechnical measures to ensure performance and safety standards are met, may be initiated at this stage, following the guidelines set out in Chapter 7. Alternatively, such investigations may be initiated once the centre line survey is completed and relevant information that may affect the scope and detail of the geotechnical investigation is available.	Detailed Materials Design Report, and Materials and Geotechnical Volume of Road Contract Documentation

Ancillary studies are sometimes carried out prior to, or parallel with, road prism investigations and include feasibility studies and reports, and the compilation of geotechnical and/or soil engineering maps. Feasibility studies are often carried out before embarking on physical investigations. However, these can, by their very nature, be commissioned at any one of the stages listed in Table 2 as costs or obstacles are identified, or when changes arise from the initial needs identification.

In certain circumstances, the client may commission the preparation of a geotechnical map during the route location phase, where problems of this nature are apparent. In broad terms, this generally entails a study of the corridor in which the road has provisionally been located, which comments on issues such as land use, surface geology, soil stability and other geotechnical issues, the availability of construction materials, and hydrological and environmental issues. Motivations for and against proposed alignments are usually also included.

A soil engineering map assists with the location of suitable construction materials sources, indicating favourable and unfavourable subgrade conditions along alternative alignments and defining problem areas. TRH2 provides guidelines for such studies, which are generally carried out by consulting engineering geologists.

The development of soil engineering maps and geotechnical maps generally parallels the preliminary and detailed materials investigations. Their usefulness has largely been negated by the availability of GIS data and commissioning specialist geotechnical engineers that have engineering geologists at their disposal on larger projects.



Structures, Tunnels, Cuts and Fills

The investigations for structures, road tunnels, cuts and fills are addressed in Chapter 7: **Geotechnical Investigations and Design**, in the following sections:

- **Embankments**, Section 4
- **Cuts**, Section 5
- **Structures**, Section 7
- **Tunnels**, Section 8

In broad terms, the primary objectives of the road prism investigation are to:

- Assess the **general suitability** of the site and environs for the proposed works.
- Provide information on **in situ conditions** for designers to create appropriate cost-effective new facilities, repairs or upgrades.
- Foresee **potential difficulties** and risks and identify and provide solutions to **problem areas**.
- Identify appropriate **methods of construction**.
- Provide information essential to the choice of **horizontal and vertical alignment**.
- Provide information for the **adequate and economic design** of the road.
- Optimise **materials utilisation** available within the road prism.
- Minimize the **environmental** impact.

5.1 Planning of Investigations

In planning road prism investigations for a particular project, the age old adage "*horses for courses*" applies. For example, with an urban road, following natural ground levels generally suffices. Limited test pitting, sampling and testing of materials to confirm general conformity with previously encountered conditions and experience is likely to be sufficient. However, for a road with unknown subgrade conditions, a more detailed depth investigation is required, especially where cuts and embankments are to be constructed. In many areas of the country, such as in the Karoo, quite uniform conditions exist and a smaller number of test pits and boreholes are necessary than in areas with more diverse conditions. A major rural freeway in rolling or rugged topography, possibly traversing different geological formations and landforms, require specialised investigatory techniques and sophisticated field and laboratory testing of materials, to find the optimal solution to the identified challenges.

Specialist geotechnical input may be required where complex geotechnical problem areas are encountered. Specialised geotechnical input in the context of this manual refers to the services of a competent geotechnical engineer who meets the requirements given in Section 2.

The following circumstances may also warrant the appointment of a specialist geotechnical engineer and/or engineering geologist to provide investigation and design assistance to the geotechnical engineer/materials engineer:

- Where the road traverses **dolomitic formations**.
- Where the road traverses **landfills and undermined areas**.
- Where problem subgrades, such as **deep alluvial deposits, highly expansive** or **highly compressible materials**, exist below embankments and are of such extent that they cannot be economically removed or dealt with by conventional engineering methods.
- Where adverse geological conditions in cuttings require special measures to **resist erosion and/or weathering**.
- Where natural slopes show signs of **instability or creep**.

The specialist geotechnical engineer, in most circumstances, adopts a similarly staged investigation up to the level required for the particular project. Furthermore, the specialist's requirements with regard to the various investigatory actions should, wherever possible, be integrated with those of the geotechnical engineer to avoid unnecessary parallel investigations. Obviously, the specialist needs to oversee the necessary works.

The need for specialised geotechnical input may be apparent at the route location stage of the road design process, should the planned alignment traverse known problematic features such as dolomitic formations or landfill sites. In

general, however, such needs are often only apparent after the Stage 1 Investigations: Desk Study and Reconnaissance, or after Stage 2 Investigations: Preliminary Site Investigations.

The flowchart in Figure 3 illustrates the interaction between the role players through the design stages of a typical project.

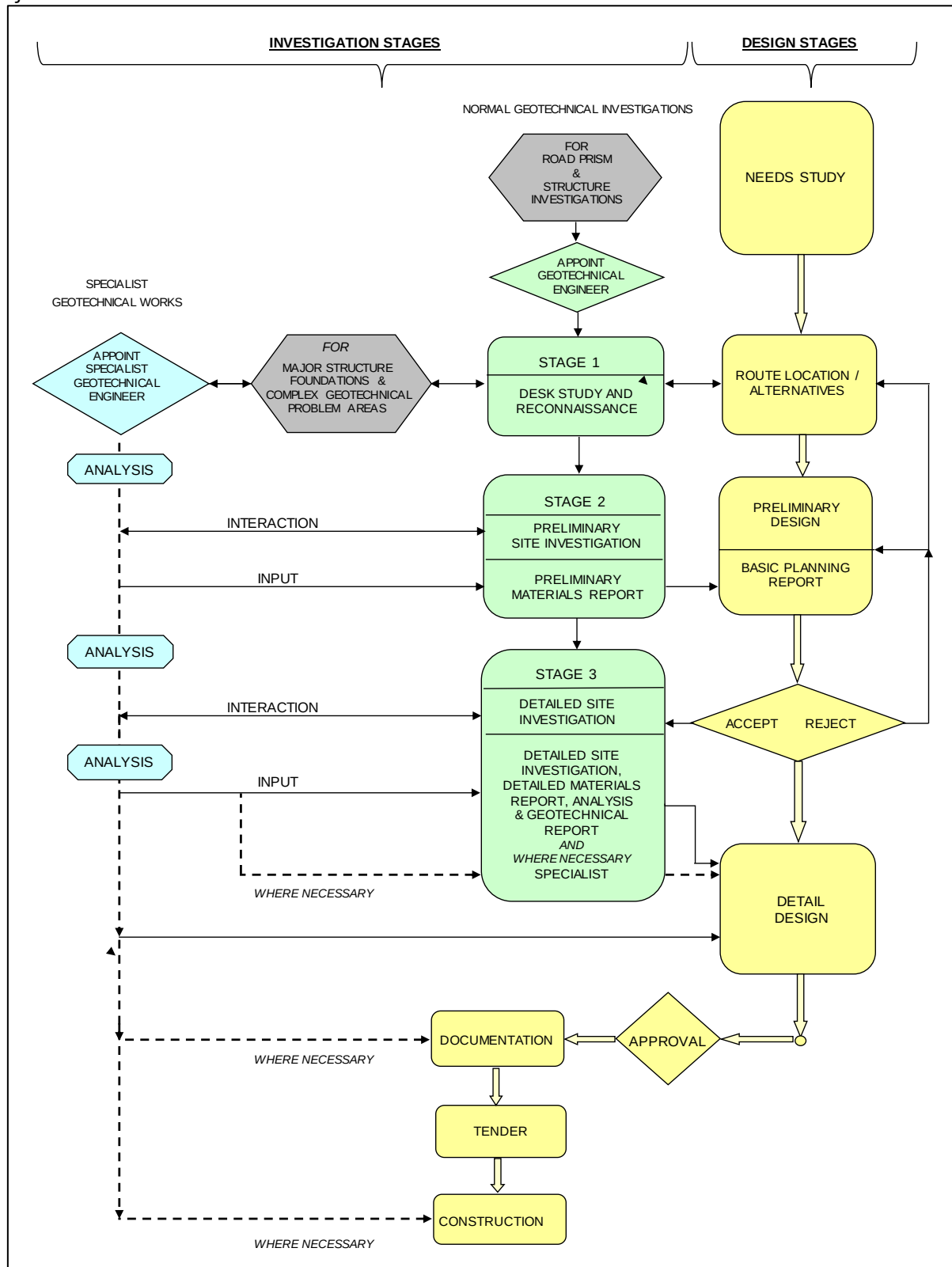


Figure 3. Typical Flowchart for Road Prism and Specialist Geotechnical Investigations

5.2 Field Investigation and Sampling Methods

The following methods are commonly used in road prism investigations:

- Profiling of soils and rocks
- Test pitting
- Geophysical testing
- Drilling and Probing

Only profiling and test pitting are covered in this chapter while geophysical testing and drilling are covered in Chapter 7: 3.2.



Profiling of Soils and Rocks

See Appendix A of profiling of soils and Appendix B for profiling of rocks.

5.2.1 Profiling of Soils and Rocks

These engineering properties of soils are important:

- **Strength**, which affects the ultimate bearing capacity or resistance to shear.
- **Volumetric change**, which affects possible distortion of the structure or support.
- **Permeability**, which influences rates of drainage affecting both strength and volume.

Reliable, systematic and uniform description of soils and rocks as they are encountered in the field provides a first assessment of the engineering properties. The soil or rock profile is a record of the vertical succession of soils and rocks as encountered at a particular location where each stratum is described in terms of defined properties. A typical core box is illustrated in Figure 4. Appendices A and B of this chapter cover the profiling of soils and rocks, respectively.

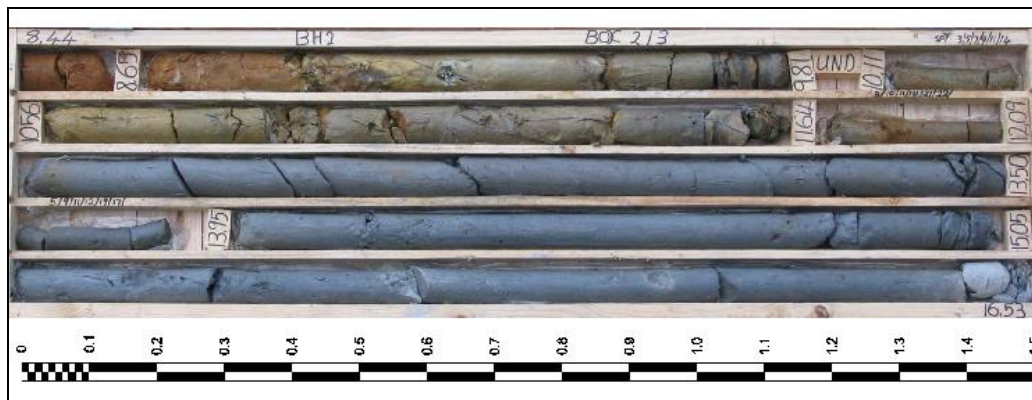


Figure 4. Core Box

5.2.2 Drilling and Probing

Various drilling and probing techniques are available for road prism investigations including:

- **Auger drilling.** This is essentially a large screw, which is driven into the ground, bringing up the material on its screw blade. It is illustrated in Figure 5.
- **Wash boring.** This technique is generally used to determine the depth of rock heads in loose fine grained granular soils (silts and sands). A casing, fitted with a casing shoe, is driven through the material as water is pumped to the bottom of the hole to flush out the cuttings. Hence, the term, wash samples.
- **Rotary percussion drilling.** An air driven hammer action on the drill rod tip breaks the rock. The air blows out the dust and chippings. A crawler mounted percussion drill is illustrated in Figure 6, where the drill is being used to install a rockbolt. The action is the same for drilling and probing.
- **Rotary core drilling.** Core holes are drilled using a core barrel fitted with a diamond tipped or impregnated crown. Rotary core drilling rigs can be either skid or truck mounted. Rotary core drilling allows extraction of intact soils or rock samples.
- **Cone penetration testing (CPT or Dutch Probe).** An instrumented cone is pushed into the ground at a controlled rate, as illustrated in Figure 7. The penetration rate is generally controlled between 1.5 and 2.5 cm/s. Many cone tips are now equipped with a pressure transducer to measure pore pressures. With this test, without having to calculate intermediate engineering parameters, direct estimations of certain design parameters can be determined:

- Safe bearing capacity and settlement for footings and rafts on clay and sand
- Ultimate end bearing, shaft resistance and settlement for driven piles in sand
- Other applications include assessment of pile driveability, assessment of excess pore pressure regime and establishing flow net details.
- **SPT.** The test consists of driving a standard thin walled sampler into soil at selected horizons in a borehole using repeated blows of a 63.5 kg hammer falling through a fixed height (760 mm). The SPT “N value” is the number of blows required to achieve a penetration of 300 mm. The test provides an indication of the density and compressibility of granular soils, and checks the consistency of stiff or stony cohesive soils and even weak rocks. The test is routinely carried out in exploratory drilling.

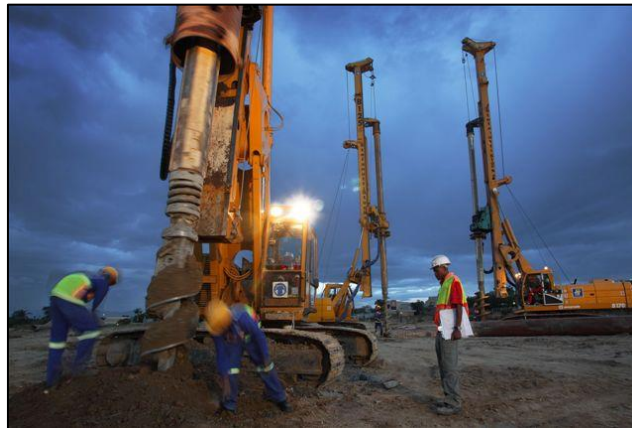


Figure 5. Auger Drilling



Figure 6. Percussion Drilling



Figure 7. Cone Penetration Test

5.2.2.1 Standard Symbols for Describing Soils and Rocks

The standard symbols for describing soils and rocks are given in Figure 8 and Figure 9, taken from Franki, 1995.

	Gravel		Gravelly
	Sand		Sandy
	Silt		Silty
	Clay		Clayey
	Ferricrete		Ferruginised
	Calcrete		Calcrete Nodules
	Silcrete		Silcrete Nodules
	Made Ground		Shattered Clay
	Permanent Water Table		Fissured and/or Slickensided Clay
	Perched Water Table		

Figure 8. Standard Symbols for Soil Profiles

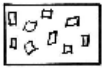
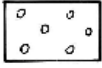
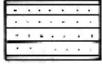
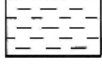
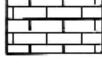
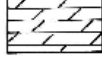
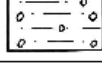
Sedimentary Rocks		Igneous Rock	
	Breccia	Plutonic	
	Conglomerate		Granite, Gabbro, Diorite, Norite
	Sandstone	Hyperbyssal	
	Siltstone		Syenite, Diabase, Dolerite
	Mudstone	Volcanic	
	Shale		Andesite, Rhyolite, Basalt
	Limestone	Metamorphic Rocks	
	Dolomite		Quartzite
	Peat		Schist
	Tillite		Slate
			Gneiss, Hornfels and other metamorphic rocks

Figure 9. Standard Symbols for Profiling Rocks

5.2.3 Test Pits

Test pits enable the assessment of in situ materials and groundwater conditions by profiling of the various soil and rock layers, and enabling both disturbed and undisturbed samples (block samples) to be taken for laboratory testing. Sample size should be concordant with the testing envisaged. Refer to TMH5 for guidelines on sampling materials.

In situ testing such as density determinations or specialised geotechnical tests, see Chapter 7, must be carried out by personnel skilled in these methods.

Section 4 of Appendix A of this chapter, contains extensive discussion and details on the excavation of test pits and the associated materials identification.

The purpose of classifying the soils and rocks encountered during site exploration is to provide an accepted, consistent, concise, and systematic internationally accepted method of describing the various types of materials present to enable useful conclusions to be drawn therefrom. It is of primary importance that the following aspects are adequately described:

- **Moisture/water**, which affects the material's entire behaviour
- **Strength**, which affects stability and ultimate bearing capacity
- **Volumetric change**, which affects possible distortion of the structure
- **Permeability**, which concerns rates of drainage within the soil, affecting changes in both strength and volume

The brief description of how materials are described herein is taken from SANRALs guidelines for test pitting (included in Appendix A), which is based on a paper by Jennings, Brink and Williams, 1973.



Test Pit Observations

Observations made during the excavation of test pits, together with the results of the associated laboratory tests, provide vital information on the subgrade conditions and characteristics of the materials. Test pits should, therefore, be done by trained personnel.

The description of soils in test pit profiles should utilize the following descriptors, in this order: MCCCCSSO

- Moisture
- Condition
- Colour
- Consistency
- Structure
- Soil type
- Origin

(i) Moisture Conditions

For example, dry, slightly moist, moist, very moist, or wet, with moist being around the OMC of the material. This may depend on the grading and/or the clay content of the material.

(ii) Colour

The colour is determined using Burland's colour discs or the Munsell colour chart as the standard. For uniformity, the colour should be noted in its natural state in the test pit profile, but should be determined in a wet state when comparing materials from one test pit profile to the next. Mottling or blotching etc. should also be noted. Abbreviations for the colours are given in Table 3.

Table 3. Standard Abbreviations for Main Colour Descriptions of Soils

Colour	Abbreviation
Black	Bl.
Blue	B.
Brown	Br.
Green	Gn.
Grey	G.
Khaki	Kh.
Mauve	M.
Orange	O.
Red	R.
White	W.
Yellow	Y.

(iii) Consistency

The consistency is a measure of the density, hardness or toughness of the soil, and is an observation based on the effort required to dig into the soil, or to mould it with the fingers. Table 4 gives the recommended definitions of consistency for granular and cohesive soils.

Sometimes there is difficulty in classifying the consistency of a cemented material which may not properly be a rock, nor fit into the granular scale, for example, pedogenic materials or stabilized road pavement layers. Table 5 gives a guide to terms that can be used in this situation.

(iv) Structure

This indicates the presence, or absence, of joints in the soil and the nature of these joints. In the case of non-cohesive soils with a granular structure, it is not recorded. Cohesive soils, on the other hand, exhibit several types of structure as shown in Table 6.

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Table 4. Consistency of Soils

Granular Soils		
Consistency	Nomenclature	Description
Very Loose	V loose	Very easily excavated with spade. Crumbles very easily when scraped with geological pick
Loose	Loose	Small resistance to penetration by sharp end of geological pick
Medium Density	Med dense	Considerable resistance to penetration by sharp end of geological pick
Dense	Dense	Very high resistance to penetration of sharp end Requires blows of geological pick for excavation
Very Dense	V dense	High resistance to repeated blows of geological pick requires power tools for excavation
Cohesive Soils		
Consistency	Nomenclature	Description
Very soft	V soft	Pick head can easily be pushed in to (up to) the shaft of handle Easily moulded by fingers.
Soft	Soft	Easily penetrated by thumb Sharp end of pick can be pushed in 30 to 40 mm Moulded with some pressure.
Firm	Firm	Indented by thumb with effort Sharp end of pick can be pushed in up to 10 mm Very difficult to mould with fingers Can just be penetrated with an ordinary hand spade
Stiff	Stiff	Penetrated by thumb nail Slight indentation produced by pushing pick point into soil Cannot be moulded by fingers Requires hand pick for excavation
Very stiff	V stiff	Indented by thumb nail with difficulty Slight indentation produced by blow of pick point Requires power tools for excavation

Table 5. Naturally or Artificially Cemented Soils

Consistency	Nomenclature	Description
Very weakly cemented	V W cem	Some material can be crumbled by strong pressure between fingers and thumb. Disintegrates under a knife blade to a friable state.
Weakly cemented	W Cem	Cannot be crumbled between strong fingers. Some material can be crumbled by strong pressure between thumb and hard surface. Disintegrates under light blows of a hammer head to a friable state.
Cemented	Cem	Material crumbles under firm blows of sharp pick point. Grains can be dislodged with some difficulty under a knife blade.
Strongly cemented	Str cem	Firm blows of sharp pick point on a hand-held specimen show indentations of 1 mm to 3 mm. Grains cannot be dislodged with a knife blade.
Very strongly cemented	V Str Cem	Hand-held specimen can be broken with hammer head with single firm blow. Similar appearance to concrete.

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Table 6. Structure of Cohesive Soils

Structure	Description	Associated Engineering Geological Problems
Intact	Structureless, no discontinuities identified	Compressible
Fissured	Soil contains discontinuities which may be open or closed, stained or unstained and of variable origin.	
Slickensided	This term qualifies other terms to describe discontinuity surfaces which are smooth or glossy and possibly striated.	Expansive/shrinking soils
Shattered	Very closely to extremely closely spaced continuities resulting in gravel sized soil fragments which are usually stiff to very stiff and difficult to break down.	
Micro-shattered	As above, but sand-sized fragments	
Stratified & Laminated & Foliated	These and other accepted geological terms may be used to describe sedimentary structures in transported soils and relict structures in residual soils.	Slope instability/non-isotropic porosity
Pinholed	Pinhole-sized voids or pores (up to say 2 mm) which may require a hand lens to identify.	Collapsible and/or compressible/porous
Honeycombed	Similar to pinholed but voids and pores > 2 mm; (pore size may be specified in mm).	
Matrix-supported	Clasts supported by matrix.	Compressible
Clast-supported	Clasts touching (matrix may or may not be present).	

(v) Soil Type

The soil type or texture in each horizon is described on the basis of grain size, and can be a combination of any of the grain sizes as described in Table 7. The internationally used Massachusetts Institute of Technology (MIT) Classification of Grain/Fragment size is used. It is important to estimate the percentage boulders in the profile as accurately as possible.

Table 7. Particle Size Classes Commonly used in Engineering (The MIT Classification)

Grain size (mm)	Classification	Nomenclature	Mineralogical composition	Identification test
< 0.002	Clay	Cl	Secondary minerals (clay minerals & Fe-oxides)	Greasy or soapy feel. Soils hands. Shiny when wet.
0.002 to 0.06	Silt	St	Primary & secondary minerals	Chalky feel on teeth. When dry rubs off hands. Dilatant.
0.06 to 0.2	Fine sand	F. S	Primary minerals (mainly quartz)	Gritty feel on teeth
0.2 to 0.6	Medium sand	M. S.	Primary minerals (mainly quartz)	Observed with naked eye
0.6 to 2.0	Coarse sand	C. S.	Primary minerals (mainly quartz)	Observed with naked eye
2.0 to 6	Fine gravel	F. Grav	Primary and pedogenised minerals (sometimes vein quartz)	Observed with naked eye
6 to 20	Medium gravel	M. Grav	Primary and pedogenised minerals (sometimes vein quartz)	Observed with naked eye
20 to 60	Coarse gravel	C. Grav	Primary rock minerals and pedogenised minerals (sometimes quartz)	Observed with naked eye
60 to 200	Pebbles / Cobbles	Pb	Primary rock Minerals (sometimes ferricrete and quartz)	Observed with naked eye
> 200	Boulders	Bl	Rocks	Observed with naked eye

(vi) Origin

It is extremely important to determine the origin of the soil, or at least to describe whether it is residual, or transported or a fill. It is generally quite easy to describe the residual soils beneath the pebble marker, but can be more difficult for the transported material above, for example, windblown sand or transported clay. In determining the nature of the transported material, the surrounding are inspected, i.e., the topography and landforms, as well as the climate, for example, wind-blown sands. It is similarly very important to be able to identify whether materials originate from man-made fills.

(vii) Water Table

Some reference should always be made to the water table in the soil profile, even to note that it is not encountered within the depth investigated. The rate of inflow into the test pit or trial hole, for example, high, medium, slow or slight, should be noted.

(viii) Ancillary Notes to Accompany Each Soil Profile

All significant features should be recorded, including any of the following:

- More accurate description of the layers of fill (if any)
- Roots
- Ant workings
- Presence of carbonate
- Iron concretions
- Salt crystals
- Sulphur
- Bulking, or lack thereof, (of replaced material in hole) should be noted as this could point out possible collapsible grain structure.
- Pebble, or gravel marker(s)
- Depth at the bottom of the hole should be recorded
- Method of excavation: type of machine, hand excavation or existing open face

5.3 Execution of Investigations

This section discusses the three stages of investigation. These stages are an essential component of road prism and geotechnical investigations. The flowchart in Figure 3 illustrates where the three stages fit into the full investigation.

5.3.1 Stage 1: Desk Study and Reconnaissance

5.3.1.1 Desk Study

A thorough desk study provides much of the information needed to confirm the feasibility of the selected alignment, and provides direction for the investigations to follow. The information that is generally sourced can include:

- **Geological information:** Plans, maps, borehole data and geophysical data can be sourced from Council of Geoscience offices, national, regional and local authorities, local museums and libraries as well as from the geology departments of universities. Local civil engineering consultants may also provide data obtained from local engineering projects. The possibility of seismic and tectonic activity must also be established.
- **Climatic and hydrological information** may be obtained from local and national authorities.
- **Surface and underground services and structures:** Copies of plans and records showing underground services such as electric cables, optic fibre cables, communication sewers, pipes, gas lines, shallow tunnels and wells should be obtained from local authorities, and service owners and providers, e.g., Eskom and Telkom. No intrusive investigations, such as test pitting, probing and drilling should be done until the exact positions of such services are established. Many services are of strategic importance and excavation in their vicinity requires approval and the implementation of strict controls. In most cases this involves hand excavation, but specialist instrumentation is available for tracing the position of buried pipes and cables.
- **Mine shafts and quarries:** Where mine shafts exist, or old mines are suspected to exist due to the presence of spoil heaps, shafts and adits (horizontal entrances to mines), maps plans and other information should be sought from official mining record repositories, the mining companies and authorities. Careful consideration must be given to establishing their position. Where shallow undermining exists, the services of an experienced geotechnical engineer are needed.
- **Landfill sites:** The location of filled-in pits is important because these are generally loose and may be unstable and water bearing. These sites are prone to collapse settlement and may require the attention of a geotechnical engineer. Industrial and domestic landfills can be the source of toxic substances, dangerous gases and deleterious substances, which pose a hazard to the investigatory staff. Details and plans should be obtained from the local authorities.
- **Air photographs and remote sensing:** Most local authorities have air photographs, ortho-photos and plans of the urban areas traversed by the road, which indicate developments, borrow areas and give an indication of land use. For new roads, air photographs are generally commissioned and include stereo pairs for a 3D effect. Expert interpretation of these assists in identifying geological features such as faults, outcrops, volcanic intrusions, karst

or dolomitic formations while vegetation, land use, drainage lines and land forms provide useful indicators of subsurface geology and geomorphologic activities.

- **Soils Engineering Map and Terrain Evaluation Report**, if available.
- **Contact details** of all affected property owners.

5.3.1.2 Reconnaissance

Before embarking on the reconnaissance, all landowners shall be timeously contacted and informed of the intended entry to their property. Much information can be gained from landowners including precipitation history, drainage lines and flows, soil or rock depth, presence of gravel and erosion characteristics. Obtaining the landowner's co-operation is an essential requisite to an adequate investigation. Landowners should also be forewarned of subsequent investigations that might follow.

In carrying out a walk over reconnaissance of the corridor along possible road alignments, it is essential to map rock outcrops, the position and dip of boundaries and faults, and other geological features taking note of:

- **Land use**
 - **Urban Environment:** Position and description of buildings and structures, evidence of subsurface structures, services, cables, pipes and tunnels that may be affected by excavations, drilling and blasting or boring.
 - **Rural environment:** Evidence of any subsurface structures such as pipelines, cables, surface drainage, mining and quarrying as may be indicated by spoil heaps, stockpiles and excavated pits.
 - **Agricultural:** Changes in vegetation, crops (which could be as a result of filled pits, subsurface water channels or shallow bedrock), swampy areas, and mole or termite activity.
 - **Surface and land forms** indicating instability, signs of springs, shallow holes, changes in slope, landslides, subsidence, depressions and sinkholes, especially in dolomitic areas, and flood lines adjacent to watercourses.
- **General features** such as access to and along the centreline, river and stream crossings, fence lines, gate positions, railway lines and sidings, power transmission lines, graves and possible stockpile areas.
- **Materials boundaries** as evidenced in traversing the road alignment.

The observations made during the field reconnaissance should be systematically recorded for future reference, together with recommendations regarding the scope of the preliminary site investigations to follow. Where conditions warranting the appointment of a geotechnical engineer (described in Section 5.1) are observed, the necessary steps to appoint such a person or specialist firm should be taken.

5.3.2 Stage 2: Preliminary Site Investigations

Generally, a preliminary grade line indicating the position and extent of all the cuts, embankments and lesser defined, "flat" areas is available when carrying out these investigations. The objective of the preliminary site investigation is to obtain an appreciation of the following:

- Are the materials to be excavated from the roadbed or from the cuttings likely to be **soft, intermediate or hard**?
- What **batter slopes** are likely be required?
- Are the **excavated materials** suitable for use in the fill?
- Are the materials obtained from the **cuttings** suitable for use in the pavement layers? In treated or untreated form?
- Are there **unsuitable materials** present within the materials depth?
- Are there **adverse founding conditions** for embankments and structures (see Chapter 7: 4 and 5)?
- Are **adverse groundwater conditions** likely to be encountered in the cuttings or below the embankments?
- Do any **stability problems** or extraneous **detrimental conditions** exist?
- Will **changes in the alignment** (vertical and/or horizontal) avoid any adverse physical features such as unsuitable founding conditions or unstable conditions, or, will it positively affect materials utilisation and the cost of the project?

To achieve these goals, a limited test pitting program is generally followed. The spacing generally provides for at least one test pit per feature such as a cutting, a embankment, structure position, a valley, a hill top, a previously cultivated land or an uncultivated area. Access and current land use determines what means of excavation is selected. The proposed extent, testing and personnel requirements for excavation must be determined. The testing should include indicator tests (grading



Test Positions in the Field

It is of critical importance that the test positions are accurately determined and recorded.

and Atterberg Limits) on all horizons identified in the soil profile, and CBR testing for all major horizons, excluding the topsoil. See Section 8 for testing details.

At this stage, geophysical investigations are also carried out. The range of appropriate tests is a function of the particular terrain, the proposed grade line and the engineering objectives. As with test pitting, at least three quotations for the works shall be obtained from experienced specialists in this field and submitted to the client for approval prior to the execution of the works. For bigger projects, SANRAL may require a full tender process to be followed. Seismic surveys are very useful in establishing rock heads in cuttings where there are no signs of rock outcrops. In dolomitic areas, gravimetric surveys and percussion drilling is a necessity. It is of critical importance that the test positions in the field are accurately determined and recorded.



Materials Depth

Materials depth describes the thickness or depth below the final road level of the road pavement where the soil characteristics have a significant effect on the road pavement behaviour and the minimum depth within which the material CBR value should be $\geq 3\%$ at the in situ density. Below this depth the strength and density of the materials are assumed to have a negligible effect on the road pavement's performance.

Where the topography is such that there are major cuttings and embankments (> 5 to 10 meters), and the site reconnaissance indicates deep weathering and thick alluvial deposits in valley lines, limited drilling may be required. These will provide the required information, for example, suitability of materials, depth, type and condition of bedrock for the Preliminary Design and Basic Planning Report.

The results of the investigations and engineering interpretations are reported in the Preliminary Materials Report, which itself is an input to the Basic Planning Report. The report also comments on the necessity of obtaining specialist geotechnical services where adverse conditions have been identified. These may include undermining, signs of instability, such as tension cracks, bent trees indicating side slope creep, significant seepage lines, slides on slopes, terracing, unstable rock slopes, dispersive soils, expansive soils, compressible soils, dolomite formations, undermining. See Section 9 for reporting details.

When test pitting needs to be done on private land, all landowners shall be timeously contacted and informed of the intended entry, the purpose and duration thereof. Where the proposed alignment traverses cultivated lands, it may be desirable to defer test pitting and/or drilling and probing until crops have been harvested.

5.3.3 Stage 3: Detailed Investigations

In planning the Detailed Investigations, the following objectives should be considered:

- Identify **varying roadbed conditions** and boundaries requiring specific treatments prior to the construction of embankments and/or pavement layers.
- Identify and quantify **unsuitable materials** beneath embankments.
- Identify **surface and subsurface drainage** lines, and groundwater regime in cuts and beneath embankments.
- Identify areas that require **specialised geotechnical attention** to provide stable platforms for embankment construction or special treatments and retention measures to ensure slope stability.
- Characterise the **various soil and rock stratum** within the various cuttings through profiling, sampling and testing to determine:
 - Excavation class: soft, intermediate or hard, as per the Standard Specifications definitions
 - Possible methods of excavation
 - Suitability for use in fill and/or pavement layers
 - Presence and quantity of spoil materials with disposal proposals
 - Treatments needed for roadbed in cuttings
 - Stable side slopes and drainage requirements in cuttings
- Provide all the materials parameters needed for an **adequate and economical design**.

The positions of all the preliminary test pits, probings and borings should be plotted on the plans (generally 1:1000 scale landscape and drainage plans) and long-sections. The various cuts and embankments are then numbered for reference purposes. The positions of further investigatory test pits, probings and boreholes needed to ensure the above objectives are met are also plotted on the plans and sections.

The following scenarios, or combinations thereof, are generally be encountered, providing an initial subdivision of subgrade conditions and an indication of investigatory needs:

- **The in situ material falls within the materials depth:** The in situ materials need to be tested to determine whether they can remain and be used in place after due processing to meet uniformity and density requirements.

- **The in situ material is well below the materials depth:** This indicates that fill layer works need to be constructed over the in situ materials, which must, in turn, be investigated to determine if they provide the necessary support and stability for the layer works.
- **The in situ materials are above the materials depth:** This indicates that a cut is necessary and investigations need to assess which of the in situ materials may be removed to stockpile, to windrow or can be processed and used for the pavement layers. Other factors, such as sub drainage, also determine the ultimate treatment or utilisation.

In determining the investigatory positions, cognisance should be given to the likely position of culverts, bridges and other structures, to rationalise the numbers of test pits and boreholes. The transition from cut to fill should always be investigated, with special attention paid to variations in moisture and soil and rock interfaces.

Tests pits are typically spaced at 150 to 200 metre intervals. In places, the test pits will be more closely spaced to identify materials boundaries and local conditions as may be encountered in the bottom of valleys, adjacent seasonal watercourses, adjacent changes in surface and subsurface geology or at the foot or near the crest of hills. On flat, featureless sections, the spacing is greater. The spacing should also be such that the different roadbed treatments required to address these conditions can be identified, quantified and designated on the plans and long-sections.

Beneath low to medium embankments, i.e., less than 15 metre in height, the depth of investigation should be at least 1 metre below the natural ground level, for possible sampling and testing for potential shear failure and settlement in the foundation strata (see Section 5.2).

Major embankments, greater than 15 m in height, need special consideration (see Chapter 7: 4). Positioning of test pits, auger holes and boreholes should take the type of embankment (flat, side embankment, side embankment/side cut or gully embankment) into account, as founding conditions may vary significantly across the length and breadth of the embankment's footprint.

To characterise the materials in cuts for use in construction, at least three test pits or auger holes should be excavated per cutting, to at least 1 metre below the final road surface, to determine the profile and to obtain samples of the different materials encountered over the depth of the hole. Where conditions, such as instability, hard rock, high water tables, or excessive depths preclude the use of test pits and/or augering, rotary drilled boreholes are utilised. Where the dipping strata are encountered, inclined boreholes are generally utilised. Where cuttings have been identified as sources for fill, or for pavement layers, they should be treated as borrow pits. Sampling and testing frequencies should then be adjusted so that the quality and extent can be proven as described in Chapter 8: 2.3.

The spacing of the boreholes should be a function of the cut length and the local geology and planned utilisation of the cut materials. In general, the spacing should not exceed 100 m intervals for single carriageway roads and 50 m for dual carriageway roads. At least two boreholes should be drilled in each significant cutting, and where possible faults and/or fracture zones are identified. Their presence and position should also be confirmed by drilling. Percussion drilling may be utilised for interpolation between rotary core drilled holes.

While carrying out the investigations, every attempt should be made to determine the ground water regime. Where materials are noticeably very moist to wet, samples should be taken to determine the actual moisture content. In significant cuttings, or where high water rest levels are recorded, standpipe piezometers should be installed for long term monitoring of the water table.

Where existing cuttings and/or embankments are being widened, or there are cuts and embankments in close proximity to the project, these should be examined closely as they could indicate:

- Likely soil or rock **profiles**
- Depth and rate of **weathering** or erodibility
- **Stability** of slopes
- Groundwater **seepage**
- Likely **excavation** characteristics
- Possible **utilisation** of materials

Particular attention should be paid to investigating specific features such as cut and fill transitions, especially in rugged topography; areas where undercutting of inclined sediments appears likely; and where material type and long term durability could pose problems, such as slaking mudrocks and shales, fast weathering rocks like dolerites and basalts, and dispersive soils.

5.4 Procurement of Services

The type, extent and estimated cost of the investigations envisaged will generally determine the level of documentation required for the procurement of these services, as well as the method to be followed. The consulting engineer, appointed institution or specialist should thus consult with the relevant authority to ensure that the necessary guidelines and procedures are followed. SANRAL, for example, have Pro-Forma documents for both formal and informal tenders, and guidelines and procedures for obtaining quotations. These can be obtained from the relevant SANRAL Project Manager.



Spacing of Boreholes

Spacing of boreholes should not exceed:

- 100 metres for single carriageways
- 50 m for dual carriageways

At least 2 boreholes should be drilled in each significant cutting.

6. POTENTIAL PROBLEM AREAS IN THE ROADBED

The roadbed may comprise the in situ material after the removal of vegetation (clearing and grubbing) and topsoil or it may be the natural in situ material remaining after cut operations to the required line and levels. As fill and/or pavement layers are constructed on the prepared roadbed, the roadbed must be stable and provide a suitable platform for the construction.

Typically, some preparation of the roadbed is necessary and a set of treatments covering the various conditions encountered along the length and width of the road footprint are normally selected as set out in Chapter 9: 2. Such treatments may include cutting to shape, compaction of the area, or scarifying the material to a specified depth followed by compaction to the required density. In some cases stabilization may be required in areas with significant problems, such as expansive clays. There are many situations where specialist geotechnical investigations are necessary to determine the extent of such problem areas or conditions and to enable suitable measures to be taken to provide the desired performance.

Problem roadbeds requiring specialist geotechnical input and investigation include the following:

- **Undermined** or tunnelled ground
- **Dolomitic** formations
- **Made ground** and landfills
- **Problem soils:**
 - Heaving soils, expansive or shrinking sub-soils
 - Soft or wet clays
 - Collapsible or compressible soils or fills
 - Dispersive and erodible soils
- **Saline soils**

All these problem roadbeds have an effect on the design of the road and structures, the constructability, the performance or load carrying ability, the long term stability, and the durability of the constructed fill or layer works. Each problem is described in more detail below.

Appendix C contains some examples of special roadbed treatment types.

6.1 Undermined or Tunnelled Ground

A number of scenarios of undermined or tunnelled ground are possible: a road could traverse an existing undermined area; future mining could take place beneath an existing road; or, there could be the presence of tunnels (existing or proposed transportation tunnels, such as Gautrain and future extensions, or even service tunnels. Examples of tunnels are shown in Figure 10. Mining companies have also been known to apply for permission to construct temporary tunnels beneath existing roads and road reserves for access and mineral exploitation. Collapse of underground cavities and shafts, with consequent subsidence of overlying soils and constructed infrastructure, is always a possibility.

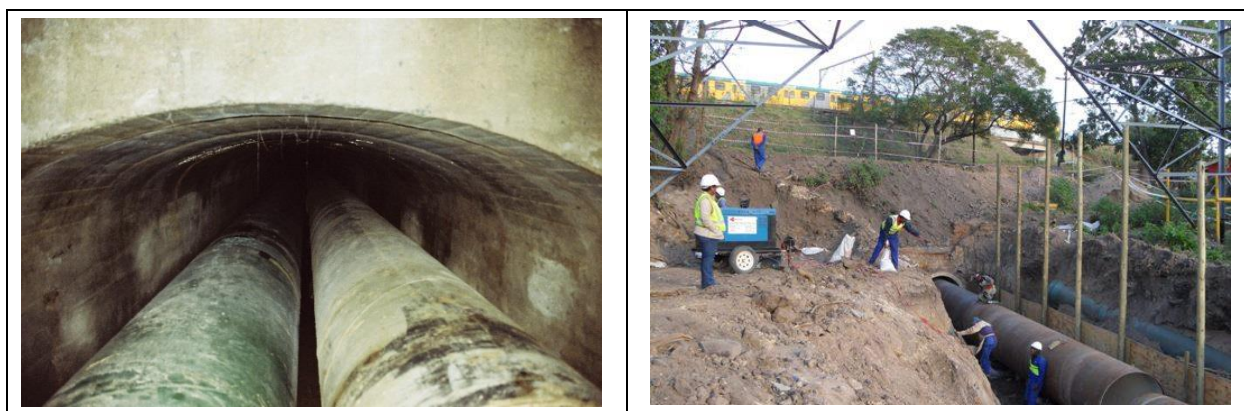


Figure 10. Examples of Tunnels

It is thus extremely important to verify both the extent and details of historical, current and planned future mining or tunnelling activities. This is especially important where greenfields projects are planned in areas where there are past, present or future mining activities. Such details would include the position and depth to a tunnel, shaft, stope (cavity resulting from the selective mining of a material), or cavity and local geology and stratigraphy, as well as an engineering assessment of the materials. This information should be proactively obtained from the offices of the Mining Commissioner and/or Chief Inspector of Mines. Generally, it is also necessary to consult the relevant mining company or tunnel authority. This information will typically be obtained during the Stage 1: Desk study and reconnaissance investigations.

Experience has shown that appointing a specialist in this field to assist the geotechnical engineer leading the investigation facilitates communication with, and the collection of relevant data and information from, the parties concerned. The specialist can also be tasked with compiling a preliminary evaluation of the situation. A specialist mining engineer would normally be appointed to carry out a detailed investigation, which may include field geophysical and geotechnical investigative methods, and evaluation of undermined areas. The specialist can then make appropriate recommendations for the measures required to provide a stable roadbed over the projected lifespan of the road.

These recommendations will generally be presented in a stand-alone report, which is incorporated into the Preliminary or Detailed Design Reports (see Section 9). Once accepted, this forms the basis of special roadbed treatments and measures to be designed and shown on the plans, and included in the project specifications. See also Chapter 9: 2.

6.2 Dolomitic Formations

6.2.1 Origin of Dolomitic Formations

Dolomites were formed by chemical precipitation in a shallow sea and comprise carbonates of calcium and magnesium with iron, manganese oxides, chert and a siliceous deposit, depending on the tidal zones in which they were formed (Wagener, 1985). The carbonate components of these rocks are soluble in acidic solutions, resulting in the development of solution cavities.

A typical profile of a dolomitic formation comprises of a blanket of transported material, sometimes underlain by a pebble marker over the residuum. In chert rich dolomites, the residuum grades from coarse angular chert gravel to insoluble wad and clay. This is followed by a highly irregular rockhead (karst topography) consisting of pinnacles (rock columns) between which cavities may be found. A pinnacle formation in the Centurion Eco Park Section on the Gautrain Route is illustrated in Figure 11. Solution cavities may be found in the upper layers of the dolomite body.

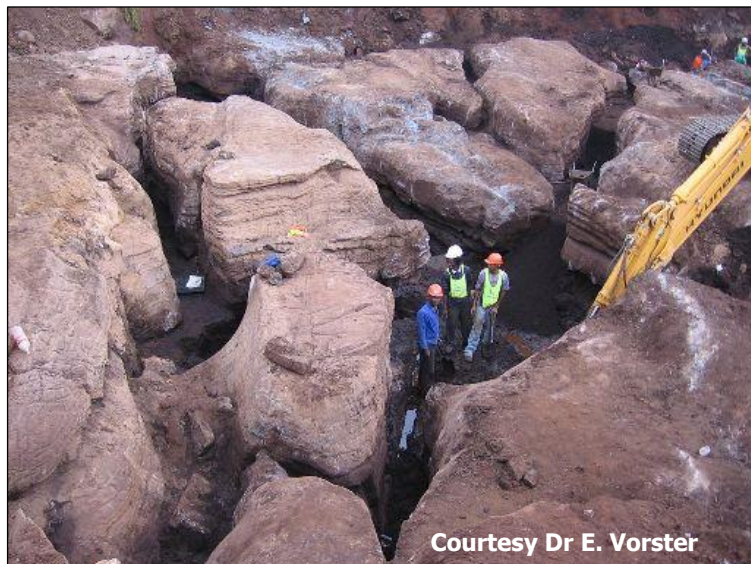


Figure 11. Pinnacles in Dolomitic Formation (from Eco Park Section on Gautrain Route)



Dolomitic Formations

Dolomites are formed by chemical precipitation and comprise carbonates of calcium and magnesium with iron, manganese oxides, chert and a siliceous deposit, depending on the tidal zones in which they were formed. The carbonate components of these rocks are thus soluble in acidic solutions, resulting in the development of solution cavities.

6.2.2 Problems Associated with Dolomitic Formations

On a typical site over dolomitic materials, the consistency or in situ strength of the material reduces with depth from relatively competent chert gravel to compressible wad, before solid rock is encountered. This is contrary to most other geological formations where consistency improves with depth. The profile at any one position can be totally different within a metre or two either way.

Jennings, et al (1965) identify two types of subsidence associated with dolomite:

- **Sinkholes**, defined as subsidence that occurs suddenly. An example of a large sinkhole from Bapsfontein in 2004 is shown in Figure 12, and the process of forming sinkholes is shown in Figure 13.
- **Compaction subsidence** or doline, formation which is a gradual and flatter subsidence.



Figure 12. Sinkhole



Recommended Reading

Problem Soils in South Africa – State of the Art. Dolomites by Dr F. Wagener. The Civil Engineer in South Africa. Vol. 27, No. 7 July, 1985.

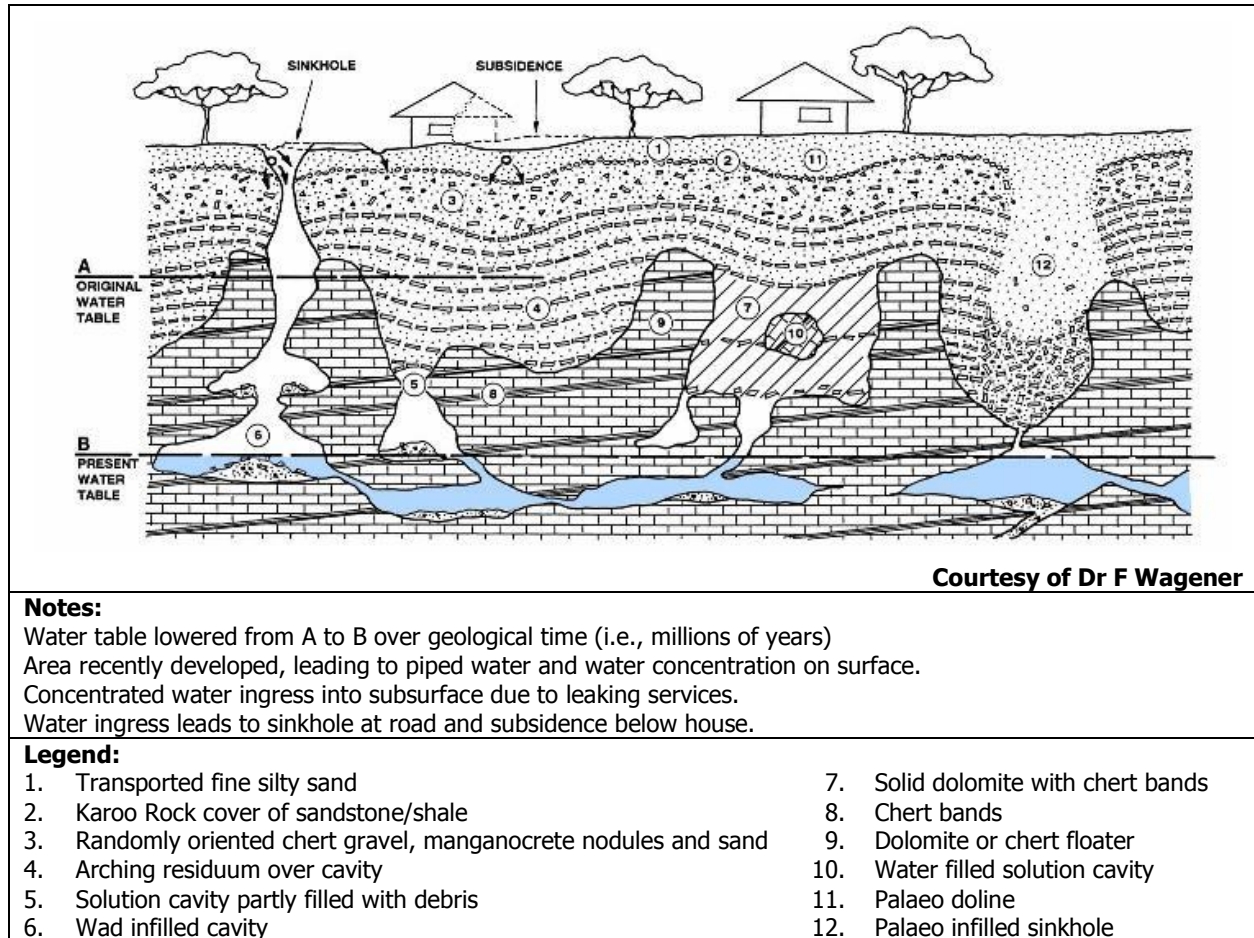


Figure 13. Typical Soil Profile Over Dolomite in South Africa

6.2.3 Investigations in Dolomitic Formations

Sinkholes and compaction subsidence have serious economic consequences. Sinkhole formation can be life threatening. For this reason, it is required that prior to any development over dolomitic formations, an investigation be carried out in accordance with the following guidelines:

- "Engineering Geological Site Characterization for Appropriate Development on Dolomitic Land" jointly published by The Council for Geoscience and the SAIEG. (Council for Geoscience, 2003).
- "Approach to Sites on Dolomitic Land", Council for Geoscience, 2007.

Both these guidelines are available from the Council for Geoscience. These stand to be surpassed by SANS 1936 "Development on Dolomitic Land. Part 1: General Principles and Requirements".

To meet these legal requirements, as well as the engineering requirements, specialists or specialist firms are generally appointed in the early stages of a project, i.e., the Route Location or Preliminary Design stage. This is to investigate the feasibility of the project and aid in identifying the alignment that poses the least risk.



Chert

Penetration testing, probing and rotary core drilling is not possible in chert.

The investigations almost always involve the use of remote sensing followed by geophysical methods and direct methods. This phased approach is necessary to enable changes in alignment to avoid problematic areas and to provide direction to the most costly and time consuming direct methods. The direct methods generally comprise trenching and drilling of many percussion holes. Borehole cameras and video recorders are used to investigate cavities. Penetration testing, or probing on a close grid, can be carried out to determine rock heads and pinnacle positions. This supplements the findings of the geophysical methods, but will not penetrate loose chert formations due to collapsing drill holes. Similarly, rotary core drilling in chert is near impossible.

South African Pavement Engineering Manual

Chapter 6: Road Prism and Pavement Investigation

Dolomitic formations probably present one of the greatest challenges to road engineers. It is essential that the investigations, evaluation of risk and design of the roadbed stabilization measures be carried out by appropriately experienced specialist geotechnical engineers, assisted by equally experienced engineering geologists and geophysicists.

The reports on the investigations, findings, evaluation and recommendations are generally stand-alone reports appended to the various reports detailed in Section 9.1: Preliminary Site Investigation Report, Basic Planning Report, and Detailed Investigation Report. The client's requirements regarding the formats of these reports need to be taken into account.



Areas with Dolomitic Formations

Dolomitic formations probably present one of the greatest challenges to road engineers. It is essential that the investigations, evaluation of risk and design of the roadbed stabilization measures be carried out by appropriately experienced specialist geotechnical engineers, assisted by equally experienced engineering geologists and geophysicists.

6.3 Expansive or Heaving Clays

Expansive clays are probably the most widespread of the problem soils in South Africa. Establishing the spatial distribution of partly saturated potentially heaving clays, as well as soft wet clays along a road, is of paramount importance.

Maps are available indicating likely areas of these soils, an example of which is shown in Figure 14. Methods of assessing the possible heave and countermeasures of potentially expansive roadbeds have been developed. Weston, 1980; Williams, Pidgeon and Day, 1985.



Expansive Clays

These are probably among the most widespread of the problem soils in South Africa.

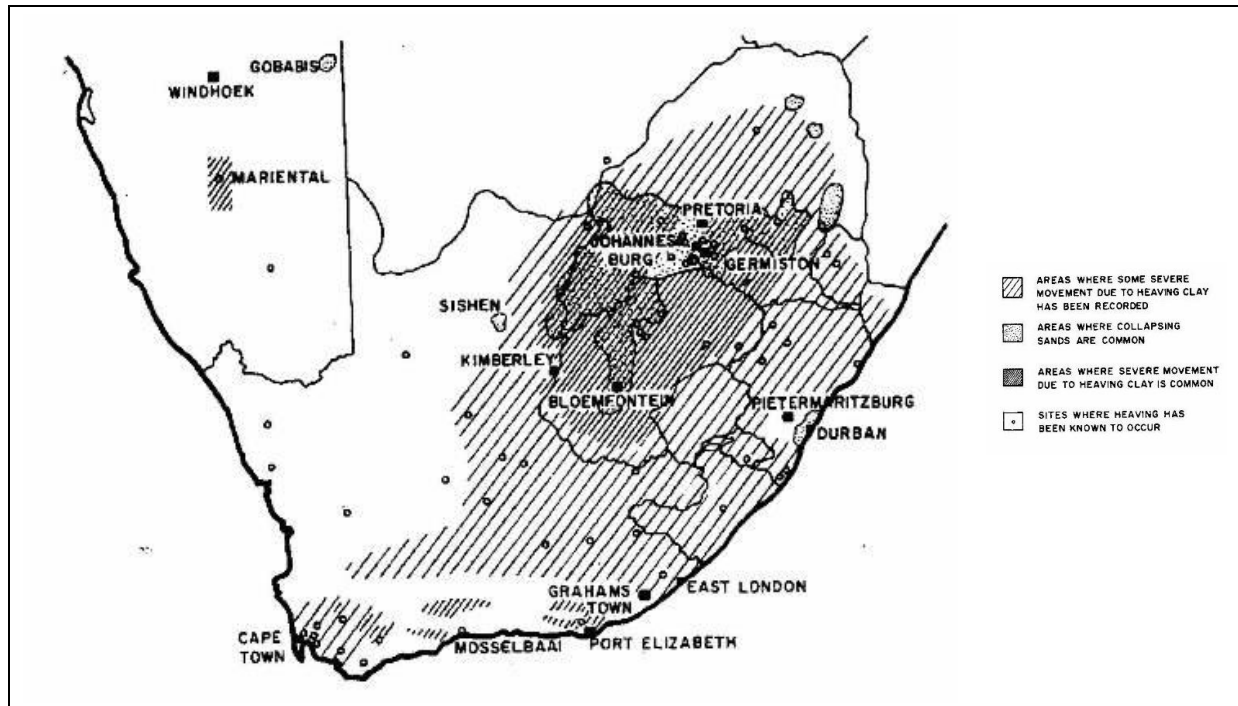


Figure 14. Distribution of Expansive Soils and Collapsing Sands

Typical damage to roads attributable to expansive soils includes:

- Severe **shrinkage** cracking following drying out of expansive clays, illustrated in Figure 15.
- Longitudinal and transverse **unevenness** caused by differential heave and shrinkage of expansive clays, see Figure 16.
- **Lifting of culverts** and in many cases, damage to pipes and other culvert structures due to expansion, see Figure 16.



Figure 15. Examples of Shrinkage Cracking



Figure 16. Unevenness and Culvert Lifting due to Expansive Clays

6.3.1 Sources of Expansive Clays

Expansive clays may be:

- Residual soils derived from the in situ chemical decomposition of **basic igneous rocks** to form expansive clays, primarily of the **smectite** group. The igneous rocks are:
 - Norite of the Bushveld Igneous Complex
 - Dolerites and basalts of the Karoo Sequence
 - Andesites and diabbases of the Pretoria Group
 - Lava's of the Ventersburg Supergroup
- Residual soils developed from **argillaceous** rocks such as:
 - Shales and mudrocks of the Ecca and Beaufort groups or the Dwyka Formation
 - Tillites from the Dwyka Formation
- **Transported soils** from the above rock types such as alluvium, gulleywash, hillwash and lacustrine deposits.

The different rock types are illustrated in Figure 18 in Chapter 8: 3.3.

Expansive clays of a transported origin present localised problems (areas of deposition), while residual expansive clays are more widespread.

In the field, expansive clays are generally black, dark grey, red or mottled yellow-grey. If the soil structure exhibits slickensiding or shatteredness, there is a potential to heave. Surface cracking also suggests heaving potential.

6.3.2 Moisture Effects

Expansion or heave occurs due to increase in the moisture regime of the soils and, as such, the effect is greater in arid to semi-arid regions. Shrinkage occurs due to drying out, and seasonal decreases in the soil moisture can be exacerbated in times of prolonged drought.

Vegetation plays a major role in conditioning the subsurface moisture regime. The network of roots supporting such vegetation actively removes vast amounts of water. Trees of the eucalyptus, willow and poplar families are notorious for the large amount of water removed by transpiration. On the removal of such trees, rebound occurs (Williams et al, 1985). The rebound can result in volume increase or swell, or even the development of swampy areas. Instability may develop in steeply sloping ground. The associated changes in stress may exceed the loading under light structures, e.g., pipes and culverts.



Recommended Reading

- Weston, D.J. 1980. **Expansive Roadbed Treatment for Southern Africa**. Proceedings for 4th International Conference on Expansive Soils. Denver.
- **Problem Soils in South Africa – State of the Art. Expansive Soils** by Williams, Pidgeon and Day. The Civil Engineer in South Africa. Vol. 27, No. 7 July, 1985.
- **Problem Soils in South Africa – State of the Art**, Proceedings, South African Institute for Engineering and Environmental Geologists, 3–4 November 2008.



Profiling

See Section 5.2.3 and Appendices A and B for more on profiling of soils and rocks.

This is why the practice of planting large shrubs at the inlet and outlets of drainage culverts to identify the headwall positions and protect them from damage during mechanised grass cutting operations has been stopped. It was found that the roots of these shrubs penetrated well below the road fill and resulted in the withdrawal of water, causing severe shrinkage related deformation. On a section of a major freeway, the water withdrawal by the shrubs was so severe that arcuate or circular cracking and differential settlement occurred on the shoulder of the road at these positions.

6.3.3 Investigating Expansive Clays

While the presence of expansive soils along the route of a new road may be evident from the desk study and reconnaissance (Stage 1 Investigations: see Section 5.3.1), the presence of localised problem areas may only be evident during, or after, the Preliminary Field Investigations.

In carrying out the field investigations, described in this section, it is imperative that the full depth of the soil profile is assessed, as these materials could be overlain by inert, transported or pedogenic horizons. Moisture, colour and structure are important descriptors, as is the depth of the water table, for an indication of the base level for heave movements. The depth of cracking is a further important indicator of moisture regime changes.

Where visual observation in the profiling of test pits, auger and rotary drilled holes has not identified the presence of expansive clays, the grading and Atterberg limit tests should provide clear indications of potentially expansive soils. The Plasticity Index and the clay content are good indicators of the activity of a soil. Van der Merwe (1964) has used the chart in Figure 17 for the preliminary identification of expansive clay soils. It should be noted that the predictions do not provide for loading, initial moisture and density of the material. Determining the mineralogical composition by X-ray diffraction analysis will confirm the presence of the expansive smectite clays.

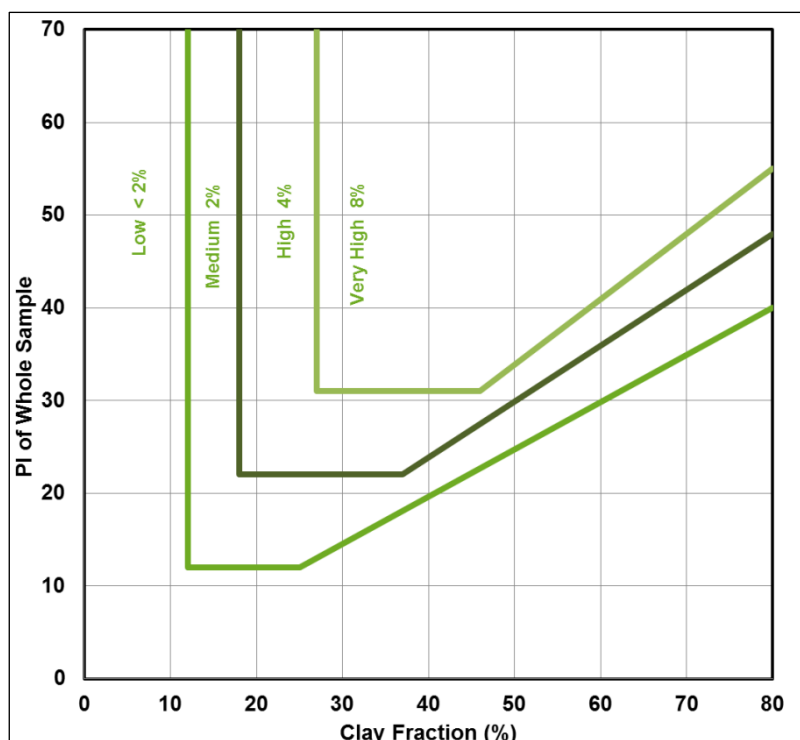


Figure 17. Prediction of Expansive Clay Soils

Field tests to measure in situ soil suction or surface heave on wetting can be carried out. Soil suction measurements are often done utilising psychrometers at regular intervals in auger holes. Free swell tests comprise the installation of a number of levelling points, wetting the points and monitoring movements. These parameters are needed for the calculation of heave from suction methods, derived by Brackley (1975).

Various empirical methods have been derived for predicting total heave. These include those of van der Merwe (1964), Weston (1980) and Brackley. All of these methods obtain a general indication of the potential expansiveness of the subsoils. Where the potential heave is significant (generally > 25 mm according to Weston), and especially where structures need to be constructed, greater in-depth investigation is needed. This possibly requires the

installation of psychrometers in auger holes to measure soil suction in the field, and the execution of double oedometer tests by laboratories experienced in this field.

Disturbed samples, as well as undisturbed samples, will be required to carry out the necessary tests to characterise the potential expansiveness of the roadbed materials. It is imperative that in situ orientation be maintained in all test samples as expansive clays are highly anisotropic and exhibit significantly lower swells in the horizontal direction. This is due to the lattice type orientation of the clays.



Anisotropy of Expansive Clays

Expansive soils are highly anisotropic and exhibit significantly lower swells in the horizontal direction than the vertical direction.

6.3.4 Counteracting the Effects of Expansive Clays

Various options are available to the specialist geotechnical engineer to aid in designing measures to counteract expansive clays:

- **Removal of expansive clay.** Where the extent of the expansive clay is limited, for example in a localised low lying area with shallow alluvium deposits, the removal of the clay from the roadbed and the replacement by competent material may provide a quick and economical solution. Where the vertical and horizontal extent is such that this cannot be practically or economically met, other solutions need to be considered.
- **Limiting moisture fluctuations.** Emery (1988) and others have shown that with time an equilibrium moisture condition develops beneath a surfaced road structure and that moisture changes in this region are minimal throughout the year. This implies that heave and shrinkage are generally greater at the outer edges of a surfaced road, especially one with unsealed shoulders. Experience has shown this is indeed the case. On some roads, various experiments have been carried out including pre-wetting the expansive roadbed (by precipitation and/or irrigation) and by constructing impermeable horizontal and vertical membranes to limit moisture fluctuations. These have been reasonably successful.
- **Removal of expansive clay and use of impermeable membranes.** More recently, success has been obtained by excavating the clay beneath the road, vertically at toe position at natural ground level, to the point where there is a constant moisture profile. Then, using end tipping methods to backfill with rockfill, of a maximum size of not more than 1/3 of the thickness to be filled, to provide interlock and bridge any instability emanating from the clay. Then, following with conventional fill. Vertical membranes are installed along the excavated edge to the undercut depth. This solution is illustrated in Figure 18. Essential to this solution, is to ensure that pockets where moisture can concentrate are not created and that any entrant moisture is spread over the width and length of the roadbed. A careful study of the longitudinal section, clay and moisture profiles is therefore necessary. At culvert and pipe positions, deeper removal of the expansive clays is made, tapering back to the general depth of undercut to limit differential movements. The backfill used here should be easily compactable material with low permeability. The undercut material is stockpiled and used for flattening the slopes, extending beyond the undercut line to limit the ingress of water. Culvert and pipe outlets and inlets must be well graded to prevent the ponding of water.

It is evident that the success of any method used is dependent upon its ability to limit moisture changes in the expansive clays in the roadbed. It is also evident that in the cracked zone, swell is three dimensional, while below this it is essentially vertical. Increasing the load over heaving clays, by raising the grade line and constructing the road in fill, can be carried out as a first step. This obviously has major economic implications arising from the large volumes of fill materials that have to be sourced, the cost of constructing the embankments as well as the extra time needed to construct the road. It is thus evident that the investigation of roadbeds where heaving clays have been identified needs to be carried out by specialists in this field, working very closely with the design team to arrive at the most appropriate, optimal and cost-effective solution. The selected solution generally comprises of specific roadbed treatments, see Chapter 9: 2.

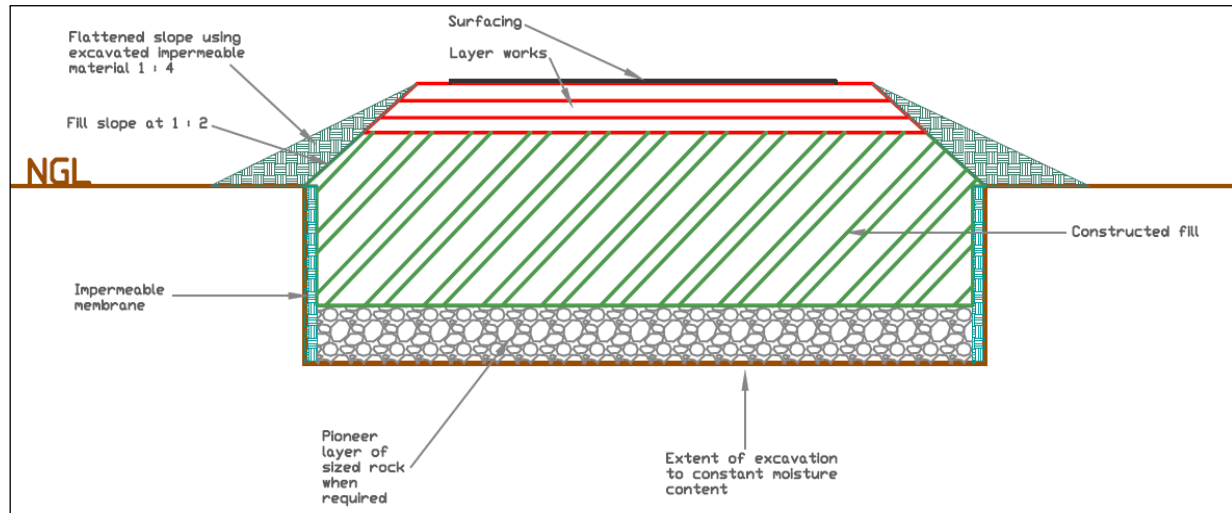


Figure 18. Schematic Representation of Treatment on Expansive Subgrades

6.4 Soft or Wet Clays

6.4.1 Origin of Soft or Wet Clays

Soft clays are generally alluvial in origin with varying organic contents and are mostly encountered in estuarine deposits (lagoons), in mature river systems, in low lying marshy areas and wetlands, and in ancient watercourses or estuaries. In estuarine areas and mature river systems, these deposits may be very deep but are generally shallower in inland marshes and wetlands.



Soft or Wet Clays

These clays are wet to saturated, have high organic contents and are highly compressible. Their shear strengths and corresponding bearing capacities are thus very low.

6.4.2 Effects of Soft or Wet Clays

These clays are wet to saturated, frequently have high organic contents and are highly compressible. Their shear strengths and corresponding bearing capacities are, thus, very low. Low permeability results in time related settlement problems. The materials are usually dark grey to black and are seldom uniform with depth. They are generally interlayered with silts and sands, which sometimes provide drainage paths, facilitating load induced settlement.

6.4.3 Investigating Soft or Wet Clays

Investigating these materials poses a problem as the excavation of test pits or drilling of auger holes is generally not possible due to the soft, generally saturated condition. They may also be below the water level. Probing and rotary drilling, associated testing and sampling provide the best means for investigating these materials. It may be necessary to construct temporary platforms to gain access to the test positions. Triple tube core barrels will generally be used to obtain continuous cores. Piston sampling is carried out at selected positions to obtain undisturbed samples for specialised laboratory testing, such as triaxial shear tests and consolidation tests. Standard Penetration tests (SPT) are also carried out at fixed intervals providing means for determining bearing capacity through established relationships. Cone Penetration Tests (CPT) provide a way of determining changes in material type and density by measuring resistance to penetration, and even pore pressures (CUPT) with depth.

The analysis of the test data is a complex issue and requires specialist attention to accurately model prevailing conditions. Use is made of sophisticated computer programs to estimate stability under various load conditions and in situ material properties, and to predict settlement over time.



Recommended Reading

- **The Prediction of Heave from the Plasticity Index and the Percentage Clay Fraction** by van der Merwe, Transactions. SAICE, Volume 6. 1964.
- **Expansive Roadbed Treatment for Southern Africa**, by D.J., Weston. Proceedings for 4th International Conference on Expansive Soils. 1980.
- **Problem Soils in South Africa – State of the Art. Expansive Soils** by Williams, Pidgeon and Day. The Civil Engineer In South Africa, Vol. 27 No. 7 July 1985.

6.4.4 Counteracting the Effects of Soft or Wet Clays

There are situations where the extent of wet, compressible clays is such that they can be removed. In these cases, the extent of these deposits is determined and suitable steps defined for their removal. These steps are then refined into roadbed treatments, as described in Chapter 9: 2. In many cases, however, the depth and nature of these deposits make it impossible to remove them. The road then has to be constructed over these materials, if realignment to avoid them or bridging is not feasible.

Both long and short term stability and settlement are a problem in constructing road embankments over soft clays. Because of the low shear strength and permeability of these materials, special construction measures have to be taken. These may include:

- Early construction of road embankments (**preloading**), **adjusting the construction rate** to maintain stable conditions (with pore pressure and settlement monitoring), with or without drainage enhancement such as wick drains (see Chapter 7: 6.1). Many of the road embankments across river flood plains and lagoons along the KwaZulu-Natal coast have been constructed using this technique.
- **Bridging soft clays** by constructing a series of closely spaced stone columns along the footprint of the road embankment, dynamically compacted into the clay subsoil, thereby providing an arched rock cover over these columns. Essentially this involves lateral displacement of the soft clays. This has successfully been carried out on a section of the N1 freeway outside Johannesburg, and at other sites.

In designing and constructing embankments over wet, compressible roadbeds, allowance needs to be made for “lost” or sacrificial fill materials that have settled into the roadbed. Measurement in place may be impossible due to settlement beneath initial roadbed levels.

There are many road embankments that have been constructed over very thick alluvial clay deposits and on-going settlement is a problem. This requires periodic reconstruction and levelling of the upper pavement layers to maintain acceptable riding quality levels. Of greater significance is the loss of serviceability of pipes and other cross drainage structures due to excessive settlements.

6.5 Collapsible Soils

A soil with a collapsible grain structure is defined as a soil which can withstand relatively large imposed stresses with small settlements at low in situ moisture contents. But, a decrease in volume and associated settlements, which may be of large magnitude, with no additional increase in the applied stress will occur if the soil wets up. The change in volume is associated with the collapse of the soil structure (Schwartz, 1985). The collapse of roadbed materials beneath roads, runways and railways can also be triggered by increasing dynamic loading, without any increase in the moisture content. (Knight and Dehlen, 1963)



Collapsible Soils

Collapsible soils have a grain structure that collapses, sometimes with a large magnitude, in the presence of water.

Other causes of collapsible structures are termite and mole activity. These types of infestation are generally noted during conventional road prism investigations. Unless addressed and adequately dealt with in the roadbed preparation, eventual collapse is inevitable due to rises in the water table, or by traffic induced loads and vibrations. These collapses are generally differential in nature, seriously affecting the road's riding quality. Pro-active steps are required to prevent such infestations to completed infrastructure. These may include the installation of mole barriers during construction.

6.5.1 Origin of Collapsible Soils

For soils to exhibit collapsible characteristics, they must have collapsible grain structures. Problems with collapse are generally associated with silty or sandy soils with low clay contents and low in situ densities (1200 to 1600 kg/m³). Initially it was thought that only transported soils such as aeolian or windblown sands have collapsible structures, due to their loose packing and single sized nature. However, collapse failures have been shown to be as prevalent in some residual granite soils of the Basement Complex. Experience has also confirmed the potential for collapse settlement in other residual materials derived from felsites, basalt, quartzite and feldspathic sandstones. In his description of the weathering process of granitic rock, Brink (1961) indicates the quartz remains unaltered as sand grains, mica relatively unaltered, however, feldspars are kaolinized and in water surplus areas, are leached out, leaving the soil with a collapsible fabric.



Recommended Reading

Problem Soils in South Africa – State of the Art. Collapsible Soils by Ken Swartz. The Civil Engineer in South Africa. Vol. 27, No. 7 July, 1985.

6.5.2 Investigation of Collapsible Soils

Recognition of collapsible materials in the field commences with accurate profiling. The identification of dry to slightly moist soils with a loose or open fabric consistency, often described as pinholed, as illustrated in Figure 19, is usually the first indication of collapse. The position in the profile and depth or thickness is important. The colloidal coatings and clay bridges on grains are often visible using a hand lens. A comparison of in situ density with laboratory determined maximum density tests often provides the next level of indicative field assessment of potential collapse, because the in situ density is much lower than the laboratory determined density.



Figure 19. Pinholed Collapsible Soil

A simple field indicator is to excavate a test pit and backfill it with all the excavated material. A shortfall indicates a soil with a potentially collapsible grain structure. DCP tests may be used to map areas of similar consistency, although the dynamic effect of the hammer impact often causes collapse in itself, affecting the results.

Jennings and Knight (1975) describe a simple field test where an undisturbed cylindrical sample of fixed or determinable volume is obtained. The material is removed, kneaded and remoulded in the cylinder, and the change in volume measured. The plate bearing test, with inundation by water, illustrated in Figure 20, provides a more sophisticated means of measuring the collapse characteristics of a soil in the field.



Figure 20. Plate Bearing Test

In the laboratory, grading and Atterberg limits assist in identifying collapsible soils as they are single sized and non-cohesive. More sophisticated testing is done using single and double oedometer tests and the collapse potential test, which is a modification of the oedometer test developed by Jennings and Knight. It is essential that the sampling and testing is carried out by adequately trained and experienced geotechnical practitioners, while the interpretation of the results of such sophisticated tests should rest in the hands of the specialist geotechnical engineer.

6.5.3 Counteracting the Effects of Collapsible Soils

Engineering solutions include:

- **Removal or partial removal** of the soils exhibiting collapsible characteristics, followed by **densification** of the roadbed by rolling with heavy rollers (usually vibratory) after wetting up of the roadbed. The use of such rollers in conjunction with wetting of the roadbed has been found to be successful to a depth of about 1 metre.
- **Surface rolling with impact rollers** (18 to 25 kJ) has been found to provide deep compaction in certain materials at various locations, both with and without wetting up the roadbed. This generally requires placement of a cohesive or well graded granular layer over the in situ materials to provide sufficient grip to rotate the 3 or 4 sided impact rollers without shearing the materials.
- Whatever methods are selected, provisions should be made for field trials to select the method and plant needed to achieve the desired result. These methods need to be adequately described and included in the list of roadbed treatments for the particular project. See Chapter 9: 2 for more on roadbed treatments.
-
- The degree of densification and the depth to which densification is required are factors that must be assessed individually for each road project. Note that due allowance needs to be made for the importation of additional fill required over the treated areas.

6.5.4 Soils and Fills with a Collapsible Grain Structure

Soils with a collapsible grain structure can adversely affect the foundation of structures. Procedures for identifying soils with a collapsible fabric both in the field and the laboratory have been developed (Schwartz, 1985). Naturally occurring decomposed soils may have a collapsible grain structure. Loose, or poorly compacted, fills are also subject to potential collapse settlement, and when wetted up can experience collapse settlement without applying additional static loading, as illustrated in Figure 22 (Schwartz, 1985). A natural soil that has a collapsible soil structure, from decomposition and leaching, may withstand relatively large imposed stresses with small settlements at a low in situ moisture content. Wetting up can result in a large decrease in volume and large magnitude settlement under an applied stress. The change in volume in the soil is associated with a change in soil structure.



Figure 21. Impact Roller

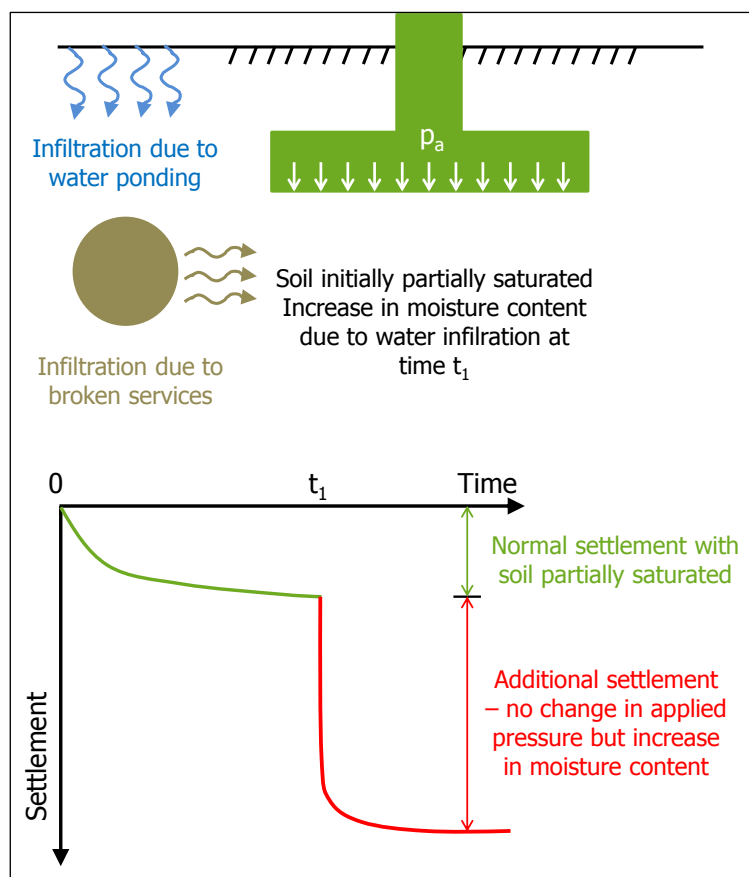


Figure 22. Basic Concept of Additional Settlement Due to Collapse

Whilst there are a number of preconditions that must be satisfied before collapse settlement occurs under static loads, not all of these preconditions need to be satisfied under heavy dynamic loads. Research has shown that on roads, under certain circumstances, an increase in the moisture content is necessary for collapse to occur. The application of dynamic loads may be sufficient to cause shear failure of bridging colloidal material. This is of

particular importance for roads, heavy duty pavements, airfields and railways where the subgrade is continuously subjected to dynamic loads. A secondary aspect is the large reduction in volume that collapsible subgrades experience with compaction, and the associated cost implication from the increased layer works quantities required.

Engineering solutions to the collapse problem of the roadbed or subgrade include the following methods:

- **In situ densification** by various types of rollers, including high energy impact compaction
- **In situ densification** by surface pounding (dynamic consolidation)
- **Remove and reuse** the material in compacted layers at predetermined moisture contents
- **Chemical stabilization** with compaction

The degree of densification and the depth to which densification is required are factors that must be individually assessed for each road project. Measures that simply avoid water penetrating the collapsible layers are risky in road construction as dynamic wheel loads are an effective shear failure triggering mechanism.

6.6 Saline Soils

Many soils in arid areas have naturally high saline contents. These salts can negatively influence conventional soil stabilizers, such as lime and cement, when constructing layer works. Certain highly soluble salts can also lead to the precipitation of these salts in upper layers in the pavement, resulting in deterioration of compacted layers and surfacing seals. Conventional conductivity testing as specified for gravels in the Standard Specifications identifies potentially problem materials and the necessary corrective action can be taken. See Chapter 3: 2.10 and Chapter 4: 2.7. This involves removal of the problem material, reduction of the solubility of the salts using lime treatment, or special preventative measures that minimise the movement of the salts through the layers. (Netterberg, 1979)

6.7 Dispersive and Erodible Soils

6.7.1 Origin of Dispersive Soils

In layman's terms, dispersive soils can be described as soils that undergo self-dispersion in water. The recognition of dispersive soils and their influence in engineered structures, such as earth dams and fills is described by Elges (1984). Dispersion occurs when the repulsive forces between the individual clay particles exceeds the attractive (van der Waal's) forces so that when the soil is in contact with water the individual particles become detached and go into suspension.

6.7.2 Effect of Dispersive Soils

On natural slopes, the presence of such soils is clearly evidenced by piping and the rapid formation and expansion of erosion dongas. In earth dams and road fills, piping can, and has, resulted in failures.



Dispersive Soils

Dispersive soils go into suspension in the presence of water.

6.7.3 Investigation of Dispersive Soils

Dispersion is prevalent in soils with a high exchangeable sodium percentage (ESP) relative to the other exchangeable cations, i.e., calcium, magnesium and potassium. High sodium levels (compared to high calcium levels) cause particles to repel one another when wet, and the associated aggregates to disaggregate and disperse. The tendency for dispersive erosion in a soil thus depends on the mineralogy and chemistry of the soil and its clays, as well as the dissolved salts in the ground water and the dispersing water. High ESP's can occur in soils with smectite (montmorillonite) clays as well as in tillites.

Natural clays can be grouped into two main categories with fundamentally different erodibility characteristics:

- **Ordinary clays**, which are relatively erosion resistant
- **Dispersive clays**, which deflocculate in the presence of relatively pure water and are, therefore, highly susceptible to erosion and piping.

Dispersion occurs when the repulsive forces (electrical surface forces) between individual clay particles exceed the attractive (van der Waal's) forces so that when the clay mass is in contact with water, individual clay particles are progressively detached from the surface and go into suspension. If the water is flowing, the



Recommended Reading

- **Problem Soils in South Africa – State of the Art. Dispersive Soils** by HFWK Elges. The Civil Engineer in South Africa. Vol. 27, No. 7 July, 1985.
- **Dispersive and Erodible Soils – Fundamental Differences** by P Paige-Green, Proceedings Problem Soils in South Africa, 2008. SAICE/SAIEG, Midrand.

dispersed clay particles are carried away, thus adversely affecting the subgrade. (Elges, 1985)

The main property governing the susceptibility to dispersion is the percentage of sodium cations on the clay surfaces relative to the quantities of the polyvalent cations, e.g., magnesium and calcium. The second main property is the total content of dissolved salts in the water. The lower the dissolved salt content, the greater the susceptibility to dispersion.

Laboratory tests utilised to determine the dispersive potential of soils include:

- **Chemical tests**, done in a chemical laboratory, to determine the ESP and the soluble salt content, where

$$\text{ESP} = \frac{\text{exchangeable sodium}}{\text{cation exchange capacity}} \times 100 \quad (1)$$

An ESP > 10 indicates a potential problem and a need for further testing. All soils with an ESP > 15 can be regarded as being highly dispersive (Harmse).

- **Crumb Test** (United States Bureau of Reclamation (USBR), 5400): In this test, a moist soil is pressed into a 15 mm cube, which is then submerged in distilled water. On hydration, the tendency of colloidal particles to deflocculate and go into suspension is observed and reported on a scale of 1 to 4, where 1 is no reaction and 4 is a strong reaction. The test gives a reasonable indication of the erodibility of the soil, but is not 100% reliable.
- **Pinhole Test** (USBR 5410/ASTM D4221): In this test, a 1 mm hole is made through a 25 mm long by 35 mm diameter soil specimen. Water is passed through the pinhole under various heads while recording the flow rate and effluent turbidity.
- **Double Hydrometer test** (USBR 5405/ASTM D4647): In this test, the 5 µm particle sizes in a soil are measured in the standard hydrometer test (see Chapter 3: 2.3). A comparison is made with a parallel test where no dispersant or mechanical agitation is applied. The 5 µm content in the parallel test is expressed as a percentage of that measured in the standard test. Values > 35% indicate dispersive soils.

Bell and Walker (2000) propose the use of the pinhole test, the crumb test and various chemical properties including the cation exchange capacity, ESP, sodium adsorption ratio, total dissolved salts and percentage sodium in saturation extract in a rating system for the classification of potentially dispersive soils.

It is apparent that the use of dispersive soils in road fills needs to be carefully considered. Measures have to be taken to prevent situations developing that can lead to piping or erosion of fill slopes, especially those of larger fills. Counter measures must, of necessity, include water management, especially where fill is located on slopes. Culvert and drainage pipe inlets may need to be protected by a skin of non-dispersive materials. Side slopes may likewise need to be protected by an outer non-dispersive or filter material. Semi horizontal filter or drainage layers in the fill may be needed to circumvent piping. Treatment of the soils with calcium cations is the normal technique used to neutralise the sodium problem, but this needs careful design.



Information on Dispersive Soils

Much of the work on dispersive soils has been done by Heinrich Elges, and mostly for earth dams. This work brought the phenomenon to the attention of the road building industry. Major problems have not been attributed to dispersive soils, but it is probably the underlying cause of many a wash-away. Designers of new roads should, therefore, be aware of the problem.

6.8 Made Ground and Landfills

Made ground and landfills can take many forms including:

- Backfilled trenches
- Constructed embankments
- Levelled or shaped fields
- Terraced slopes
- Buried refuse and rubble
- In-filled borrow pits
- Quarries and landfills
- Reclaimed land
- Other landfills

Roads and road structures planned in urban or semi-urban areas often cross zones underlain by old backfills or man-made embankments and landfills, old construction sites and sports fields, in other words 'filled-up ground'. Such fills are by nature not only very compressible and potentially collapsing, but could also pose additional threats. For example, they may contain unsuitable materials of various types, be environmentally unfriendly, could generate excessive methane, or, have perched seasonal water tables. Special consideration should therefore be given to the planning of geotechnical investigations in such areas. The scope and results of these investigations should indicate whether the materials could be left in place after sufficient compaction, treated to serve as a roadbed, or removed entirely. Should the material be spoiled, the type and depth of material to be removed must be identified, the stability of the material whilst being excavated assessed, and the necessary construction plant identified. Should the filled up ground only require in situ compaction, the geotechnical engineer should indicate the proposed depth of in situ compaction and propose the densification process together with the type of plant most suitable for the compaction and to ensure stability of the materials.

In general, many of these will be easily recognisable, although some purposely rehabilitated areas may need a trained eye to pick up signs of earlier activities while others may only be revealed by intrusive investigations. Generally, all these will have some influence on the provision of a stable uniform roadbed for a new road or the widening of an existing road, generally by way of compressible, possibly even collapsible roadbeds, differential settlement and even more complex situations arising from altered surface and subsurface drainage. Many landfills originate from the dumping of waste in old surface excavations, i.e., borrow pits, quarries or open cast mining areas, and with time rise above natural ground level. Dumped materials have been shown to comprise household refuse, all kinds of industrial refuse including toxic substances, medical waste, animal waste, other organic waste and even old machinery and vehicle wrecks! Furthermore, with time the decomposition of organic matter has led to the formation of methane and other gases, to such an extent that on some sites it is being recovered. Other areas may be contaminated with waste fluids, for example, industrial effluents and oils, and their resulting gases lead to unsafe conditions.

The first step in determining the presence of made ground, is a desk study. Local authorities will have records of their own services and approved activities as well as of ownership, which provides a means of determining past utilisation and activities. In carrying out reconnaissance in the field, variations from adjacent areas usually provide the first indication of made ground. These may include features such as unnaturally steep or flat areas, changes in soil type and/or colour, changes in vegetation, lack of vegetation, surrounding land usage and changes in drainage lines and patterns.

The excavation of test pits and the examination of the soil profile provide clear evidence of whether the ground has been disturbed or not. Even properly backfilled excavations will be recognisable by many indicators including soil structure consistency, density, colour variations, uniformity, presence of inclusions and waste materials and particle orientation.

Probably the most problematic aspects of man-made ground are the:

- General **looseness** or compressibility of the in-filled and altered material.
- **Abrupt changes** in consistency, density and compressibility that occur over short distances, which may be caused by traversing the edges of excavations, especially where these may be in rock.

Where the presence of such features is indicated, use is generally made of DCP probing, auger drilling and where hole collapse is a problem, percussion drilling to determine the line and depth of apparent disturbance. Where appropriate, rotary drilling and in situ testing are generally carried out thereafter, to provide core and test results to enable determination of the strength and settlement parameters.

Where stability and/or settlement problems are indicated, and where realignment of the road is not feasible, solutions such as:

- **Densify** the roadbed, e.g., impact rolling and dynamic compaction, illustrated in Figure 23
- **Remove and replace** the problem materials
- **Bridging** the problem area may be considered

Health considerations may rule against the remove and replace option. The extent of the problem determines the most appropriate solution ("*horses for courses*").

Other than minor occurrences of made ground, such as local terracing, levelling of ground and infilling of trenches, which can be easily overcome, specialist geotechnical input and intensive investigation is required. This is particularly necessary for larger man-made filling activities such as large excavations in mines and quarries that have been filled-in, and large landfills.

As with other problems that may be encountered in the roadbed, the selected and appropriate steps in addressing these problems need to be converted into specific sequential steps, and included in the list of roadbed treatments required along the line of the new road or road widening. See Chapter 9: 2.

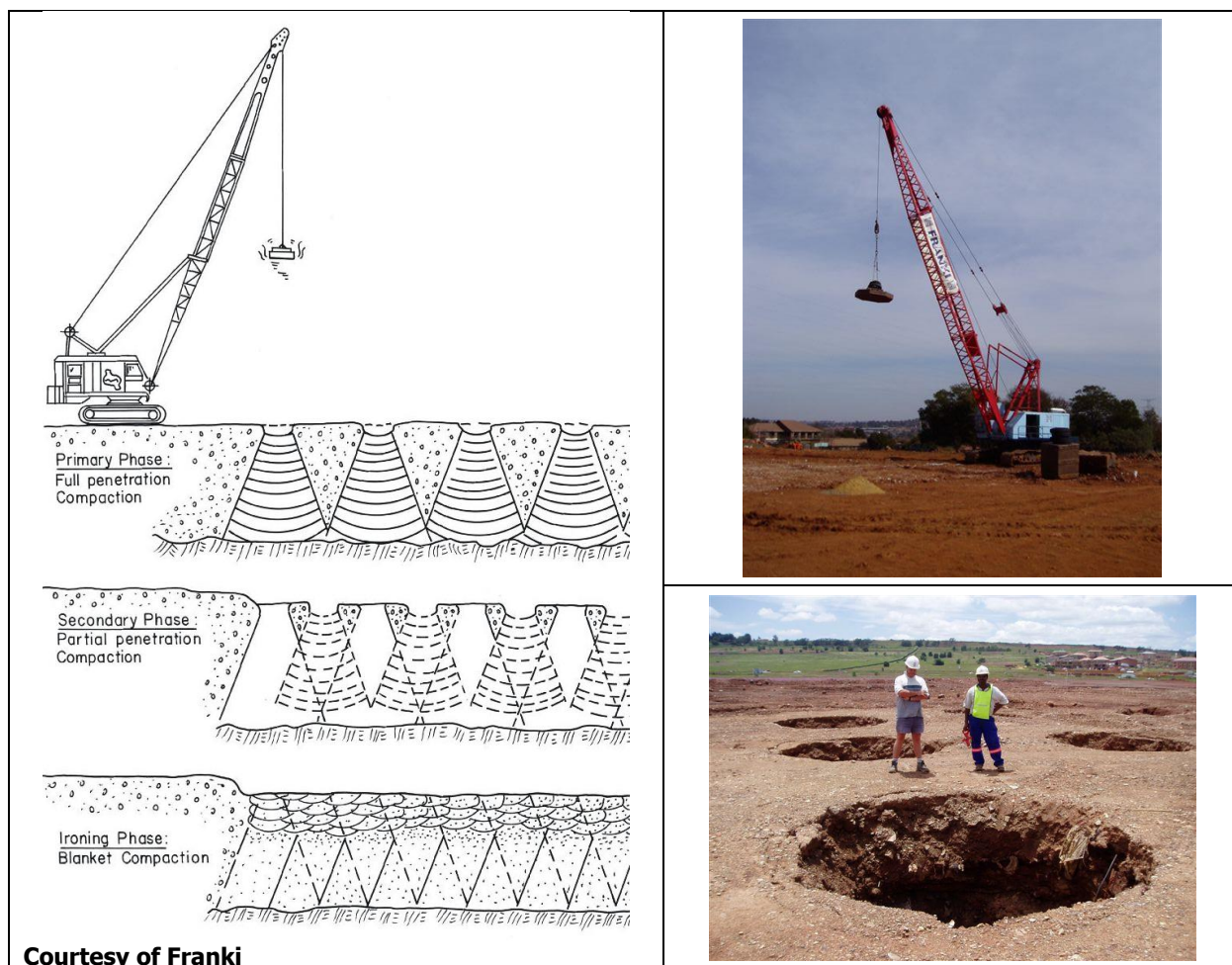


Figure 23. Principles and Illustrations of Dynamic Compaction

7. ROAD PAVEMENT INVESTIGATIONS

This section covers the investigation of existing road pavements to provide information for the planning of periodic maintenance measures, such as reseals or asphalt overlays, as well as for upgrading and rehabilitation design.

The road pavement investigations identify the types, severity and extent of pavement distress. "Uniform sections", which exhibit similar distress patterns, and can therefore be treated in a similar manner, are also identified. This section deals with additional investigations to provide more detailed information on the existing pavement structure and structural capacity.

It should be noted that road rehabilitation often includes pavement widening and the construction of sealed or gravel shoulders. This particular section concentrates on the investigation of the existing traffic lanes and shoulders. Where widening is to be carried out, it normally involves work on in situ materials, hence, the investigation is covered under Section 5, Road Prism Investigations.

7.1 Investigation Stages

The various stages of investigatory work carried out on existing road pavements follow the strategy given in TRH12. Projects that require attention are initially identified at network management level, using Pavement Management Systems (PMS). Detailed information on PMSs are covered in TRH22, and are briefly discussed in Chapter 14: 5.

The sequence and scope of investigations depends on how the information is to be used and also the Road Authority's policy regarding the phasing of the reporting and the ultimate construction work. Typical phasing of road pavement investigations is covered in Section 7.5.

7.1.1 Investigations Required for Inputs into PMS

Surveillance methods used to gather information as inputs into PMS include, inter alia:

- **Riding quality** measurements (Section 7.3.1)
- **Rut depth** measurements (Section 7.3.2)
- **Surface texture** (Section 7.3.3)
- **Deflection bowl** measurements (Section 7.3.4)
- **Visual inspections** (Section 7.3.5)

Once roads in need of attention have been earmarked, more comprehensive investigations are carried out. The aim is to acquire sufficient information to enable the most effective solution to be implemented. These investigations form the basis of the Pavement Condition Assessment.

7.1.2 Pavement Condition Assessment

The pavement condition assessment is covered in two stages:

- **Initial Road Pavement Assessment**, which includes:
 - A desk study in which all available information of the pavement from the PMS and as-built data is gathered.
 - A detailed visual assessment of the pavement's condition is carried out, utilising appropriate manuals including TRH6 and TMH9 for flexible pavements, and TRH19 for concrete pavements. Note that, a revised TMH9 will be available in 2014, which will supersede the older manuals, such as TRH6, TRH19, TMH12 and M3-1. The revised TMH9, "Standard Visual Assessment Manual" (2014) includes sections for surfaced roads, block pavements, concrete pavements and gravel roads. It describes how to rate distress in terms of degree (severity) and extent (prevalence) of the type of distress.
 - Pavement surveillance measurements of deflections, rut depth, texture depth, skid resistance and riding quality.
- **Detailed Road Pavement Assessment**, which includes the following intrusive or destructive investigation methods:
 - Test pits and trenches
 - Core sampling
 - DCP probes



TRH Revisions

Many of the TRH guideline documents are in the process of being updated. See the SANRAL website, www.sanral.co.za for the latest versions.



Drainage

Drainage is an extremely important consideration for pavements! Water is the primary cause of premature failure, accelerated distress and reduced structural capacity.

All aspects of drainage are comprehensively covered in SANRAL's Drainage Manual and not repeated in SAPEM. Download the Drainage Manual from www.nra.co.za.

The results of the Pavement Condition Assessment are utilised in the project's intervention assessment and/or rehabilitation design. Several other aspects also have to be taken into account in the rehabilitation design, such as, geometric and environmental considerations, and constructability. Usually, several rehabilitation design options are considered. An economic analysis is undertaken to finally choose the most effective rehabilitation method and design for the project.

The results of the investigations are also used in drawing up the specifications in the Tender Document, and in assessing the various quantities for the Pricing Schedule. See Chapter 11 for more details.

7.2 General Considerations

7.2.1 Traffic Safety

The safety of the investigation team, as well as pedestrians and the travelling public, is of paramount importance. Safety measures that should be implemented depend upon the location of the project, traffic volume and type of investigation survey, and include, inter alia:

- Warning and speed restriction signs
- Cones and barriers
- Flagmen
- Reflective safety vests

The establishment of staff and equipment on the road should not be allowed until all the warning signs and traffic accommodation measures have been put into place, as covered in Section 4. Safety aspects are further emphasised in this section of the manual where intrusive investigations, such as test pits, are carried out, See Section 7.4.1.

7.2.2 Scope of Investigation

The types and frequency of investigation should be selected to keep the investigations within logistical and economic limits, and depend to a large extent on factors such as:

- **Road category.** Roads carrying high volumes of traffic require a higher level of design reliability than roads that carry light traffic. Typically higher testing frequencies and more sophisticated investigation procedures are required on high traffic volume roads.
- **Variability of existing pavement materials.** The degree of variability of materials in the road pavements influences the frequency of testing.
- **Pavement type.** Investigations are selected to suit the type of pavement under investigation. For example, pavements with bound layers, such as concrete pavements, or pavements with asphalt bases and surfacing layers, can be investigated by taking core samples. Cores samples are, however, not possible if the pavement consists of surfacing seals and unbound, granular layers.

In essence, the investigation should be aimed at providing the designer with sufficient information to find the most practical and economical rehabilitation or upgrade design solution. Consideration should always be given to the benefit of using more sophisticated equipment against the additional costs involved.

Experience has shown that, particularly in the case of larger projects, the investigation should be divided into at least three distinct phases:

- Firstly, carry out the **non-intrusive investigations**, for example, riding quality, rut depth, texture depth, deflection measurements and visual assessment. Allow sufficient time for these results to be evaluated. This information assists in determining uniform sections and the positions and frequencies of the intrusive investigations.
- Secondly, carry out the **intrusive investigations** that include the excavation of test pits or trenches, core sampling of bound materials, and dynamic cone penetrometer (DCP) probes.
- Thirdly, additional testing, typically including further **trial pits and DCP** probes, is often necessary to fill in information gaps that become apparent once the results of the first two phases are collated.



Investigation Team Safety

The safety of the investigation team, as well as pedestrians and the travelling public, is of paramount importance.

7.2.2.1 Uniform Sections

One aim of the pavement assessment is to determine uniform sections. These are sections where the pavement's condition in terms of functional properties, such as riding quality and rut depth, is similar, and, the types of materials, condition of materials and pavement structures are similar. Uniform sections are assigned one rehabilitation design.

There are many methods of determining uniform sections. Many use a statistical parameter, such as the sum of cumulative differences (known as CUSUM), to determine locations where there is a significant change in one or more pavement parameters. The CUSUM is the cumulative sum of differences between the values and the average for that section. That means that, for example, if all the values are above the average, the sum steadily increase, which plots as a line with a positive slope. The sum of cumulative differences is typically calculated for each maximum deflection value and plotted over the length of the section. Where the plotted parameter changes sign, i.e., where the slope changes, indicates a new uniform section. A good reference for the sum of cumulative differences methods is the AASHTO Design Guide (1993). Data from a road rehabilitation project is shown in Figure 24. Superimposed on the maximum deflection data (Y-max), roughness and rutting are CUSUM lines, shown in blue. In this case, the rutting and Y-max data both suggest a change in the pavement state at km 16.6, indicated by the change in slope direction of the CUSUM line.

While statistical methods are undoubtedly useful, it is recommended that the methods are not used in isolation and especially not using only one parameter. It is rather recommended that a more holistic approach is used, in which the uniform section delineation is based on an expert appraisal of all available information. In general, sections of a project which have severe rutting and poor riding quality are likely to show relatively high deflections. In other words, the functional properties and the deflection measures are usually in agreement, aiding the selection of uniform sections. Graphical displays of data in stripmap form, an example of which is given Figure 24, are very useful for assessing all data and deciding on the uniform sections. The delineation of uniform sections should be based on not only where the data are the same, but should focus on the intervention action that can be considered in the different areas. TRH12 recommends the delineation focusses on:

- Areas requiring **no rehabilitation action**
- Areas with **only surfacing problems**
- Areas with **localised problems**
- Areas requiring **structural strengthening**. These areas may need further subdivision.

Once the initial uniform sections have been determined, the next step is to carry out intrusive testing to gather more detailed information on the thickness and quality of the various layers in the pavement. This allows further refining of the initially defined uniform sections.



Uniform Sections

A uniform section is a section of road for which the condition and structure are similar. Appropriate rehabilitation options are, therefore, suitable for the whole section. The final design selected should be used on the full uniform section.

Uniform sections should not be so short as to introduce construction problems.

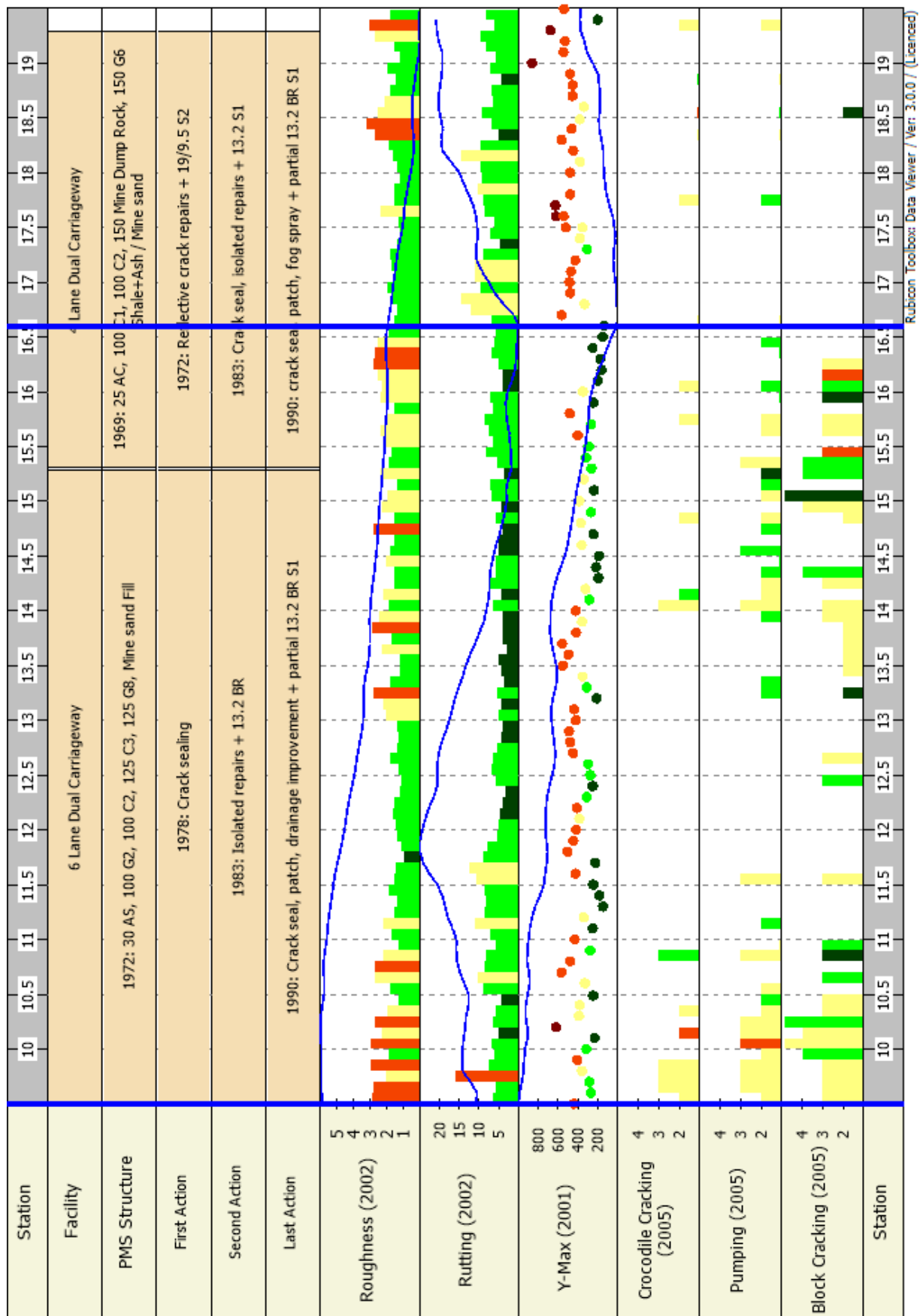


Figure 24. Stripmap Representation of Data from the Initial Assessment Phase

7.3 Field Investigation and Sampling: Non-Intrusive Methods

Non-intrusive investigation methods include those that measure the functional condition of an existing road pavement, such as roughness and texture depth. Others, like rut depth and deflection, provide information on the pavement's structural capacity. In the pavement rehabilitation design process, the results of these investigations are used individually to assess the pavement's condition, and holistically to get a clearer picture on the pavement's behaviour and pavement life.

Advances in the electronics field in recent years have led to the development of sophisticated equipment to carry out and record these measurements. It is possible to combine several functions into one road surveillance vehicle so it is only necessary to traverse the traffic lane once to capture a huge quantity of information. The various types of equipment are discussed further in Chapter 14: 3.4.

7.3.1 Measurement of Pavement Roughness

Pavement roughness is generally defined as an expression of the irregularities in the pavement surface that adversely affect the riding quality of a vehicle (and thus the user). Roughness is also referred to as the smoothness of a road pavement. Causes of roughness are manifold, ranging from poor/uneven construction of surfacing to chip loss, ravelling of asphaltic surfacing, potholes, patches to local settlements and subsidence. Roughness is an important pavement characteristic as it affects not only the riding quality but also travel times, fuel consumption and vehicle maintenance costs.

The roughness of a road pavement can be expressed either as Present Serviceability Index (PSI), Half Car Index (HRI) or International Roughness Index (IRI). IRI is typically used in South Africa. An example of the IRI scale for various types of roads is given in Figure 25, and is taken from the COTO Roughness Guidelines (2008). These concepts were developed from the AASHO Road Test, which is described in Chapter 6: 2.2.1.

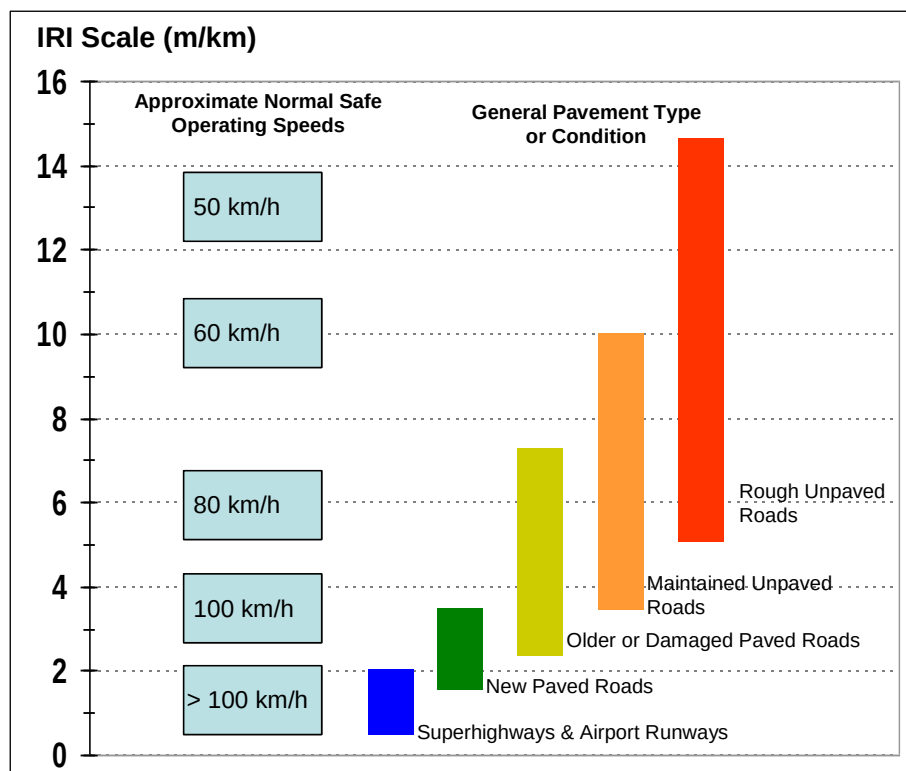


Figure 25. IRI Interpretation Scale

7.3.1.1 High Speed Profiling Devices

Methods to measure roughness have evolved considerably over recent years and high-speed road profilers are now available in this country that are capable of providing accurate scaled models of the pavement. The systems are mounted in vans that use laser or ultrasonic sensors to measure differences in the road surface. Microprocessors and other data handling and processing instrumentation capture this information. The resulting data, in the form of

a continuous plot of the road's IRI, is then passed on to the designer in electronic format. Examples of these vehicles are the Road Surface Profiler, shown in Figure 26, and SANRAL's Road Survey Vehicle, shown in Figure 27. These vehicles measure rutting, roughness, texture, crack width, detects road furniture, signs (and reflectivity of signs), gradient and crossfall, and take photographs of the road and the areas adjacent to the road.



Figure 26. Road Surface Profiler



Figure 27. SANRAL's Road Survey Vehicle

These devices are not successful in profiling gravel roads. The devices are very expensive and have to be well calibrated, which is a complex and expensive operation. This results in a high cost of measurement.

7.3.1.2 Precision Rod and Level

The operational principles of the precision rod and level are illustrated in Figure 28 (taken from Sayers and Karamihas, 1998). The operation is very similar to that of a normal rod and level operation, as used for surveying. However, in view of the high precision required for the profile of calibration sections, the precision rod and level equipment has a higher precision and the operation should follow the standard test method (ASTM E1364-95). The test requires at least two persons and is time consuming and labour-intensive. A typical profile measurement will involve around 260 readings, and an experienced team can profile approximately 600 metres per day. The method is therefore only suited for measuring profiles on calibration sections or for research or construction control purposes.

Once the profile of a calibration section has been measured, the profile is processed to determine the IRI of the section. The IRI can then be used to calibrate response type systems, while for profiling validation, both the measured profile and the IRI can be used.

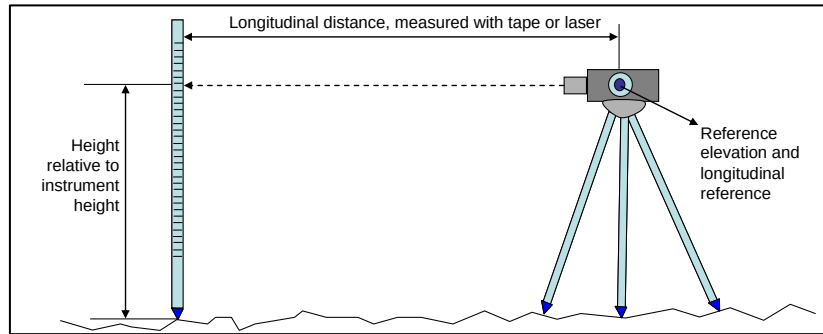


Figure 28. Operation of the Precision Rod and Level

7.3.1.3 Dipstick

The Dipstick is a hand operated instrument that measures the elevation difference between its two support legs. The instrument is advanced by lifting and moving the rear leg to a position ahead of the front leg in the required direction. An audio signal is released when a measurement is concluded. The instrument is very accurate and is used for calibrating purposes. The Dipstick can measure 200 metres per hour. The Face Dipstick™ is shown in Figure 29.

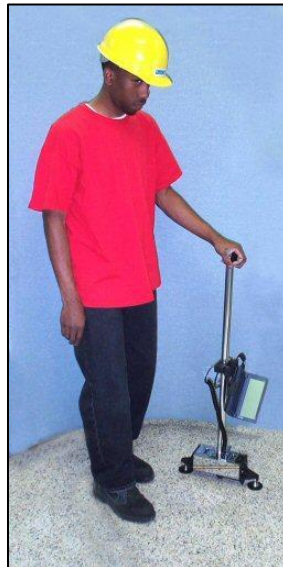


Figure 29. Face Dipstick™

7.3.1.4 Walking Profilometer

A walking profilometer is also used to measure roughness. The ARRB Walking Profilometer is illustrated in Figure 30. Profile measurements are performed at walking pace or roughly 800 metres per hour, with a practical production rate of 4 km per day. The outputs from the device include the distance, grade and IRI.



Figure 30. ARRB Walking Profilometer

More information on roughness measurements, including background on the devices and setting up surveys, is included in the 2008 COTO guidelines (which will be republished as TMH13).

7.3.2 Rut Depth Measurements

In TMH9, rut depth is defined as the maximum deformation measured under a 2 metre straight-edge placed transversely across the rut. The presence, severity and shape of rutting provide valuable insight concerning a pavement's condition. Wide, even shaped ruts, illustrated in Figure 31, indicate that the weakness in the pavement is located in the lower pavement layers. Narrower, more clearly defined ruts indicate that the problem is in the upper pavement layers, as illustrated in Figure 32.

Rutting is a safety concern because of aquaplaning, which occurs as a result of water pooling in the ruts and not draining away.

The simplest way to measure ruts is manually, with a 2 metre straightedge. A calibrated metal wedge, which is inserted between the road surface and the lower surface of the straightedge, is normally used to accurately measure the rut depth. Due to the time consuming nature of this work, initial rut depth measurements should generally be taken in the outer wheel path at intervals of 100 m, but should be guided by the results of the detailed visual assessment. Where there is a prevalence of rutting, more closely spaced measurements should be taken to quantify the depth of the rutting.



Aquaplaning

Aquaplaning, or hydroplaning, occurs when a layer of water builds between the rubber tyres of the vehicle and the road surface, leading to the loss of traction and thus preventing the vehicle from responding to control inputs such as steering, braking or accelerating. If it occurs with all wheels simultaneously, the vehicle becomes uncontrollable.

The grooves that form the tyre thread are designed to disperse water from beneath the tyre, providing high friction even in wet conditions. Aquaplaning occurs when a tyre encounters more water than it can dissipate. Water pressure in front of the wheel forces a wedge of water under the leading edge of the tyre, causing it to lift from the road. The tyre then skates on a sheet of water with little, if any, direct road contact, resulting in a loss of control.

The risk of aquaplaning increases with the depth of standing water, speed of the vehicle, tyre pressure and tyre footprint. In general, cars aquaplane at speeds above 72 km/h, where water ponds to a depth of at least 2.5 mm over a distance of 9 meters or more.

Other factors, such as surface texture, as well as the pavement's crossfall, camber, and grade, also play a part in aquaplaning. For instance aquaplaning is less likely to occur on grades, even though the pavement is rutted, than along flat grades or at the bottom of vertical curves, where the water in the ruts collects to form a thick film during and after rainfall. (Wikipedia).



Figure 31. Wide Subgrade Rutting



Figure 32. Narrow Wheelpath Rutting

Vehicles equipped with several lasers mounted on a beam, coupled with electronic data capturing and recording devices, simultaneously measure the rut depths in both wheel paths. These systems enable closely spaced rut depth measurements to be taken and recorded, making it easy to manage and manipulate the data. Many of the vehicles equipped to measure roughness also measure rutting, an example of which is the Road Surface Profilometer shown in Figure 26. Guidelines for interpreting rutting data are given in Table 8, from TRH12.

Rut depth measurements can be plotted against other parameters, such as maximum deflection measurements, to provide more insight into the pavement's performance.



Shapes of Rutting

Wide, even shaped ruts (Figure 31) indicate that the weakness in the pavement is located in the lower pavement layers. Narrower, more clearly defined ruts (Figure 32) indicate that the problem is in the upper pavement layers.

More information on rutting measurements, including background on the devices and setting up surveys, is included in the 2010 COTO guidelines on rutting measurements.

Table 8. Structural Interpretation of Rut Depths

Rut Depth	Interpretation
< 10 mm	Sound
10 to 20 mm	Warning
> 20 mm	Severe

7.3.3 Surface Texture Measurements

The texture of the road's surface is a functional property that plays an important role in skid resistance, particularly under wet conditions. Skid resistance tends to increase with increased texture depth. Texture depth also determines whether the road surface requires a pre-treatment before it is resealed with a surfacing seal. Road surface texture can be split into two categories, namely micro and macro texture.

7.3.3.1 Micro Texture

Micro texture is the fine sandpaper feel of the surface, and is primarily a property of the aggregate making up the road surface. Micro texture can be measured with a portable pendulum tester as described in ST2 of TMH6. This instrument is mainly used in small scale investigations and returns the PSV (Polished Stone Value) of the surface stones.

For larger projects or network level surveys, there are basically four types of devices available for testing micro texture. These are fixed slip devices, sideways force measurement devices, locked wheel systems and variable slip devices. Fixed slip and sideways force measurement devices give more comparable results and are suitable for network type surveys as they are measuring at low tyre/surface interface velocities. Typical examples of these instruments are:

- The **SCRIM** (Sideways-force Routine Investigation Machine), illustrated in Figure 33, uses a smooth standardised rubber tyre, skidding over a wet surface at a 20 degree angle. The ratio of the sideways force to the normal load on the wheel is termed the "sideways force coefficient of friction" (SFC). The higher the SFC value, the greater the micro texture. Table 9 illustrates recommended guidelines for the classification of appropriate levels of risk for typical site categories. A lower micro texture is required for free flowing high speed roads than for lower speed roads, where sharp bends and braking actions are expected. This SCRIM is difficult and expensive to calibrate, hence it is not used regularly in South Africa.
- The **Griptester** is a fixed slip device that measures the tyre/surface friction on a wheel that moves at 20% of the moving speed. For example, if the vehicle is moving at 50 km/h, the wheel moving at $50 \times 0.2 = 10$ km/h. The device is usually mounted on a trailer and towed behind a vehicle. The Griptester is shown in Figure 34.



Griptester

The Griptester is the most common device used in South Africa for testing micro texture.

Table 9. Guidelines for Skid Resistance

Road Description	Lower Limit (SFC @ 50km/h)				
	0.35	0.40	0.45	0.50	0.55
Dual carriageway Motorway	✓				
Dual carriageway with minor intersections Single carriageway		✓			
Approaches to and across major intersections Single carriageways with minor junctions			✓		
Gradients > 5%, longer than 50 m			✓		
Bends with radius < 250 m, speeds 70 km/h			✓		
Gradients > 10%, longer than 50m				✓	
Approaches to traffic signals, pedestrian crossings, rail crossings					✓



Figure 33. SCRIM to Measure Micro Texture



Figure 34. Griptest to Measure Micro Texture

A close relative of the fixed slip devices are the variable slip devices. These basically follow the same principle as the fixed slip devices, except that the resistance is applied by a braking system so that the tyre/surface friction can be varied. A typical example of this type of device is the Roar device manufactured by Norsemeter in Norway, shown in Figure 35. Load and drag forces are measured when the wheel is locked and dragged of a wetted surface for between 1 to 3 seconds at a time. These values are then converted to produce a skid number (SN). Brake force meters or locked wheel systems are rarely used in large scale measurements, because the high interface velocity induces extremely high tyre wear.

When using any of these machines it is important to take all variables, such as tyre, air, water and surface temperatures, into account to produce consistent and reliable results. Seasonal changes must also be taken into account when comparing annual network results. For example, pavements are washed clean during a rainy season, which improves the microtexture of the road surface.



Figure 35. Norsemeter to Measure Micro Texture

7.3.3.2 Macro Texture

Surface macro texture provides pathways for water to escape between the vehicle tyre and road surface interface. Macro texture measurements may be carried out using the “sand patch” test method described in test method ST1 of TMH6. The Australian test method MAT-TP346, “Determination of the Average Texture Depth of a Pavement Surface Using the Sand Patch Method”, measures macro texture in a similar way (TMH6). These tests, which tend to be time consuming, should be carried out both within and between the wheel paths to assess the variability of the surface texture. Tests should typically be carried out at 200 metres intervals. Closer spacings are recommended where the detailed visual inspection shows problems with the road’s surface texture.

The macro texture of the pavement’s surface can also be measured by means of a laser system. Devices are available to take these measurements in a push mode at a speed of 5 km/h, or by using lasers mounted at the front of a motor vehicle, when travelling at highway speeds. The laser shines as a fine beam of light onto the road and a receptor receives the reflected signal. The difference between this reading and the calibrated distance is the texture depth.

Specialised road surveillance vehicles, such as the SANRAL vehicle shown in Figure 27, are equipped to carry out macro texture depth measurements at close intervals, and as in the case of roughness and rut depth measurements, this enables a much greater population of results, as well as quicker and easier data management and manipulation. The vehicles are usually equipped with a texture measurement laser in the left wheel path. There are, however, vehicles equipped with texture lasers in the left, right and in between the wheel paths.



Consider Variables in Texture Tests

When using any of the devices to measure texture, it is important to take all variables, such as tyre, air, water and surface temperatures, into account to produce consistent and reliable results.

Macro texture measured with lasers is expressed as Mean Profile Depth (MPD). MPD can be compared with the sand patch texture depth by using Equation (2).

$$\text{Sand Patch (Estimated Texture Depth): } \text{ETD} = 0.8 \text{ MPD} + 0.2 \quad (2)$$

MPD values are interpreted according to the guidelines in Table 10.

More information on texture measurements, including background on the devices and setting up surveys, is included in the 2009 COTO guidelines on skid resistance and texture, available on the SANRAL website, www.nra.co.za.

Table 10. Interpretation of Texture Depth

Measured Texture Depth (mm)	Assessment
0.2	Very poor
0.5	Poor
1.0	Adequate
1.5	Adequate - rough

7.3.4 Deflection Measurements

Road pavements deflect under wheel loads. This deflection provides valuable information about the pavement structure and condition. The deflection is measured under the load and at distances of 2 meters away from the load. The maximum deflection measured under the load is used in some methods for estimating structural capacity. The deflection bowl, an example of which is shown in Figure 36, gives information on the pavement structure.

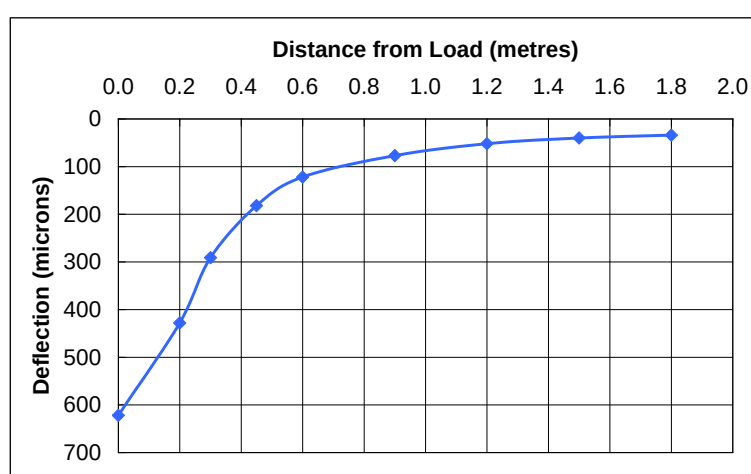


Figure 36. Example of a Deflection Bowl

Deflection measurements have been undertaken in countries around the world for many years, and research has produced a variety of pavement design methods based on applications of these measurements. See more on these in Chapter 10.

Deflections are measured with a Benkelman Beam, deflectograph and FWD. TMH6 contains a test method for measuring deflection, using a Benkelman Beam illustrated in Figure 37. The end of the beam is placed between the dual wheels of a loaded truck with a standardised axle load, tyre spacing and tyre pressure. The truck is moved slowly, causing a deflection in the road's surface, which is measured by the beam. Measurements can be taken as the truck's wheels approach the beam and when the dual wheels are directly over the end of the beam. In this way, the radius of curvature as well as the maximum deflection can be measured.

The Benkelman Beam method is tedious. Other less time consuming methods have been developed that tend to supersede it. These are the deflectograph, which is a modified version of the original french La Croix deflectograph, and the Falling Weight Deflectometer (FWD). The deflectograph is shown in Figure 38 and the FWD in Figure 39.

The deflectograph device works on the same principles as the Benkelman Beam. However, the placing of the beam is automated and deflection measurements are carried out electronically in the large, specialised vehicle. In essence, the unit "leapfrogs" beams on either side of the vehicle, measuring the deflection bowl and maximum deflection at intervals of 2 metres as it travels along the road. These data are captured and stored on a computer in the vehicle.



Figure 37. Benkelman Beam for Measuring Deflection



Figure 38. Deflectograph for Measuring Deflection



Figure 39. Falling Weight Deflectometer (FWD) for Measuring Deflection

The FWD testing principle is different, in that a calibrated load is dropped onto the surface of the road. This produces a deflection, which is monitored by several geophones, one located at the centre of the impact load, and the others at set distances, usually 0, 200, 300, 450, 600, 900, 1200, 1500 mm and 1800 mm from the point of impact of the load. This enables the maximum deflection, as well as the deflection bowl to be captured electronically. The FWD is installed in a trailer which is towed by a van equipped with a computer for capturing and storing the data.

These systems each have their advantages and disadvantages, but both are able to measure deflections much quicker and more efficiently than the Benkelman Beam. The FWD is now the device most commonly used in South Africa, and around the world.

FWD data can be very useful in helping to divide rehabilitation projects into uniform sections within which the pavement's response to FWD loading is similar. FWD data can also be used to calculate the degree of load transfer between adjacent slabs in concrete pavements. This provides information on "faulting" between the slabs, and gives an indication of voids under the slabs.

Besides the standard Falling Weight Deflectometer, this technology has been developed for a range of applications:

- The **light weight deflectometer** (LWD) is a portable falling weight deflectometer at is used primarily to test deflections during construction. The deflection can be backcalculated to determine the in situ pavement layer moduli.
- The **heavy weight deflectometer** (HWD), which employs high loads, is used mostly for investigating airport pavements.
- The **rolling weight deflectometer** is designed to gather data continuously on the move at speeds of 80 km/h or more. SANRAL's has such a device, named the Traffic Speed Deflectometer (TSD), illustrated in Figure 40.



Figure 40. SANRAL's Traffic Speed Deflectometer

The frequency of testing using the standard Falling Weight Deflectometers usually varies depending on the type of survey being conducted. Recommended frequency of testing for network level surveys is every 200 metres. For project level surveys, a higher frequency is required, with measurements recommended at 50 metre intervals. Measurements should be done in the left wheel path to measure the area which carries the highest traffic load under normal traffic conditions. The FWD equipment itself is covered in ASTM D4694, while the test method is defined in ASTM D4695. The COTO guidelines, which will be republished as TMH13, contain information on calibrating and validating the FWD, and the planning of network level surveys.

7.3.4.1 Interpretation of Deflection Measurements

The interpretation of Falling Weight Deflectometer (FWD) deflection results are widely used to evaluate pavements and give crude estimates of the remaining life. Some guidelines for the interpretation are given here, based on TRH12, Maree (1990) and Horak (2008). Much of the discussion in this section is taken from Horak (2008). Further discussion is provided in Chapter 10: 7.5.4.

The deflection bowl can be used to identify weak areas in the depth of a pavement structure and over the length of a uniform section, without detailed knowledge of the pavement structure, using deflection bowl parameters such as the base layer index (BLI), middle layer index (MLI) and lower layer index (LLI). The formulae for calculating these parameters are shown in Table 11.

Table 11. Deflection Bowl Parameters

Parameter	Formula
Base layer index (BLI) ¹	$BLI = D_0 - D_{300}$
Middle layer index (MLI) ²	$MLI = D_{300} - D_{600}$
Lower layer index (LLI) ³	$LLI = D_{600} - D_{900}$
Radius of curvature (RoC)	$RoC = \left(\frac{(L)^2}{2 D_0 (1 - D_{200}/D_0)} \right)$
	where D_0 = Maximum (peak) deflection ⁴ , measured under the load D_{300} = Deflection at 300 mm sensor D_{600} = Deflection at 600 mm sensor D_{900} = Deflection at 900 mm sensor L = 200 mm for the FWD

Notes

1. Previously referred to as surface curvature index (SCI)
2. Previously referred to as base curvature index (BCI)
3. Previously referred to as base damage index (BDI)
4. Also known as Y-max.

A deflection bowl measured under a load can be divided into three zones, as reflected in Figure 41 (from Horak, 2008):

- **Zone 1** is the closest to the load, and generally lies within 300 mm from the load. In this zone, the curvature of the bowl is positive. This zone is mainly surface and base layers, and correlates well with the base layer index (BLI).
- **Zone 2** is typically between 300 mm to 600 mm, although the exact positions depend on the pavement structure. In this zone, the curvature switches from a positive to reverse curvature. This zone is mostly the subbase layers, and correlates well with the middle layer index (MLI).
- **Zone 3** lies furthest away from the load, and is generally from 600 mm to up to 2 000 mm from the load. The curvature is reverse and the deflection eventually reduces to zero. The extent of the deflection bowl depends on the pavement structure. Zone 3 is mostly selected and subgrade layers, and correlates well with the lower layer index (LLI).

Condition classification criteria have been developed for a number of FWD deflection bowl parameters. Limiting criteria, relating the cumulative number of E80s to a number of deflection bowl parameters are available. The criteria given in TRH12 are shown in Table 12. Criteria for different behaviour states are given, including a crude estimate of remaining life for pavements with deflection bowl parameters within those ranges. These correlations to remaining life must be used with great care, as they can lead to an over simplification and inaccuracies.

Horak has also suggested criteria for assessing pavements in terms of sound, warning and severe, shown in Table 13. By using these assessment criteria, deficiencies in the structural layers are identified. By assessing a length of road, the possible cause of structural deficiencies can be deduced.

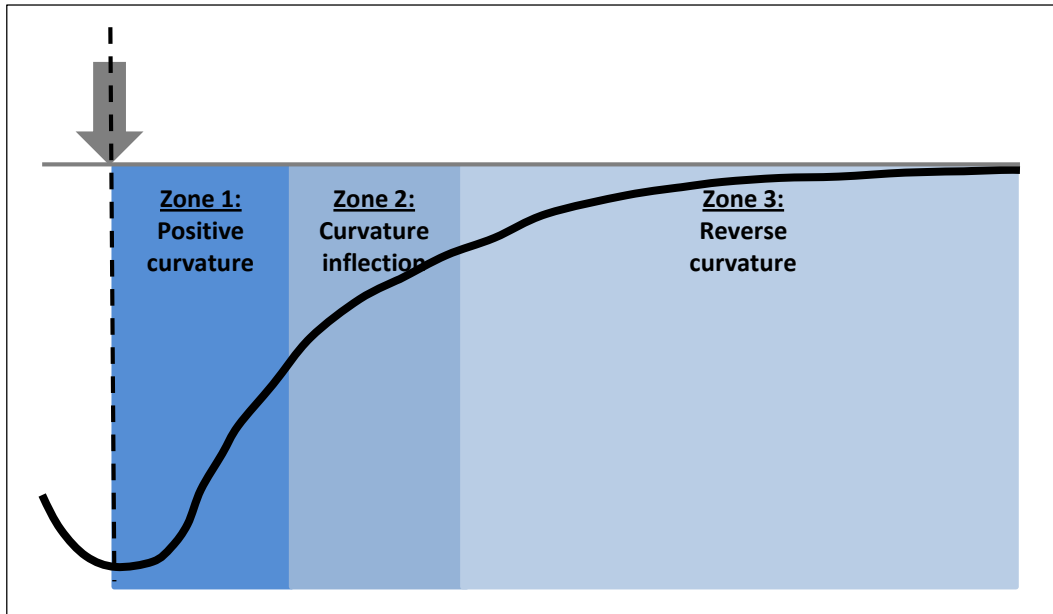


Figure 41. Zones of a Deflection Bowl

Table 12. Behaviour States for Granular Base Pavements

Behaviour State	Traffic Range (MESA) ¹	Maximum Deflection (mm)	BLI (mm)	MLI (mm)	LLI (mm)
Granular Base Pavements					
Very stiff	10 – 100 (12 – 50)	< 0.3	< 0.08	< 0.05	< 0.04
Stiff	3 – 10 (3 – 8)	0.3 – 0.5	0.08 – 0.25	0.05 – 0.15	0.04 – 0.08
Flexible	1 – 3 (0.8 – 3)	0.5 – 0.75	0.25 – 0.5	0.15 – 0.2	0.08 – 0.1
Very flexible	0.003 – 1 (< 0.8)	> 0.75	> 0.5	> 0.2	> 0.1
Asphalt Base Pavements					
Very stiff	10 – 100	< 0.25	< 0.05	< 0.03	< 0.03
Stiff	3 – 10	0.25 – 0.4	0.05 – 0.20	0.03 – 0.1	0.03 – 0.05
Flexible	1 – 3	0.4 – 0.6	0.20 – 0.4	0.1 – 0.15	0.05 – 0.08
Very flexible	0.003 – 1	> 0.6	> 0.4	> 0.15	> 0.08
Cemented Base Pavements					
Initial phase slab state	10 – 100	< 0.15	< 0.04	< 0.03	< 0.03
Initial fatigue cracking	3 – 10	0.15 – 0.25	0.04 – 0.10	0.03 – 0.06	0.03 – 0.05
Substantial fatigue cracking	1 – 3	0.25 – 0.4	0.10 – 0.3	0.06 – 0.1	0.05 – 0.08
Flexible phase	0.003 – 1	> 0.4	> 0.3	> 0.1	> 0.08
Concrete Base Pavements					
Initial phase slab state	10 – 100	< 0.1			
Initial fatigue cracking	3 – 10	0.1 – 0.2			
Substantial fatigue cracking	1 – 3	0.2 – 0.3			
Flexible phase	0.003 – 1	> 0.3			

Note

1. Revised value in parenthesis suggested by Horak (2008).

Table 13. Deflection Bowl Parameter Structural Condition Rating Criteria

Pavement Base Type	Structural Condition Rating	Deflection Bowl Parameters				
		Ymax	RoC	BLI (mm)	MLI (mm)	LLI (mm)
Granular base	Sound	< 500	> 100	< 200	< 100	< 50
	Warning	500 – 750	50 – 100	200 – 400	100 – 200	50 – 100
	Severe	> 750	< 50	> 400	> 200	> 100
Cementitious base	Sound	< 200	> 150	< 100	< 50	< 40
	Warning	200 – 400	80 – 150	100 – 300	50 – 100	40 – 80
	Severe	> 400	< 80	> 300	> 100	> 80
Bituminous base	Sound	< 400	> 250	< 200	< 100	< 50
	Warning	400 – 600	100 – 250	200 – 400	100 – 150	50 – 80
	Severe	> 600	< 100	> 400	> 150	> 80

In concrete pavements, the design philosophy is to ensure proper load transfer at the joint/crack under moving traffic loading. This capability to transfer loads across the joint/crack can be defined in terms of relative vertical movement as the load moves across the joint/crack. It can therefore be measured by actually moving a wheel load across the joint/crack or by using the FWD, that is measuring the difference in deflection between the loaded slab and the adjoining slab (the other side of the joint/crack). The guidelines in Table 14 can be used to judge the severity of relative vertical movement under 40kN wheel loading. This approach is discussed further in Chapter 10: 5.3.2.2, where rehabilitation options for concrete pavements are explored.

Table 14. Deflection Measurements over Joints and Cracks in Concrete Pavements

Relative Vertical Movement	Severity
<0.1 mm	Minor
0.1 to 0.2 mm	Warning
> 0.2 mm	Severe

More information on the analysis of FWD data can be found in Chapter 10: 3.5.1 and 7.5, TRH12 and in the COTO deflection guidelines, which will be republished as TMH13.

(i) Backcalculation

Backcalculation of layer stiffnesses from deflection measurements is a technique to obtain a quantitative indication of layer stiffnesses under loading. The following inputs are required: the measured deflection bowl and applied pressure, the layer thicknesses at the measurement location, and an indication of the material types in the layers.

With this information, the backcalculation process consists of the following steps:

- Using the layer and material information, a **best estimate of the layers stiffnesses** is made.
- Using these stiffnesses and the loading representing the deflection measurement device, the **calculated deflection bowl** is determined, typically using layered elastic theory (see Chapter 2: 3 and 4).
- Compare the **measured and calculated deflections**.
- Change the **layer stiffnesses** to improve the match between the measured and calculated deflections.
- This process is repeated until an **acceptable match** is obtained.

Software packages are available that automate the backcalculation process. See Chapter 10: 7.10 for more details.

Backcalculation requires some skill and experience to perform well, and is therefore a specialist exercise. It is important to understand how changes in layer properties affect the deflection bowl, and to have a good understanding of material behaviour. Without these basic skills, the results of a backcalculation analysis can be highly unreliable and inaccurate, even when there is a seemingly good match between the measured and calculated deflection bowls. Because of this, backcalculation is more of an art than an exact science. (Rubicon Solutions, 2005)

7.3.5 Visual Observations

A visual assessment of the pavement should be made. The description, classification (degree) and extent of any evident distress is recorded in accordance with the standards described in TMH9 and TRH6 for flexible pavements and M3-1 and TRH19 for concrete pavements. Note that, a revised TMH9 will be available in 2014, which will supersede the older manuals, such as TRH6, TRH19, TMH12 and M3-1. The revised TMH9, "Standard Visual

Assessment Manual” (2014) includes sections for surfaced roads, block pavements, concrete pavements and gravel roads. It describes how to rate distress in terms of degree (severity) and extent (prevalence) of the type of distress.

The following aspects are included in the visual observations:

- General surface appearance
- Cracking
- Spalling
- Ravelling (stone loss)
- Texture, e.g., flushing, bleeding, etc.
- Pumping
- Rutting
- Surface moisture
- Pot holing
- Patching
- Any other distress features

These visual defects are discussed in more detail, with illustrations, in Chapter 14: 4.

7.4 Field Investigation and Sampling: Intrusive Methods

Several intrusive investigation methods are used in road pavement investigations, including: test pits, trenches, core sampling, and Dynamic Cone Penetrometer (DCP) probes. These are described in more detail in the following sections.

7.4.1 Test Pits

Test or trial pits provide a means of accurately determining the thickness of the layers in an existing pavement. When as-built information is not available, test pits are vital to establish the pavement structure. Even when information on the pavement construction is available, test pits have an extremely valuable role in confirming the actual “as constructed” pavement structure, material quality and condition. An example of an excavated test pit is shown in Figure 42.



Test Pits

Test pits are one of the most **important** means for investigating an existing road pavement.

To ensure a realistic assessment of the materials, test pits should be excavated in both **good and poor areas**.



Figure 42. Example Test Pit

Besides the thickness of the pavement layers, other details regarding the existing pavement can be gleaned from test pits, for example:

- Samples can be taken to assess the **moisture contents** of the materials in the various pavement layers. This enables the in situ moisture contents to be compared to their respective optimum moisture contents.
- Disturbed samples representing material from the various layers can be taken for **Indicator (Atterberg limits and gradings), density and CBR testing**, so that they can be classified in terms of TRH14 or using the material classification system for determining the design equivalent material class (Chapter 9: 15, or TG2). See Chapters 3 and 4 for details on the tests.
- Indications can be gained as to whether pavement layers have been **cementitiously stabilized**, also whether carbonation of the stabilized material has taken place with time. Spraying non-calcareous materials with phenolphthalein and dilute hydrochloric acid (HCl) can assist with this, see Section 7.4.1.1.
- A **visual assessment** of the asphalt can be carried out, to assess the presence of interconnected voids as well as other modes of distress, such as stripping of the aggregate from the binder.
- The extent of **vertical cracking** can be visually assessed by examining the cracking pattern as the test pit is excavated.

7.4.1.1 Procedure for Test Pit Investigation

(i) Positioning of Test Pits

Consideration should be given to the frequency and positioning of test pits, and is normally the responsibility of the design engineer. Hard and fast rules regarding the frequency of test pits cannot be set, as it is dependent on several factors, such as the variability of the pavement's condition, variation of materials found in the pavement layers, road category and budget. Preliminary "uniform sections", determined using non-invasive testing, form a basis for locating test pits to determine the cause, mechanism and degree of distress. Generally sufficient test pits should be located in each of the "uniform sections" to determine the thickness and quality and condition of their pavement layers. In very general terms, allowance should be made for test pits at intervals of 200 metres.

On site it may, in some instances, be found that a test pit has to be moved from its predetermined location, such as when it falls on a localised repaired area, e.g., a patch, or for safety reasons. Refer to Section 7.4.1.2 for dealing with asphalt layers in test pits. Test pits are usually located across the wheel path, but may be positioned differently, depending upon the objectives of the investigation. Any movement away from the predetermined site must however be sanctioned by the design engineer prior to commencing with the excavation.

(ii) Road Safety

Road safety during the excavation of test pits is critically important. The location of the test pit should preferably always be selected as to allow for the maximum possible sight distance. Where this is unavoidable, it is necessary to increase the number of warning signs and to utilise "advance warning" flagmen. Under no circumstances should the test pit crew be allowed to commence excavation on the roadway until all warning signs and traffic accommodation measures have been put into place in accordance with Part 13 of Volume 2 of the SADC Traffic Signs Manual (2000). All personnel must be equipped with reflective jackets, in good condition, which must be worn at all times when working on or near the travelled way. Refer to Section 4, Accommodation of Traffic during Investigations.

(iii) Surface Condition

Before the test pit is excavated the pavement surface condition, as well as other salient aspects, are recorded. It is essential to photograph the existing pavement surface at the location of the test pit just before it is excavated. A board showing the test pit number, road details and kilometre distance should be shown in the photograph. Distress, such as rutting should be made visible by means of a straightedge placed across the test pit location. If the cracks at the test pit site are of such a nature as to possibly not be clearly defined in the photo, they should be "highlighted" by moistening the surface, or by marking them with chalk. A standard sized object, such as a pen or a box of matches, should be placed on the surface to give an indication of scale in the photograph. It is sometimes necessary to take more than one photograph of the test pit to adequately record the surface condition. Where there are adjacent features that may be the primary or a contributory cause of any of the pavement distress, for example, damaged or silted side drains, ponding of water on the edge of the pavement, or vegetation on the gravel shoulder, then these features should be photographed and included in the relevant reports.

In addition to the photographs, it is essential that the pavement's surface condition is recorded in detail, as described in Section 7.3.5.



Road Safety

Road safety during execution of intrusive testing is of paramount importance to both the road user and the personnel carrying out the work.

(iv) Excavation of Test Pits

When test pits are excavated in existing pavements for rehabilitation design purposes, the methods employed are different from those used in the investigation of new, greenfields type projects.

Test pits in existing pavements should not be excavated using a mechanical excavator such as a TLB. Instead, the work should be carried out using picks and shovels, as well as hand-operated power tools. This is to ensure that one layer at a time is delicately excavated, so that the structure and consistency of material in each of the pavement layers can be observed. As the layer is excavated, the material is stockpiled separately, ensuring that it is not contaminated by material from the other layers. The material from each of the layers should be stockpiled around the test pit, to facilitate sampling once the excavation has been completed. In some instances, where there are thick layers of asphalt or in the case of concrete pavements, it is necessary to cut through these layers using a rotary pavement saw before proceeding with the excavation of the underlying unbound materials. Materials for moisture content measurements should be placed in a sealed container immediately after excavating, to not allow moisture to escape and the material to dry out.

The behaviour of the material in each layer during the excavation process should be carefully observed as it gives vital information as to the consistency and "structure" of the layer, for example, a stabilized layer that remains in hard chunks during the excavation process possibly indicates that in situ processing using conventional construction equipment will be difficult. Details on the observations that must be made are discussed later in this section.

The test pit must be large enough to allow the person profiling it to climb into the excavation to adequately profile the pavement layers. It should also be large enough to provide sufficient material for samples for laboratory testing.

Test pits in existing pavements are usually excavated to a depth of 1.0 metres, but the depth is dependent on the overall objectives of the investigation. Rarely are they excavated to depths of more than 1.2 metres. Where the excavation is stopped at a depth less than that intended, for example, when solid rock, shattered rock, or boulders, are encountered, the reasons should be clearly recorded as they give vital clues regarding possible subsurface issues, such as drainage.

7.4.1.2 Description of Surfacing/Asphalt Layers

The removal of surfacing or asphalt layers during the test pit operation should be done as carefully as possible. If the pavement consists of multi-layers of asphalt or seals, each layer should be described separately and, if possible individual samples taken. If it is not possible to separate the individual layers during excavation, then a full-depth sample should be taken for later separation in the laboratory. During the excavation process, the condition of the individual surfacing/asphalt layers should be fully described according to the criteria given in Table 15.

If it is not possible to identify the particular surfacing or asphalt mix types visually, or from as-built records, then it may be necessary to test the sample in the laboratory to determine the mix type and constituents. This is especially for cases where this information influences the particular rehabilitation strategy. If, for example, a modified binder was utilised in a surfacing seal or asphalt mix, then this should be recorded in the description of the layer. If it appears that the binder is modified but there are no records thereof, then the binder should be described as "possibly modified".

Table 15. Description of Asphalt and Seals

Asphalt Mix Type	Description
Asphalt, continuously graded	AC
Asphalt, semi-gap graded	AS
Asphalt, gap-graded	AG
Asphalt, open graded	AO
Asphalt, porous	AP
Asphalt, stone mastic	AM
Other/Proprietary	Describe
Seal Type	Description
Single seal	S1
Double seal	S2
Sand seal	S3
Cape seal	S4
Slurry seal (7.1 mm max size)	S6
Slurry seal (10 mm max size)	S7
Asphalt Layer	Description
Asphalt layer is dense, no visible voids	Dense
Asphalt has visible voids, some may be interconnected	Semi-porous
Asphalt is open textured, interconnected voids	Porous
Layer is fully bonded with the layer below	Bonded
Layer delaminates easily from the layer below	Delaminated
Moisture evident at interface/s	Wet
Asphalt Condition	Description
Mix/layer is shiny and soft, bitumen remains on fingers	Fresh
Mix/layer is tacky or sticky, no stains on fingers	Tacky
Dull and dry appearance, only slightly tacky	Aged
Hard and brittle (oxidised/severely aged)	Brittle
Binder stripped from the aggregate, little or no cohesion	Stripped

7.4.1.1 Identification of Cemented Pavement Layers

The presence of cemented pavement layers, generally subbase layers, and whether the layer has carbonated, may be identified by the reaction of phenolphthalein and diluted hydrochloric acid on the material. These chemicals are pre-prepared in separate plastic squeeze or spray bottles for use in the field. The following procedure is used:

- **Step 1: Phenolphthalein** solution is sprayed to cover the material in a narrow vertical band on one side of the test pit. A colour change to purple indicates high alkalinity and therefore the likelihood that the layer is cementitiously stabilized. No change in colour indicates that the layers were not stabilized or that carbonation has taken place, thereby reducing the level of alkalinity. An example of the purple/red colour is shown in Figure 43.
- **Step 2:** Dilute **hydrochloric acid** is sprayed in a similar manner adjacent, but not on top, of the strip where the phenolphthalein was sprayed. If effervescence takes take over portion of the vertical band, this is evidence that the layer was originally stabilized but has since carbonated. It should be noted that some materials in their natural state contain carbonates which cause effervescence in the presence of hydrochloric acid. Effervescence is illustrated in Figure 43.

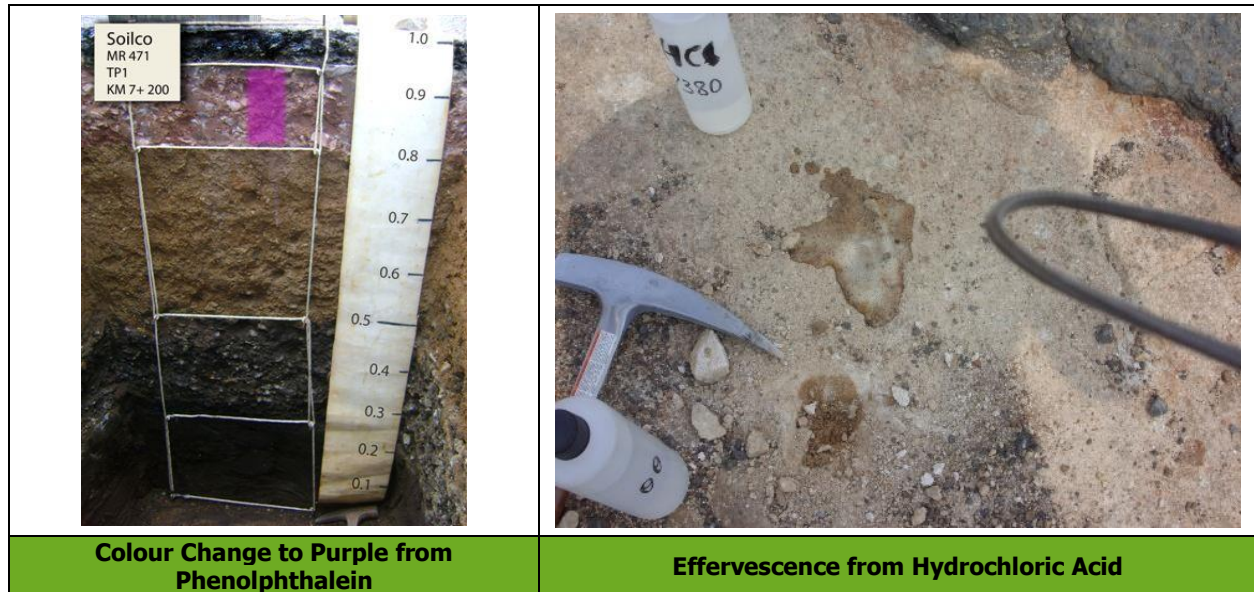


Figure 43. Cementitious Stabilization Checks using Phenolphthalein and Hydrochloric Acid

(i) Carbonation

During the manufacture of lime and cement, limestone (calcium carbonate) is burned at high temperatures to produce calcium oxide by driving off carbon dioxide from the carbonate ion. This is a reversible reaction as the unstable calcium oxide molecule (or its hydrated form, calcium hydroxide) readily re-absorbs carbon dioxide from the atmosphere to return to the more stable calcium carbonate molecule. This process is known as carbonation and can affect both lime and cement when used in the stabilization of road materials.

Carbonation is identified by the reaction of the material phenolphthalein and hydrochloric acid. If the phenolphthalein spray turns red and the HCl does not cause significant effervescence of the material, the material is well stabilized, has a pH greater than about 10.5 and shows little carbonation. If the phenolphthalein does not indicate a red colour and significant effervescence occurs with the acid, a high proportion of carbonate material is present and carbonation is likely to have occurred. The material is likely to be weakened in many cases and premature failure could result. Carbonation usually occurs in the following circumstances:

- **Upper surface** of a stabilized layer due to poor curing, delayed sealing or wetting and drying.
- **Lower portion** of a layer due to build-up of carbon dioxide beneath the layer.
- **Cracking** of the stabilized layer, as illustrated in Figure 44. In the figure, the phenolphthalein does not turn red along the cracks, and HCl causes effervescence of the material (not shown), indicating the material in and adjacent to the cracks has carbonated.
- **Insufficient stabilizer** added to satisfy the Initial Consumption of Stabilizer (ICS). See Chapter 3: 6.3.1.



Carbonation

During the manufacture of lime and cement, limestone (calcium carbonate) is burned at high temperatures to produce calcium oxide by driving off carbon dioxide from the carbonate ion. This is a reversible reaction and the unstable calcium oxide molecule (or its hydrated form, calcium hydroxide) readily re-absorbs carbon dioxide from the atmosphere to return to the more stable calcium carbonate molecule. This process is known as carbonation and can affect both lime and cement when used in the stabilization of materials for roads.

Carbonation is identified by the reaction of the material to phenolphthalein and hydrochloric acid.



Figure 44. Effect of Carbonation Adjacent to Cracks in a Stabilized Layer

If the design tests, cementing agents and construction processes are good and appropriate for the material or situation, carbonation will not be a problem.

7.4.1.2 Description of Gravel Pavement Layers

The descriptions of the granular layers under the surfacing and asphalt layers in the pavement should follow the MCCSSO, utilised for the profiling of soil horizons (see Section 5.2.3), but should be adapted for pavement layers, as covered under each of the facets discussed below. The details are also given in Appendix A.

(i) Moisture

In most instances, the moisture condition within the specific layer would be uniform and should be described in accordance with Table 16. Where the following conditions are evident, however, they should be recorded in detail:

- **Variation** in moisture within the layer
- Higher moisture at the **top** of the layer
- Higher moisture at the **bottom** of the layer
- Higher moisture **adjacent** to any cracks in the layer

A sample should be taken from each layer and immediately sealed for the later determination of the moisture content in the laboratory. Where there is a visual difference in moisture content within the layer, separate samples should be taken and tested.

Table 16. Description of Moisture Condition

Moisture Condition	Description
No visible signs of moisture	Dry
Sufficient moisture present to cause a colour change and not dry	Slightly moist
Sufficient moisture for a colour change. Moisture close to optimum moisture content	Moist
Sufficient moisture to cause material to stick to the skin. Moisture is above optimum	Very moist
Free water visible. Below water table or due to permeability inversion.	Wet

(ii) Colour

All colours should be described in terms of the Burland colour chart, which is available from SAICE. Note that to enable a comparison with similar layers in other test pits, the descriptions of colour should be done with the material in a moist state.

(iii) Consistency

Depending upon on the availability and accuracy of as-built information, usually phenolphthalein and hydrochloric acid are used as indicators to assess, or confirm, whether a particular layer has been stabilized. This is done by spraying the chemicals on the material exposed on the sides of the test pit.

It is important to have this information on the cementitious stabilization as the description of consistency is dependent on whether the layer has been cemented or not. Consistency should be described according to Table 17. In cases where the layer also consists of gravel, pebbles, and aggregate particles, an estimate of the proportion of the matrix in comparison to aggregate should be made. The rock type as well as its hardness should also be recorded.

Table 17. Description of Consistency

Material Types	Condition	Description
Non-cohesive and granular soils	Material can be easily excavated with a shovel	Very loose
	Material can be reasonably easily excavated with a shovel	Loose
	Material is excavated with a shovel with difficulty	Medium dense
	Material must be loosened with a pick before it can be excavated	Dense
	Difficult to penetrate the material and power tools are required	Very dense
Silt, Clay, and Very Clayey	Material can be easily kneaded with fingers	Very soft
	Material can be kneaded with fingers only with a measure of force, and can be easily penetrated with the thumb	Soft
	Material can only be kneaded with difficulty and thumb can only penetrate with substantial effort	Firm
	Material can only be penetrated with thumbnail but cannot be kneaded with fingers. A hand pick is required to excavate the material	Stiff
	Indentation with the thumbnail is difficult and material can only be excavated with power tools	Very stiff
Stabilized	Some material can be crumbled by fingers	Very weakly cemented
	Cannot be crumbled by fingers but some crumbling with strong pressure between fingers and hard surface is possible	Weakly cemented
	Material crumbles under firm blow of sharp pick	Cemented
	Firm blow of sharp pick on hand-held specimen results in 1 to 3 mm indentation	Strongly cemented
	Similar appearance to concrete	Very strongly cemented

The behaviour of bitumen stabilized materials, either bitumen emulsion or foamed bitumen, results in a layer that has characteristics that fall between those of a granular layer and a cement stabilized layer. It may, therefore, be necessary to utilise a combination of the above tables to adequately describe the in situ consistency. A good understanding of the behaviour and characteristics of these types of layers is necessary for an accurate description and assessment of their performance in the pavement structure.

(iv) Structure

The structure of the pavement layers is important as it provides clues regarding the pavement's condition and any underlying cause of distress. Structural characteristics should be described in accordance with those in Table 18.

(v) Soil Type

Each layer in the test pit should be described in terms of the soil or material type. The description of the material in the test pit must correlate with the description of the material based on the laboratory test results. The profiles of any test pit can thus only be finalised once the relevant testing has been completed.

Table 18. Description of Structure

Condition	Description
Layer is homogenous through its full depth	Uniform
Layers within layers can be observed	Layered, including the number of layers
Very thin layer(s) evident, e.g., biscuit layer	Laminated, including location of lamination
Segregation of material within a layer	Segregated
Cracking	Type, size, direction, accumulation of fines, etc.
Slickensided	Degree
Other	Any other structural characteristics evident

(vi) Origin

Material within the upper pavement layers are generally imported, and should not be described as transported. It is important to record the layer type, i.e., base, subbase, selected layer, fill and, if such information is available, the borrow pit or quarry from which the material was obtained. In some cases, for example, in cuttings, the selected layer may comprise in situ materials, in which case they should be described as residual or as reworked residual. If identifiable, additional information should be recorded, such as treatment in place, where the in situ materials are ripped and recompact, or cases where no treatment has been undertaken at this level in the pavement. Examples of this that could be identified would be altered orientation of particles within a shale layer, or shattered residual rock. When the material in the lower portion of the test pit is identified as residual, the descriptive system covered in, Appendix A should be used.

A photograph should be taken of the test pit's profile once it has been excavated and profiled, with the test pit details visible in the photograph, normally on a board, as shown in Figure 42. As a means of overcoming the problem of shadows partially obscuring the profile, a digital camera with a powerful auxiliary flash should be used. Another photograph of the test pit should be taken to show the stockpiles of material around the test pit. This photograph provides the designer with useful information regarding the general quality of the material in the various pavement layers.



Descriptions for Field Use

Summaries of the descriptors used in this section are included in Appendix A.

7.4.2 Test Trenches

Test trenches are longer than normal test pits, and typically extend across the outer wheel path and at least partially across the outer shoulder. They are excavated in exactly the same way as normal test pits. Although test trenches entail more time and work than normal test pits, they are able to provide more information on:

- **Position and extent of rutting.** Once the trench has been excavated, string lines can be fixed along the interfaces of the various pavement layers. This will enable the position and extent of the rutting to be assessed. For example, it can be seen whether the rutting is confined to the asphalt layers, or whether it extends deeper into the underlying pavement layers.
- **Consistency of the layerworks across the pavement.** When road pavements have been widened along the outer edges of the pavement, the test trenches will show where the changes in the pavement structure occur. The trench should then be profiled along its length and representative samples of the materials in the various pavement layers taken for testing.

Due to the increased effort and cost of carrying out test trenches, they should be limited to projects where there is a need to assess rutting and/or there is evidence, or a strong likelihood, that widening of the road pavement was carried out previously.

7.4.3 Core Sampling

Sampling of pavement materials by means of cores is quicker and less expensive than test pits, but is limited to fairly well-bound materials, such as strongly cemented stabilized materials, asphalt, and concrete. Water that is used to cool the drilling crown tends to cause weakly bound materials, such those found in cement stabilized subbase layers, to disintegrate. Although attempts have been made to use compressed air instead of water as a coolant, this method has rarely been successful.

Core samples are used to determine layer thickness, and the specimens can be tested for various engineering properties, such as compressive strength and void content.

Factors that should be considered when carrying out core sampling include:

- **Core diameter.** The diameter of the core used to check layer thickness is usually 100 mm. While this is satisfactory for this purpose, larger diameter cores are sometimes required, such as for coring concrete when compressive strength testing is required. Larger core diameters, up to 200 mm, are useful when checking asphalt quality, especially in thinner layers, when the larger sample size enhances testing accuracy.
- **Quality of coring equipment.** The coring machine should be sufficiently stable to enable the core to be cut accurately and cleanly. The cutting crown and water cooling system should be in good condition, otherwise the material in and around the core heats up, which could affect the results of tests on the cores.
- **Temperature of material.** Newly paved asphalt should be allowed to cool down to ambient temperature before core sampling is carried out. Due to the risk of deforming the core and thus affecting the test results, coring should not be carried out when the pavement temperature is above 40 °C. Coring in the early morning hours is normally preferable.



Temperature for Asphalt Coring

Coring of asphalt should not be carried out at temperatures above 40 °C.

During the rehabilitation investigation process, core samples can be taken at more frequent intervals than the test pits, to provide more information on the thickness and properties of the bound layers in the pavement.

After extracting the core, the cavity in the pavement should be backfilled as described below.

7.4.4 Backfilling of Test Pits, Trenches and Core Holes

Pavement test pits and trenches, as well as core holes, require special care when backfilled to avoid settlement and resultant damage to vehicles and tyres. Also, the surface should be properly sealed to prevent the ingress of water into the pavement. This aspect is particularly important in cases where rehabilitation work is not carried out soon after the design work is completed and the existing pavement has to be trafficked for a significant period before rehabilitation.

7.4.4.1 Backfilling Test Pits and Trenches

In the case of test pits and trenches, there is usually a shortfall in the quantity of material needed to backfill the excavation because samples have been taken for laboratory testing. New material must then be imported. In most cases it is best to arrange for the supplementary material to be a crushed stone product of G2 quality.

The backfilling procedure should commence with the material from each respective pavement layer to be replaced in turn, in its original position/layer. The material should be thoroughly compacted in layer thicknesses not exceeding 150 mm using “Wacker” impact or vibratory plate type compaction equipment, see Figure 45. When backfilling test pits or trenches on heavily trafficked roads, where vehicle counts exceed approximately 5 000 per day, the subbase layer should consist of G2 quality material and should be stabilized with 3% cement. The same quality material should be used for the base layer and should be lightly stabilized with 1% cement.



Figure 45. Vibratory Plate Compactor

On more lightly trafficked roads, and especially when it is intended to carry out full rehabilitation of the road pavement, it is not necessary to stabilize the subbase and base layers. In these circumstances, the material excavated from the test pit or trench can be reused in all layers except the base layer, which should always consist of G2 quality crushed stone.

To control compaction quality, the following minimum densities should be specified for layers corresponding to the following layers in the existing pavement:

- **Selected layers:** minimum 93% of MDD
- **Subbase layers:** minimum 95% of MDD
- **Base layers:** minimum 98% of MDD

The base layer should be compacted to a level 20 mm to 30 mm below the level of the surrounding road surfacing. The surface of the base should be tacked using 30% diluted stable grade bitumen emulsion. A paint brush should be used to apply the tack coat to the exposed edges of the excavation, to ensure a proper seal. A period should be allowed for the bitumen emulsion tack coat to fully break, and to achieve a uniform black colour before the surfacing is applied.

Either bagged cold mix asphalt or hot mix asphalt can be used to surface the test pit or trench. In both cases, the mix should consist of fine, continuously graded asphalt, with a maximum particle size of 7.1 mm. Cold mix asphalt should be used at a minimum temperature of 60 °C. This can often be achieved by positioning the bags of cold mix asphalt in the sunshine, opening them up and spreading the asphalt so that it warms up while the test pit or trench is excavated. In cold weather conditions, some form of heating has to be applied.

When hot mix asphalt is used, it should be placed at a minimum temperature of 120 °C; proper compaction will not be achieved if the asphalt is placed at lower temperatures. Ensure that all newly placed hot mix asphalt has reached ambient temperature before opening to traffic to prevent premature deformation. It should be borne in mind that high air temperatures extend cooling off times.

The asphalt should be laid 2 mm to 5 mm proud of the surrounding surfacing to prevent water ponding and water ingress. Once it has been fully compacted, a light application of bituminous emulsion or some proprietary products are useful to ensure the patch is watertight.

7.4.4.2 Filling of Core Holes

Core holes should be properly filled with asphalt to prevent the ingress of rainwater into the pavement. Before filling, the core hole must be emptied of water and should either be allowed to dry out or be physically dried using an absorbent cloth. A paint brush is used to coat the wall with 30% dilute stable grade bitumen emulsion. Once the bitumen emulsion has broken to a uniform black colour, the core hole is filled with fine, continuously graded asphalt, with a maximum particle size of 7.1 mm.

Either cold mix asphalt or hot mix asphalt, with minimum temperatures of 60 °C and 120 °C, respectively, can be used for this purpose. A steel trowel is used to settle the asphalt against the wall of the core hole and it is filled with the asphalt in approximately 40 mm thick layers, and compacted with a Marshall hammer. The mix is compacted just proud of the surface of the surrounding pavement.

7.4.5 DCP Probes

Dynamic Cone Penetrometer (DCP) probes are used extensively in this country for investigating road pavements. The method is relatively inexpensive, and enables a rapid evaluation of in situ pavement materials.

The DCP is shown in Figure 46 (Paige-Green and du Plessis, 2009), and consists of a steel hardened 60° cone fitted to the end of a 16 mm steel rod. An 8 kg hammer is dropped onto the anvil fitted to the top of the rod to drive it into the pavement materials. The penetration is typically measured every 5 blows, and in road pavement investigations is normally advanced just into the subgrade layers, generally about 800 mm in depth. A test method for DCP testing is ST6 in TMH6.

The probe is unable to penetrate some materials, such as asphalt and strongly cemented subbase layers, while it is sometimes difficult to



Backfilling Test Pits and Trenches

Supplementary material used to fill test pits and trenches should be a crushed stone of **G2** quality.



DCP Reference

A good reference for the DCP is "*Design Manual for Low Volume Sealed Roads Using the DCP Design Method*". Ministry of Transport and Public Works, Republic of Malawi. This guideline can be downloaded from www.afcap.org.

penetrate well compacted crushed stone base layers. In these cases a decision has to be made to either drill through or remove the obstructing layer before proceeding to complete the penetration to a depth of 800 mm. It is important to note if the DCP did not penetrate (DNP) a layer.

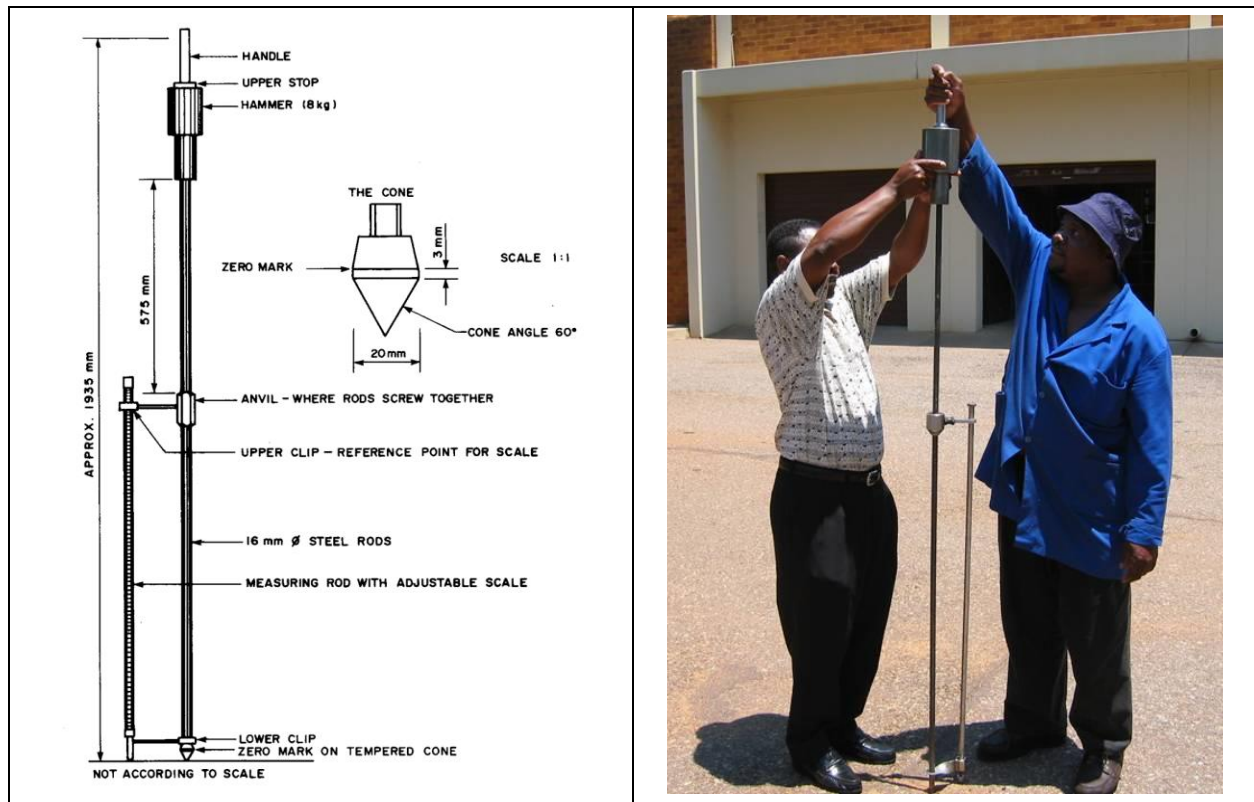


Figure 46. Dynamic Cone Penetrometer

DCP results are influenced by the existing moisture regime of the pavement. Tests undertaken during the wet season may show the pavement to be weaker than if tests in the dry season, when in situ moisture contents tend to be lower.

The results of DCP tests can be used in conjunction with computer software to gauge the structural capacity of the pavement and to estimate in situ materials properties, such as CBR, UCS and dynamic modulus. Calculations to estimate the structural capacity of the pavement are based on the number of blows required to probe to a depth of 800 mm, known as DSN_{800} . Where it was not possible to penetrate a layer (refusal), in the DSN_{800} calculation it is necessary to allocate a penetration rate (D_N) to the refusal layer. For example, a typical penetration rate of 1 mm per blow could be allocated to an asphalt layer. Thus, if the asphalt layer is 50 mm thick, the number of blows to penetrate this layer would be 50. Chapter 10: 7.3 covers ways in which DCP results are used in pavement design. Guidelines for the interpretation of DCP results are given in Table 19. A good reference for the DCP is the "Design Manual for Low Volume Sealed Roads Using the DCP Design Method" (Republic of Malawi, 2013).

Table 19. Interpretation of DCP Penetration Results

DCP number (mm/blow)	Inferred In Situ CBR	TRH14 Classification	Pavement layer
25 – 40	3 – 7	G10	Fill
15 – 25	7 – 15	G9	Lower Selected Layer
7 – 15	25 – 45	G7	Upper Selected layer
3 – 7	45 – 150	G5	Subbase (uncemented)
< 1	> 150	G2	Base/cemented Subbase

7.5 Phasing of Investigations

As mentioned earlier in Section 7.2, the phasing, as well as the scope of investigations, depends on the severity of the pavement distress. For example, the PMS may indicate:

- **Only minor distress is evident and the work can be carried out as part of the routine maintenance of the road.** In this case, it is likely to only be necessary to check the accuracy of the PMS by way of a cursory visual inspection. A short report is normally compiled that details the items of routine maintenance required.
- **The problem is caused by water ingress through the surfacing, in which case only a reseal is necessary.** When the pavement distress is likely to be attributable to a surfacing problem, verification is required by carrying out the Initial Assessment (Section 7.1.2). This investigation should be sufficient to confirm whether a spray seal or asphalt overlay would be sufficient to prolong the life of the pavement. Some engineering judgement is required as to whether it is necessary to carry out the surveillance testing or just to rely on the Detailed Visual Assessment. The information obtained from the PMS, such as deflection measurements, assists with this decision. Should this assessment indicate that the pavement has more serious deficiencies, then a full-scale Detailed Pavement Assessment is warranted. Details that should be included in the Initial Assessment Report are covered in Section 9.2.1.
- **The pavement is severely distressed and full rehabilitation is required.** In this case, both the Initial Assessment and the Detailed Pavement Assessment are required, with the full range of investigations covered in this section required. The details that should be included in the Detailed Assessment Report are covered in Section 9.2.1.

Secondly, the phasing and scope of the road pavement investigations may depend upon the road authority's strategy for a particular project. The available budget also has an influence. For example, it may be intended to employ a holding measure instead of full-scale rehabilitation, or, alternatively, substantial vertical and horizontal realignment may be required if the existing geometrics are of a low standard. It is therefore essential to discuss the intended strategy for a particular project before deciding on appropriate pavement investigations.

7.6 Testing and Reporting

More detailed information on testing is contained in Section 8. As already mentioned, items regarding pavement investigations that should be included in the various reports usually required by Road Authorities are covered in Section 9.2.



Discuss Strategy with Client

It is essential to discuss the intended strategy for a particular project with the road authority before deciding on appropriate pavement investigations.

8. MATERIALS TESTING FOR INVESTIGATIONS

Laboratory testing of materials sampled during road prism and/or road pavement investigations is a major facet in the characterisation and rational utilisation of in situ, available material from the roadbed, cuttings or existing pavements. In situ testing in the field, as described in Sections 5 and 7, provides insight into the strength and behaviour of materials in place. Laboratory testing, as described in Chapters 3 and 4, allows for more accurate testing and determination of the effects of loading, drainage and other man-induced influences on undisturbed samples from road pavements, the roadbed or in cuttings, but also provides a means for determining the strength and other engineering characteristics of materials in the constructed state.

8.1 Testing of Materials

Many factors influence the testing of materials, including:

- **Representivity** of the samples, see TMH5
- **Labelling, packaging, handling and transportation** of the samples to the testing laboratory, see TMH5
- **Selection** of tests carried out, for the characterisation of materials or modelling of layers
- Selection and procurement of **testing laboratories**
- Samples **storage**
- **Preparation** of samples for testing
- **Testing**, according to **standardised procedures** by competent, experienced testing personnel utilising standardised, calibrated testing equipment.

Storage, preparation and testing are part of the South African National Accreditation System (SANAS) laboratory accreditation, which aims to ensure reliability of test results. Refer to Chapter 5: 1.1.

8.2 Selection and Procurement of Testing Laboratories

Most road authorities require the laboratories utilised for routine testing of materials for road prism and road pavement investigations are SANAS accredited. SANAS accreditation is discussed in more detail in Chapter 5: 1.1. The SANAS website, www.sanas.co.za/directory.php lists accredited laboratories. Accreditation details may also be obtained from the accredited laboratories.

In general, the applicant (usually the appointed consulting engineering company or specialist geotechnical engineer or engineering geologist) will obtain at least three quotations from reputable and suitably accredited civil testing laboratories for the envisaged testing work. Some authorities may require that formal tenders be acquired for such testing when the estimated costs of the testing exceed certain limits, in which case the required procurement policies of that authority should be ascertained and followed accordingly. There may also be certain criteria to evaluate quotations and/or tenders, and the applicant should ascertain the clients' requirements.

Specialised testing is generally only carried out in a few commercial civil laboratories, research institutions such as the CSIR, certain national or provincial authorities and at some universities. It may be necessary to appoint more than one laboratory to have the full range of envisaged specialised testing performed.

8.3 Size and Representative Test Samples

A sample is described in TMH5 as being a portion or a combination of portions of a lot of material. A representative sample is one, which when investigated, will display similar characteristics and properties as the whole. It is apparent that the larger the sample, the more representative it becomes. The sample size should thus be such that each of the various components will be identified and be quantified according to its proportion of the whole, and will thus make a proportionate contribution to its characteristics and properties when subjected to scrutiny and testing. Factors such as particle size and variations in depth (in either soil or pavement profile) contribute to decision making by the sampler. This is one of the many reasons why investigations, and sampling of materials, should only be carried out by experienced personnel.

The size of the test sample is important. Some tests require very little material while others require large samples. In general, more than one type of test will be carried out on a sample. For example, indicator tests, a maximum density/optimum moisture content, a CBR, an unconfined compression test and an Indirect tensile test are carried out on a raw (unmodified sample), as well as on samples modified



Representative Samples

A representative sample is one, which when investigated, will display similar characteristics and properties as the whole.

or stabilized with different types of stabilizers. Similarly, a rock sample may be crushed to provide various sizes and specific sizes may be required for tests such as ACV, 10% FACT, durability, flakiness index determinations, petrographic analyses and shrinkage, for example. A further consideration is the need to retain some of the sample for re-testing should an error occur during testing or for correlation testing purposes. Many authorities specify sample retention for fixed periods. For example, SANRAL typically require retention of borehole cores until the end of the maintenance period.

Considering the cost of obtaining a sample of the required size, and the need for a representative sample, it is good practise to err on the safe side and ensure that samples are sufficiently large to meet all the requirements. Sample reduction can be done at the testing laboratory using appropriate methods as described in TMH5. Storage and transport are, however, costly. Using experienced personnel, well versed with both sampling and testing needs, contributes to keeping the sample size within acceptable limits.

For further guidance regarding sampling, sample size and procedures to ensure the sample is representative, see Sections 5 and 7 in this Chapter, and Chapter 3, Chapter 4, as well as TMH1, TMH5, TMH6 and the relevant SANS methods and standards.



Sampling

Investigations and sampling of materials should only be carried out by experienced personnel.

8.4 Sample Types

Road Prism Investigations encompass investigations for new roads (greenfield projects) as well as for road upgrades as described in Section 5. Samples from these investigations include:

- **Disturbed samples:** These may be loose soils and gravels, rock fragments, blast rock recovered from field investigations. For example, test pitting, trenching, auger and percussion drilling operations, trial blasts, as well as soils and aggregates sampled from stockpiles at commercial sources.
- **Undisturbed samples:** Undisturbed soil samples may be soils sampled during rotary core drilling operations (piston samples), undisturbed soil samples or wax coated block samples excavated during test pitting. Also included are rock core recovered from rotary drilling operations.

Pavement investigations encompass the sampling and testing of existing road pavements and supporting layers. Samples from these investigations include:

- **Disturbed samples:** These may include crushed stone gravels, natural gravels, broken out fragments of bound materials (bitumen treated or cemented layers) or broken out fragments of road bituminous surfacings (asphalt or stone/slurry seals).
- **Undisturbed Samples:** Undisturbed samples may be cores drilled or blocks cut from bound or cemented layers as well as cores drilled from concrete structures or pavements.

8.5 Labelling, Packaging, Handling and Transportation of Samples

A sample without a label is useless, unless it remains in the sole possession of the sampler until it is handed over to the testing laboratory or receiving institution, and the relevant details are provided. The sample container should be labelled as follows:

- A **unique number** against which the sample details are recorded on a suitable sampling sheet, e.g., a bag or container number.
- Have a suitable **weatherproof label** attached to the side of the container, not on the lid, with the required identification details indelible. A similar label should also be inserted inside the container.
- The **identification details** are generally a project number or name, the sample number and the test type. For example, indicator, or indicator and CBR, or strength testing, which may include CBR, UCS and ITT testing.

An example of a well labelled sample container is shown in Figure 47. Note the identical label waterproofed in a plastic bag that goes in the sample container.



Figure 47. Example of Labelling of Sample Container

Sample containers should be:

- Appropriate for the **sample size and type**
- **Weatherproof**
- Capable of withstanding the anticipated **handling** without breaking, loss or change to the sample
- Handling and **storage friendly** in size and shape

Core boxes are generally made from soft woods and are susceptible to warping if left uncovered. Boxes should be marked on the lids, ends and on the insides of the lids with such details as project name, project/contract number, site description, kilometre position, box number and series number. Core boxes must have handles and lockable lids, for safe handling and transportation. It is common practise to sheath all soft cores in plastic wrap to prevent moisture and material loss.

It is essential that samples taken for the determination of moisture content are stored in airtight containers. Undisturbed samples should be wrapped in straw or bubble wrap before placing them in lined rigid containers to prevent damage when handled or transported. It is similarly essential that the samples can be removed from their containers, without undue loss or disturbance.

In transporting samples from the point of origin to the testing or storage facility, it is essential that the samples be handled carefully so that the sample containers are not damaged and the labelling remains intact. The samples should be protected in adverse weather conditions.

Transporting of samples is sometimes carried out by subcontracted hauliers. In these cases, it is essential that the samples are appropriately packaged and labelled, to ensure their undamaged delivery. The transporting agency must be briefed on the handling and protection of the samples, for example, what actions to take in the event of damages to samples, to never drop sample containers, and to never overturn core boxes.

8.6 Testing

Testing is generally categorised as follows:

- **Routine laboratory testing**, which is carried out on a daily basis by most civil laboratories and does not require the use of highly sophisticated and expensive testing equipment and expertise. Routine laboratory testing includes:

- Tests on soils and gravels from cuts and fills to determine the materials properties, and to investigate their use in place or in the various road formation and pavement layers.
- Tests on bituminous and other treated soils and gravels from existing road pavements to determine their properties and condition.
- Tests on recovered cores from boreholes and blast rock from cuttings or roadbeds to investigate founding conditions, the stability of cut slopes or the possible use of processed excavated materials as crushed stone base materials, as aggregate for concrete, asphalt or chip seals or other uses such as gabion rock.
- Tests on asphalt and bitumen treated samples, grading and binder content, as well as tests on the recovered binder.
- Materials designs (cement or bitumen stabilized materials) on gravel materials that may be obtained from the cuttings or from borrow pits or quarries.
- **Specialised laboratory testing** is carried out by only a few specialised laboratories and research organisations. This testing requires sophisticated, very expensive equipment and requires highly trained staff to execute the work. Testing frequencies are generally lower, and tests are more time consuming and costly to execute. Specialised testing includes:
 - Soils and gravels: strength, durability and permeability tests on disturbed samples, and strength and permeability tests on undisturbed samples
 - Rock samples: identification tests, strength and durability tests
 - Cemented samples: strength and durability tests

Table 20 lists some typical routine and specialised laboratory tests for road prism and pavement investigations.

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Table 20. Typical Routine and Specialised Laboratory Tests

Material	D/UD ¹	Minimum Sample Size ²	Test description	Test Type: R or S	Ch/Cl ⁴
Soils and gravels From test pits, slots, sampling tubes, block samples, core or auger samples from road prism and road pavement investigations. Also includes materials from commercial sources.	D	5.0 kg	Grading/particle size distribution	Indicator tests (R)	Ch, Cl
	D	5.0 kg	Atterberg limits		
	D	5.0 kg	Soil mortar analyses	Foundation indicator (R)	Ch, Cl
	D	5.0 kg	Hydrometer analyses		Ch, Cl
	D, UD	3.0 kg	In situ moisture content	Investigative (R)	Ch
	UD	n/a	In situ density test	Investigative (R)	Ch
	D	50 kg	Maximum dry density and optimum moisture content	Control test (R)	Cl
		30 kg	CBR Test	Strength test (R)	Cl
		30 kg / stabilizer type / content	UCS Test		Cl
		30 kg / stabilizer type / content	ITT Test		Cl
	D, UD	10 kg	Shearbox test	Strength test (S)	Ch
	D, UD	10 kg / point	Triaxial test		
	D, UD	10 kg	Permeability test	Investigative (S)	Ch
Rock and rock core samples	UD	100 mm core	Point load test	Strength test (S)	Ch
	D	100 mm core	UCS		
		100 mm core	Petrographic / thin film analysis	Investigative (S)	Ch
		20 kg	ACV, 10% FACT	Strength (R)	Ch
		10 kg	MgSO ₄ / Ethylene Glycol	Durability (S)	Ch
		5 kg	ALD	Investigative (R)	Ch
		5 kg	Flakiness Index	Investigative (R)	Ch
	Asphalt samples/cores	UD	100 mm diameter	Relative density	Investigative (R)
D		5 kg	Binder content	Investigative (R)	
		5 kg	Particle size distribution		
		1 litre	Penetration	Investigative (S) Tests on recovered binder (S)	Ch
		1 litre	Softening point		
		1 litre	Ductility		
		1 litre	RTFOT		
		1 litre	Chemical composition (e.g., asphaltenes)		
Concrete samples From pavement investigations	UD	100 mm core	Crushing strength	Tests on concrete cores/sawn blocks (S)	Ch

Notes:

1. Disturbed (D) or Undisturbed (UD) Samples
2. Recommended field sampling sizes, which are generally reduced to the appropriate testing size by the testing laboratory.
3. Test type: Routine (R) or Specialised (S)
4. Characterisation (Ch) or Classification (Cl) Tests

8.7 Retention of Samples

It is generally required that untested samples, or those portions of samples remaining after testing, are retained for an agreed period by the testing laboratory. This is to enable further testing, if required, or to have certain tests repeated if there is any doubt regarding the test result. The testing laboratory may need to lease storage facilities, which must be discussed when obtaining quotes or tenders for testing.

In particular, all drilled cores stored in core boxes must be kept in locked premises. The boxes should be suitably treated against rot or rat and termite action if the likely storage period exceeds one year. The cores are generally made available for inspection by prospective tenderers at, and after, the contract site inspection. Typically, these are then transported to the site, and returned to storage on completion of the project, unless the road authority authorises their disposal. In the case of large bridges or road tunnels, the authority may decide to store the cores in a permanent facility near the site.

8.8 Reporting

Although most testing laboratories have their own reporting sheets, many roads authorities require the use of their own specific reporting sheets. When the road authority does not have specific reporting sheets, they typically require that their logo is used on the laboratory report as the sole logo or as the lead logo. It is necessary for the laboratory and the organisation requesting the testing to establish the client or road authorities requirements and to inform and supply the relevant information to the laboratory. There may be situations when, in addition to hard copies, the test results must also be provided in electronic format. Again, the requirements of the particular authority need to be ascertained and complied with.



Sample Retention

Untested samples, or those portions of samples remaining after testing, normally need to be retained for an agreed period by the testing laboratory. This is to enable further testing, if required, or to have certain tests repeated if there is any doubt regarding the test result.

9. COMPOSITION OF TEST DATA AND REPORTING

Reporting on road prism investigations (Section 5) and on road pavement investigations (Section 7), carried out on behalf of the various road authorities, is generally required on completion of preliminary site investigations, on the completion of the detailed investigations, and in the compilation of the contract documentation.

In the case of **road prism investigations**, the reports are generally as follows:

- Preliminary Materials Report
- Detailed Assessment and Design Report
- Materials Investigation and Utilisation Report (Volume 6 for SANRAL)

In the case of **road pavement investigations**, the reports are generally as follows:

- Initial Assessment Report
- Detailed Assessment and Design Report
- Materials Investigation and Utilisation Report (Volume 6 for SANRAL)

These reports generally cover all relevant information gained from desk studies, field reconnaissance and investigations, the findings and the interpretation of test and other data, as well as materials designs, earthworks designs and solutions to the various engineering challenges identified. They also provide a suitable means of recording other relevant data, for both the designer and contractor, facilitating an overall appreciation of all factors and influences that need to be considered in the design and construction of the road or road pavement.

9.1 Reporting for Road Prism Investigations

9.1.1 Preliminary Materials Report

Most road authorities require the compilation of a Basic Assessment Report for all greenfields or new road projects. This report covers all aspects affecting the proposed location and design of the road and associated works. A precursor to this report is the Preliminary Materials Report, which contains information with a direct influence on the design proposals therein, especially for the selection of both horizontal and vertical alignments. As such, this report needs to be studied and its recommendations approved well in advance of the Basic Assessment Report.

The following aspects are generally commented upon in a typical **Preliminary Materials Report**:

- The general **geology** of the area, and its effect on the geotechnical or materials design and road location.
- Portions of the route that are underlain by **problematic subgrades** such as dolomitic foundations and expansive soils. See Section 6.
- A description of the broad nature of the **materials resources** available within the broad corridor of the route and their possible influence on the selected alignment. For example, whether construction materials, such as selected subgrade materials, subbase materials or even materials for base layerworks, are likely to be available from the road prism, or require importing. Comment on the presence of deeply weathered soils and lack of weathered materials, or other related issues.
- The **availability of sources** of hard aggregate for concrete and upper pavement layers, and suitable sand and gravel, must be dealt with at this stage. Where these resources are in short supply, expropriation may be desirable at this stage and should be recommended, if considered necessary. This information should be forthcoming from the investigations described in Chapter 8: 2.
- Proposals for safe **batter slopes**, expectations on shrinkage or bulking factors. The proposed batter slopes, based on stability conditions during the basic planning stage may eventually have to be flattened depending on geometrical alignment and/or volumes of materials required.
- Likely **subsurface ground water** conditions and their possible influence on the road pavement design.
- The likely **traffic load spectrum**, and the possibility of growth due to future economic developments or attracted traffic.
- A tentative **pavement design** with alternatives, but without detailed analysis. The cost of the analysis of the proposed pavement designs. This information should be forthcoming from the investigations described in Chapter 10.
- A preliminary list of **bridges, large culverts and other important structures** in kilometre sequence. Possible bridge foundation types, based on the results of existing data and preliminary drilling and augering investigations. This information should be forthcoming from the investigations described in Chapter 7: 7.

- **Test data** on appropriate test data sheets of the road authority (M1 series for SANRAL). A locality plan and a plan showing the position of test pits, boreholes or geophysical testing, if carried out, and other salient features relative to the proposed alignment.

The required number of copies of the Preliminary Materials Report differs for each client. The Preliminary Materials Report is generally included in the Basic Assessment Report.

9.1.2 Detailed Assessment and Design Report

This report generally covers the information, engineering assessment and proposed designs from the road pavement and prism investigations described in Sections 5 and 7. Also included are sections on other issues such as structures, pavement designs and materials sources, as well as information of a broader general nature but pertinent to the specific road project. Details of assessments and designs from all geotechnical investigations are also included either in the report or as a stand-alone volume(s) of the report.

A Typical **Detailed Assessment and Design Report** includes paragraphs or sections as listed below:

(i) Introduction

The Introduction includes:

- Consultant's **appointment details** and brief
- A **general description** of the project
- An **Executive Summary** highlighting problem areas, design recommendations and special construction requirements.

(ii) Physiography

This section covers a description of the location and general nature of terrain, commenting on:

- **Topography** along the route
- **Drainage**, for example, drainage lines, watercourses traversed
- **Climate**, including temperature and rainfall data, general weather patterns, occurrence of mist, snow, berg winds
- **Vegetation** and **land use**
- **Infrastructure** including accessibility of power and water, proximity to roads, railways and ports, regional telecommunications

(iii) Geology

The Geology section includes comments on:

- **General geology** of area, referring to geological plans, sections, soil survey plans included in the report
- **Detailed geology** along the route, what materials can be expected in the roadbed and the cuttings
- **Influence of geology** on design and construction
- **Effect of geology** on availability of construction materials
- Geologically **unstable areas**, e.g., sinkholes, natural slopes, undermined land

(iv) Description of Road Alignment

This section should provide:

- Detailed description of the route and its **vertical and horizontal alignment**
- Description of the **various cuts and embankments**, describing the salient features of each, e.g., type, position, numbering or reference
- **Problem areas** should be highlighted and where appropriate, make reference to plans or sections which detail such areas

(v) Road Prism Investigations

This section includes a description of the investigations, and the findings.

- **Description of Investigations.** The various techniques utilized to investigate the cuttings, fills, structure foundations and other features requiring specific attention, for example, undermining, compressive or expansive subgrades or dolomitic formations should be described. These techniques may include test pitting, trenching, auger drilling, core drilling, percussion drilling, geophysical testing, geological mapping, in situ testing and laboratory testing of disturbed or undisturbed samples. Reference should be made to plans and sections that show positions of all test pits, boreholes, or other investigation points. The location in the report of the description of the test results, logs and plans should be cross-referenced. The forms used in, and the format of the report, should follow that of the relevant road authority.
- **Findings of Road Prism Investigations.** Under this subheading, the information gathered in the investigations, such as visual assessments, soil and rock profiling, in situ and laboratory testing and geophysical testing and its engineering significance is discussed and appropriate engineering solutions proposed. Problematic or large cuts and embankments, as well as extraordinary features such as undermining, landfills, marshes, limestone and dolomitic foundations receive specialist geological and geotechnical attention. Due reference should be made to the relevant reports and test data, if not included in this report. Each individual cutting and embankment or feature should be described in terms of the findings and proposed engineering solutions/requirements. The descriptions will address salient issues such as:

For cuttings:

- Moisture conditions, water tables, details any special measures required to address groundwater or seepage
- Detailed profile and engineering classifications of each material type in the profile
- Proposed cut lines and roadbed treatments (See Chapter 9: 2)
- Determination of excavation class of the materials encountered and estimated volumes in each class (See Chapter 9: 3)
- Possible utilization of cut materials, such as spoil, fill construction, pavement layer construction and source of aggregate
- Proposed cut slopes with due reference to test data, analyses, specialist geotechnical investigations and analyses (See Chapter 7: 5)

For Embankments:

- Moisture conditions, water tables, details any special measures required to address wet or saturated subgrades
- Location and extent of unsuitable founding material below fills
- Special treatments necessitated by unfavourable roadbed conditions (see Chapter 7: 4)
- Special treatments or construction methods necessitated by physical constraints or by use of substandard materials (see Section 6 and Chapter 9: 2 and 3)
- Proposed batter slopes with due reference to test data, analyses, specialist geotechnical investigations and analyses (See Chapter 7: 3 and 4)
- Sources of construction materials

Reference should be made to test data, borehole logs, drawings, sections and plans which form part of the report, but may be located in Appendices or in separate volumes of the report.

(vi) Earthworks Design

Under this heading, the earthworks design is presented. See Chapter 9: 3 for details on earthworks design.

- **Balance of Earthworks.** Comment on the quantities of materials in the cuttings, their quality and proposed usage considering haul and other costs to arrive at the optimal materials utilization. Adjustments made for spoiled materials, i.e., substandard quality or excessive moisture content; bulking of materials and special applications, such as rock toes, pioneer and drainage layers, are discussed with reference to the mass haul diagram, geotechnical drawings, plans and sections as well as test and other technical data. Proposals should be made for addressing materials shortfalls. Such proposed sources are described in detail (see Chapter 8) covering such issues such as haul distance, material type, extent, method of excavation, processing required, and environmental requirements pertaining to use of and rehabilitation of the source.
- **Classification of Excavation.** Discussion of the classification of excavation materials from the various cuttings is presented in tabular form, and justifications for these classifications explained. This section also includes a geotechnical evaluation and discussion on test results, tables, plans, chainages or stake values, where relevant. Where necessary, the prescribed forms should be used.
- **Geotechnical Investigations, Stability Assessments and Proposals**
 - Subgrades and Roadbed: This section includes descriptions of the special features investigated as described in Section 5, highlighting the



Earthworks Design

The source information for the earthworks design should be obtained from the investigations in this Chapter and Chapter 9.

types of investigations, methods used, the results obtained, the engineering assessment thereof and the treatments or special measures recommended. These are generally in the form of roadbed treatments which are presented in tabular form and shown on Materials Design Plans (sometimes referred to as Soil Survey Sheets) and on appropriate long-sections as described in Chapter 9: 2. Appropriate reference should be made here to any preceding investigations such as dolomite studies or investigations. Such reports are generally appended to this report.

- **Embankments.** A description of the special features of each embankment investigated (as described in Chapter 7: 4), highlighting the types of investigations, methods used, results obtained, engineering assessment thereof, and special measures and proposals should be included. The stability of these embankments considering founding conditions, settlement (type, extent and period), or heave, as appropriate, should be discussed. Where special measures are required to improve the stability of some of these embankments, each measure should be discussed in detail referring to test data, plans and sections describing, detailing and quantifying such measures.
- **Cuttings:** The special features of each cutting investigated (as described in Chapter 7: 5) highlighting the types of investigations, methods used, results obtained, engineering assessment thereof and special measures and proposals required to address such should be included. The stability of the cuttings considering excavation methods, stabilization measures, drainage and roadbed treatment and drainage as may be appropriate should also be discussed. Where special measures are required, the details should be discussed with reference to test data, plans and sections describing, detailing and quantifying such measures.

(vii) Construction Materials

The following issues should be discussed:

- **Materials from the excavation** of the cuttings commenting on quality and quantities of each identified materials type (see Chapter 7: 5). This classification should be according to TRH14.
- **Utilization of materials** from cuttings including suitability for fill construction, selected layers, subbase layers or for other uses after processing (as described in Chapter 9).
- Methods used to **enhance or reduce quantities**, as may be advantageous over specific sections or over the whole length of the project, such as, widening or deepening cuts to obtain more materials.
- The project's **materials requirements**, and for each type comment on proposed source(s), i.e., road prism, borrow pit, quarry or other identified source. These requirements may include:
 - Materials for fill construction
 - Materials for rockfill, rock toes
 - Materials for base, subbase and selected layers
 - Sand for asphalt concrete
 - Sand for drainage purposes
 - Aggregate for concrete or asphalt
 - Rock for gabion construction and stone pitching
 - Water for construction

The materials requirements and proposed sources should be tabulated.

Each proposed borrow pit or quarry should be described, including commercial quarries and sources, and the following information included. Reference should be made to the test data sketches and plans and location thereof in the report.

- Location of proposed point of use
- Haul route and distance
- Type of material available
- Test data and location thereof in the report
- Proposed utilisation of material
- Overburden removal
- Excavation method
- Selection requirements
- Processing requirements
- Environmental requirements (Refer to the EMP (Chapter 8: 2.5) as required)
- Drainage and rehabilitation

(viii) Pavement Design

Pavement design procedures are described in detail in Chapter 10. A summary of the investigations, surveys, projections and other relevant data is generally given in this report as a background and motivation for the proposed pavement design and alternatives, if relevant. As such, the discussion includes:

- **General aspects**
- Regional **developmental needs**
- **Traffic surveys**, vehicle loadings, growth projections over the design life
- Pavement **design methodology**
- Influence of **environment**
 - Topography
 - Climate
 - Drainage
- **Availability of construction materials** for pavement design
- Recommended and alternative **pavement designs**, including the merits of each
- **Cost-benefit** analyses
- **Summary** and proposed pavement design for:
 - Freeway
 - Ancillary roads
- Summary of **pavement layer quantities**
- **Cost estimate**

(ix) Structures

The investigations for the founding of structures are described in detail in Chapter 7: 7. The findings, including the test data, core logging and geological and geotechnical interpretations are generally included as a section in this report, or as stand-alone volumes. If the information is included in a stand-alone volume, the report itself will be limited to a list and description of all structures detailing the proposed founding types and salient information, with references to the other volumes or reports.

(x) Test Data

Reporting of laboratory test data and field profiling of soil and rock faces as well as any field testing should, as far as possible, be done on the relevant road authority's forms or plans. SANRAL requires the use of its M1 series and certain other standardized forms. The reporting institution should ascertain the client's requirements. For subsoil investigations, standard borehole log sheets should be used. Where specialized testing or other data for which there are no standard reporting sheets or forms are available, it is recommended that the client's approval be obtained to use a purpose designed form.

(xi) Drawings

The following drawings or plans are generally included in a Detailed Assessment and Design Report:

- **Key plan**
- **Geological plans** and sections
- **Soils map**, if required
- **Road Prism Investigation Plans**, sometimes referred to as Centreline Soil Survey Long-Section or Plans, showing
 - Position of test pits and boreholes
 - Position of seismic traverses
 - Numbering of cuts
 - Type and extent of roadbed treatments
- **Long-sections** and/or cross sections through deep cuttings, high embankments, structure foundations
- Layout plan(s) of **proposed quarries or borrow pits**, including test pit positions and cross sections based on the soil profiles and borehole logs.
- Other **special plans and drawings**, pertaining to each particular problem area as required
- Interpreted seismic or other geophysical **exploration data**

9.1.3 Contract Documentation

Contract documentation is required for all construction projects, including the construction of new roads, upgrading or widening of existing roads, or for periodic maintenance of existing roads. The contract documentation is either an entire document, or a section of a set of documents dedicated to convey selected materials and site information that is needed by prospective tenderers and to the appointed contractor. On SANRAL projects, this volume is generally Volume 6 of the standard set of contract documents and is usually titled "Detailed Materials Report" or "Materials Investigation and Utilisation Report". This volume generally contains all the factual information included in the Detailed Assessment and Design Report, e.g., test data, borehole data and plan sections, and is similarly compiled. The style differs, as all proposals are now requirements. Chapter 11 also discusses contract documentation.

The engineer's assessment of the engineering conditions and challenges are given in good faith. However, the contractor's attention must be drawn to the fact that these are based on the information gained and actual conditions may differ as construction progresses.

The materials and pavement designs are stated, but all discussion on interpreted engineering conditions, interpreted materials behaviour and properties, alternative designs and alternative pavements are excluded from this document. The responsibility for the design remains in the domain of the design engineer or consulting engineer.

The general contents include the following sections:

- **Introduction**, as for Detailed Assessment and Design Report, Section 9.1.2
- **Physiography**, as for Detailed Assessment and Design Report, Section 9.1.2
- **Geology**, as for Detailed Assessment and Design Report, Section 9.1.2
- **Description of Alignment**, as for Detailed Assessment and Design Report, Section 9.1.2
- **Road Prism Investigations**, as for Detailed Assessment and Design Report, Section 9.1.2
- **Earthworks Design**, requirements only
- **Construction Materials**, factual data
- **Pavement Design**, requirements only
- **Structures**, requirements and factual data
- **Test data**, all test data
- **Drawings**

9.2 Reporting For Road Pavement Investigations

9.2.1 Initial Assessment

Most road authorities require the compilation of a report detailing the findings and recommendations for further detailed investigations (if required) following the completion of the initial assessment of the road pavement. The following aspects are generally included in an Initial Road Pavement Assessment Report:

- An **Introduction** covering the location of the road, a brief description of the regional climate and a general description of the traffic using the road.
- A **description** of the road including the category, number of lanes, width, presence of climbing lanes, access points or intersections and interchanges.
- A list and discussion of **available information**, including:
 - As built records such as pavement description, layer thicknesses, material type and any test data
 - Traffic data
 - Maintenance history
 - PMS data, which may include network level visual assessments, roughness measurements, rut depth measurements, skid resistance measurements and sometimes deflection measurements. This information is generally gained from the road authority.
 - A description of the detailed visual assessment carried out over the length of the project to identify uniform sections.



Road Pavement Investigations Reporting

- The **Initial Assessment Report** details the findings and recommendations for further detailed investigations (if required).
- The **Detailed Assessment and Design Report** covers the information, engineering assessment and proposed strategies and designs, for sections requiring structural improvements.
- **Contract Documentation** is needed by prospective tenderers and by the contractor appointed to carry out the construction of the project.

- Initial **structural capacity** analysis of various pavement sections considering the projected future traffic and traffic load spectrum.
- Establish **requirements and priority of action** for the sections in each of the following categories:
 - No problem areas
 - Areas with surfacing problems
 - Localized areas with structural problems
 - Extensive areas with structural problems

The presentation of test data should be on appropriate test data sheets of the road authority. The report generally contains a locality plan, and a plan(s) showing any salient features revealed at this stage.

9.2.2 Detailed Assessment and Design Report

This report generally covers the information, engineering assessment and proposed strategies and designs. The report is essentially directed at the sections of the road requiring structural improvements, forthcoming from the investigations described in Section 7. Also included are discussions on the materials sources, as well as information of a broader nature, but pertinent to the specific road project, such as climate, traffic patterns, seasonal variations, infrastructure, future developments, availability of material sources, and environmental constraints.

A Typical **Detailed Assessment and Design Report** includes chapters or sections titled:

(i) Introduction

This section covers:

- **Consultant's appointment** details and brief
- **General description** of the project
- **Executive Summary** highlighting the different strategies considered, and those recommended, as well as economic analyses for the different options

(ii) Physiography

This section includes a description of the location and general nature of the terrain, commenting on:

- **Climate**, including temperature and rainfall data, general weather patterns, occurrence of mist, snow and berg winds
- **Infrastructure** covering accessibility of power and water, proximity to roads, railways and ports, and regional telecommunications

(iii) Geology

The geology section should discuss the general geology of area and its influence on the availability of construction materials and their durability.

(iv) Description of the Road or Freeway

The detailed description of the road should include:

- Vertical and horizontal **alignment**
- **Road category**
- Road **cross-section** including the number of lanes, lane widths, shoulder types and widths, climbing lanes, intersections and accesses
- **As-built** road pavement(s)

(v) Road Pavement Investigations

The findings and recommendations of Initial Road Pavement Assessment should be discussed. The additional investigations carried out on the uniform sections decided in the Initial Assessment must be described. These may include additional deflection, roughness, skid resistance, and pavement profile measurements, as described in Section 7.3. Where intrusive investigations have been carried out, such as test pit, borehole or trench profiles, and photographs and laboratory test data, these should be discussed and analysed. It is important to cross reference all testing positions on the plans and sections.

The forms and formats of the relevant road authority should be used to summarise the results.

(vi) Pavement Evaluation

All information gathered from the various investigations and surveys are considered when deciding on uniform sections. Uniform sections are categorised according to:

- Requiring **no action**
- Only **surfacing** problems
- **Localized** problems
- Requiring probable **structural strengthening** in terms of life in E80s.

The findings in respect of each uniform pavement section is discussed in respect of present condition, causes and mechanisms of distress, distress manifestations and degree, pavement behaviour and current pavement state.

(vii) Rehabilitation Design and Approach

In this section, the past and future traffic loadings are described. The design methods used for pavement rehabilitation are described in Chapter 10: 5 to 9. Typically three methods for pavement rehabilitation design have traditionally been used in Southern Africa, the deflection method, the DCP method and the South African Mechanistic Design Method (SAMDM). It is recommended that more than one design method is used to assess the structural capacity of the pavement structure alternatives. The design methods used must be adequately described, covering all inputs and strategies considered to meet the structural demands on the pavement. All other inputs and considerations playing a role in the selection of appropriate strategies should also be discussed, including:

- Availability of **construction materials**
- **Environment** and service conditions
- **Constructability** of each of the options considered

(viii) Economic Analysis

The objective of the economic analysis, as part of the project-level rehabilitation investigation procedure, is to determine the most economical of the appropriate remedial options. This is done by taking into account:

- **Agency costs** including
 - Initial rehabilitation costs, including traffic accommodation costs
 - Maintenance costs
 - Capital costs
 - Salvage value
- **Road user costs** including
 - Delay costs due to rehabilitation activities
 - Vehicle operating costs
 - Accident and time costs

The various rehabilitation options should be compared by calculating the total present worth of cost (PWOC) of the various items for each option. See TRH12 for details.

(ix) Ancillary Works

Details of any ancillary works must be described. This includes:

- **Side drain** construction
- **Subsoil** drainage
- **Sub-pavement** drainage systems, such as herringbone collectors and drainage layers
- **Repairs to drainage** systems, i.e., pipes, inlet and outlet structures
- Repairs to **larger structures**

(x) Summary and Recommendations

This section should include a summary of the various options, and motivation for the recommended remedial option outlining the cost benefit analysis, expected maintenance needs and expected design life.

(xi) Drawings

All drawings and sections plans are included in this section. Test data, schedules, logs and photographs may also be included here, or may be given in Appendices.

9.2.3 Contract Documentation

All contract documentation, whether it be for the construction of new roads, the upgrading or widening of existing roads or just for the periodic maintenance of existing roads, is contained in either an entire document or a section of a set of documents dedicated to convey selected materials and site information. These documents are needed by prospective tenderers and by the contractor appointed to carry out the construction of the project. On SANRAL projects this volume is generally Volume 6 of their standard set of contract documents and is usually titled "Materials Investigation and Design Report" or "Materials Data". Chapter 11 discusses the compilation of contract documentation.

This contract documentation generally contains all the factual information included in the Detailed Assessment and Design Report, including test data, plans and sections, and is similarly compiled. However, the style differs as all proposals are now requirements and the design is the final design as accepted by the client. The final design will be selected after assessment of the various strategies, options as well as the economic analyses. Consideration is given to such matters as overall pavement management strategies, funding and political priorities.

The engineer's assessment of the engineering conditions and challenges are given in good faith. However, the contractor's attention must be drawn to the fact that these are based on the information gained and actual conditions may differ as construction progresses.

The materials and pavement designs are given per section of the road. However, all discussion on interpreted engineering conditions, interpreted materials behaviour and properties, alternative designs and alternative pavements are excluded from this document, so that the responsibility for the design remains in the domain of the design or consulting engineer.

A major aspect, often overlooked by designers in finalizing repair and reconstruction area quantities, is the relative uniformity of the originally constructed road pavement. The condition of areas in lower or in relatively unstressed conditions may be very close to the distressed condition, and may actually become distressed in the period between the completion of the investigations and assessments and the time the contractor starts the work, or by the time the construction work is completed.

Another important consideration is that a few large patches are more easily and much more economically constructed than a multitude of smaller patches. The economic limits between patching and reconstruction are of the utmost consideration, as are other aspects such as traffic accommodation and road user costs.

The general contents of the Contract Documentation should include:

- **Introduction**
- **Physiography**
- **Geology**
- **Description of alignment**
- **Road prism investigations**
- **Road pavement design.** Only the required design and construction requirements as recommended in the Detailed Road Pavement Assessment
- **Construction materials**
- **Ancillary works**
- **Test data**
- **Drawings**
- **Test data**

These sections are as for the Detailed Road Pavement Assessment, Section 9.2.2.



Engineers' Assessment

The engineer's assessment of the engineering conditions and challenges are given in good faith. However, the contractor's attention must be drawn to the fact that these are based on the information gained and actual conditions may differ as construction progresses.

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TRH Revisions

Many of the TRH guideline documents are in the process of being updated. See the SANRAL website, www.nra.co.za for the latest versions.

SAPEM CHAPTER 6: APPENDIX A

SOIL (AND WEATHERED ROCK) PROFILING OF TEST PITS AND AUGER HOLES

No engineering structure is better than the materials on which, or of which it is built. It is therefore of primary importance that the following aspects of its character are adequately described:

- **Moisture/water**, which affects its entire behaviour
- **Strength**, which affects its stability and ultimate bearing capacity
- **Volumetric change**, which affects possible distortion of the structure
- **Permeability**, which concerns rates of drainage within the soil, affecting changes in both strength and volume

The purpose of classifying the soils and rocks encountered during site exploration is to provide an accepted, consistent, concise, and systematic internationally accepted method of describing the various types of materials present in order to enable useful conclusions to be drawn therefrom.

It is therefore important that any soil classification adopted, should make use of a system that would address the characteristics mentioned above, both in terms of material characteristics and classification methodology. **What follows are not to be seen as the only classification systems available, but rather those that are preferred by SANRAL for use in their projects.**

Description of Soils and Rocks in Test Pits and Auger Holes

This guideline briefly describes the Jennings, Brink and Williams paper "Revised Guide to Soil Profiling for Civil Engineering Purposes in Southern Africa" (as originally published in the Civil Engineer in S.A. Vol. 15, No. 1 in January 1973) and subsequently updated in 2002, as directed below, which is now advocated for use in all SANRAL soil/rock investigations. Some additional guidelines are given in Tables A.1 to A.4 and A.6 of this Appendix in respect of proposed symbols to be used as abbreviations on simplified soil profiles and cross-sections normally depicted on the AO-Soil Survey Drawing in the Detailed Reports, or on simplified soil profiles prepared for pavement design purposes.

As what follows is only a brief summary, **as amended for SANRAL's own purposes, it is of the utmost importance that all investigatory site staff have a copy of the abovementioned updated version as embodied in Section 1 of "Guidelines for Soil and Rock Logging in South Africa (2nd Impression 2002)"** on site with them for quality assurance purposes.

As directed in the Introduction chapter of the abovementioned updated publication, geological formations or deposits can be divided into the two principal groups; 'soils' and 'rocks', the term 'soil' embracing the comparatively soft, loose and uncemented deposits, while the term 'rocks' refers to the hard, rigid or weathered to some degree, and/or strongly cemented deposits.

They can be further subdivided into four further categories, i.e. rock, residual soil, transported soil, and pedogenic deposits, or combinations of these.

The description of soils in test pit profiles should utilize the following descriptors according to Jennings, Brink and Williams, in the following order: moisture condition, colour, consistency, structure, soil type and origin (**MCCSSO**). In cases where *weathered /decomposed* rock is encountered, profilers may under 'consistency' wish to rather refer to 'hardness' and 'degree of weathering' as defined in Section 3 of the 2002 document referred to above. The description order then becomes **MCHWSSO**, where H refers to hardness and W to the degree of weathering.

(i) Moisture Conditions

For example, dry, slightly moist, moist, very moist, or wet, with moist being around the OMC of the material. This may depend on the grading and/or the clay content of the material.

(ii) Colour

Use Burland's colour discs or Munsell colour chart as the standard. For uniformity, the colour should be noted in its natural state in the test pit profile, but should be determined in a wet state when comparing materials from one test pit profile to the next. Mottling or blotching etc. should also be noted. Abbreviations for the colours are given in Table A.1.

Table A.1. Standard Abbreviations for Main Colour Descriptions on Soil Survey: Drawings and Cross-Sections or Simplified Soil Profiles

Colour	Abbreviation	Colour	Abbreviation
Black	Bl.	Mauve	M.
Blue	B.	Orange	O.
Brown	Br.	Red	R.
Green	Gn.	White	W.
Grey	G.	Yellow	Y.
Khaki	Kh.		

(iii) Consistency

The consistency is a measure of the density, hardness or toughness of the soil, and is an observation based on the effort required to dig into the soil, or to mould it with the fingers. e.g., very loose, dense, etc. Table A.2 and Table A.3 give the recommended definitions of consistency.

Table A.2. Consistency of Granular Soils

Consistency	Nomenclature	Description
Very Loose	V loose	Very easily excavated with spade. Crumbles very easily when scraped with geological pick
Loose	Loose	Small resistance to penetration by sharp end of geological pick
Medium Density	Med dense	Considerable resistance to penetration by sharp end of geological pick
Dense	Dense	Very high resistance to penetration of sharp end; and requires blows of geological pick for excavation
Very Dense	V dense	High resistance to repeated blows of geological pick requires power tools for excavation

Table A.3. Consistency of Cohesive Soils

Consistency	Nomenclature	Description
Very soft	V soft	Pick head can easily be pushed in to (up to) the shaft of handle; easily moulded by fingers.
Soft	Soft	Easily penetrated by thumb; sharp end of pick can be pushed in 30 – 40 mm; moulded with some pressure.
Firm	Firm	Indented by thumb with effort; sharp end of pick can be pushed in up to 10 mm; very difficult to mould with fingers; can just be penetrated with an ordinary hand spade.
Stiff	Stiff	Penetrated by thumb nail; slight indentation produced by pushing pick point into soil; cannot be moulded by fingers; requires hand pick for excavation.
Very stiff	V stiff	Indented by thumb nail with difficulty; slight indentation produced by blow of pick point; requires power tools for excavation.

Sometimes there is difficulty in classifying the consistency of a **cemented** material which may not properly be a rock, nor fit into the granular scale, e.g. **pedogenic** materials, or stabilized road pavement layers, etc.

Table A.4 gives a guide to terms that can be used.

Table A.4. Naturally or Artificially Cemented Soils

Consistency	Nomenclature	Description
Very weakly cemented	V W cem	Some material can be crumbled by strong pressure between fingers and thumb. Disintegrates under a knife blade to a friable state.
Weakly cemented	W Cem	Cannot be crumbled between strong fingers. Some material can be crumbled by strong pressure between thumb and hard surface. Disintegrates under light blows of a hammer head to a friable state.
Cemented	Cem	Material crumbles under firm blows of sharp pick point. Grains can be dislodged with some difficulty under a knife blade.
Strongly cemented	Str cem	Firm blows of sharp pick point on a hand-held specimen show indentations of 1mm to 3mm. Grains cannot be dislodged with a knife blade.
Very strongly cemented	V Str Cem	Hand-held specimen can be broken with hammer head with single firm blow. Similar appearance to concrete.

(iv) Structure

This indicates the presence, or absence, of joints in the soil and the nature of these joints. In the case of non-cohesive soils with a granular structure, it is not recorded. Cohesive soils, on the other hand, exhibit several types of structure as shown in Table A.5.

Table A.5. Structure of Cohesive Soils

Structure	Description	Associated Engineering Geological Problems
Intact	Structureless, no discontinuities identified	Compressible
Fissured	Soil contains discontinuities which may be open or closed, stained or unstained and of variable origin.	
Slickensided	This term qualifies other terms to describe discontinuity surfaces which are smooth or glossy and possibly striated.	Expansive/shrinking soils
Shattered	Very closely to extremely closely spaced continuities resulting in gravel sized soil fragments which are usually stiff to very stiff and difficult to break down.	
Micro-shattered	As above, but sand-sized fragments	
Stratified & Laminated & Foliated	These and other accepted geological terms may be used to describe sedimentary structures in transported soils and relict structures in residual soils.	Slope instability/non-isotropic porosity
Pinholed	Pinhole-sized voids or pores (up to say 2 mm) which may require a hand lens to identify.	Collapsible and/or compressible/porous
Honeycombed	Similar to pinholed but voids and pores > 2 mm; (pore size may be specified in mm).	
Matrix-supported	Clasts supported by matrix	Compressible
Clast-supported	Clasts touching (matrix may or may not be present).	

(v) Soil Type

The soil type or texture in each horizon is described on the basis of grain size, and can be a combination of any of the grain sizes as described in Table A.6. Boulders, cobbles, gravel, sand, silt and clay, etc. The internationally used MIT (Massachusetts Institute of Technology) Classification of Grain/Fragment size shall always be used.

Table A.6. Particle Size Classes Commonly used in Engineering (The MIT Classification)

Grain size (mm)	Classification	Nomenclature	Mineralogical composition	Identification test
< 0.002	Clay	Cl	Secondary minerals (clay minerals & Fe-oxides)	Greasy or soapy feel. Soils hands. Shiny when wet.
0.002 to 0.06	Silt	St	Primary & secondary minerals	Chalky feel on teeth. When dry rubs off hands. Dilatant*
0.06 to 0.2	Fine sand	F. S	Primary minerals (mainly quartz)	Gritty feel on teeth
0.2 to 0.6	Medium sand	M. S.	Primary minerals (mainly quartz)	Observed with naked eye
0.6 to 2.0	Coarse sand	C. S.	Primary minerals (mainly quartz)	Observed with naked eye
2.0 to 6	Fine gravel	F. Grav	Primary and pedogenised minerals (sometimes vein quartz)	Observed with naked eye
6 to 20	Medium gravel	M. Grav	Primary and pedogenised minerals (sometimes vein quartz)	Observed with naked eye
20 to 60	Coarse gravel	C. Grav	Primary rock minerals and pedogenised minerals (sometimes quartz)	Observed with naked eye
60 to 200	Pebbles / Cobbles	Pb	Primary rock Minerals (sometimes ferricrete and quartz)	Observed with naked eye
> 200	Boulders	Bl	Rocks	Observed with naked eye

* **Dilatancy** is a property whereby a material consisting of closely packed soil grains increases in volume as shearing occurs. If a part of saturated silt is placed in the palm of the one hand and shaken to and fro, or tapped, a film of water will appear on the surface. If the pat is then squeezed in the palm, or probed with a finger the surface will become dull as the water is withdrawn into the dilating material.

NB: It is important to estimate the percentage boulders in the profile as accurately as possible, as this is not only important in assessing the Class of Boulder Excavation in terms of the COTO Specifications, but also in assessing the viability of a Borrow Pit area.

(vi) Origin

It is extremely important to determine the origin of the soil, or at least to describe whether it is residual, or transported or a fill. It is generally quite easy to describe the residual soils beneath the pebble marker, but can prove more difficult for the transported material above e.g. windblown sand, transported clay, or originating from, for example residual shale. In determining the nature of the transported material, one needs to inspect the surroundings, i.e., the topography and landforms, as well as the climate, e.g., for wind-blown sands. It is similarly very important to be able to identify whether materials perhaps originate from man-made fills. A knowledge of the transported soil's origin assists in the identification of engineering geological behaviour as illustrated in Table A.7.

Table A.7. Origins of Transported Soils in Southern Africa

Transported Soil Type	Agency of Transportation	Source Rock	Soil Type	Associated Engineering Geological Problems
Talus (coarse colluvium)	Gravity	Any rock outcropping directly above talus deposit	Unsorted angular gravel and boulders	Slope instability
Hill wash (fine colluvium)	Sheetwash	Acid crystalline Basic crystalline Arenaceous sedimentary Argillaceous sedimentary	Clayey sand Clay Sand Clay or silt	Grain structure Heave Grain structure Heave or high compressibility
Alluvial or gulley wash	Streams or gulleys	Depends on catchment	Gravel (rounded), sands, silts & clays	All possible problems
Lacustrine deposit	Stream depositing in pan, lake or subterranean pool in cavernous rock	Usually mixed source	Sand Silt Clay	Compressibility Heave or high compressibility
Estuarine deposit	Tidal rivers and tides depositing into saline water	Mixed	Sand Silt Clay	Quicksand High sensitivity
Aeolian deposit	Wind	Mixed	Sand	Collapse grain structure
Littoral deposit	Waves	Mixed	Beach sand	Collapse grain structure
Sandy soils of mixed origin	Sheetwash, wind, termites	Various	Sandy/gravelly	Collapse fabric; dispersive characteristics; compressibility subject to flooding

(vii) Water Table

Some reference should always be made to the water table in the soil profile, even to note that it is not encountered within the depth investigated. The profiler should distinguish between a perched (seasonal) or a permanent water table when the accompanying notes to each profile are compiled in terms of 3.8 of the guideline dated 2002. More complete and proper guidelines as to how this distinction could be made, are given in the paper by Jennings et al (1973) given in the Bibliography at the end of this Manual.

(viii) Ancillary Notes to Accompany Each Soil Profile

All significant features should be recorded, including any of the following: water table, rate of inflow into test pit or trial hole, i.e high/medium/slow/slight, more accurate description of the layers of fill (if any), or roots, ant workings, presence of carbonate, iron concretions, salt crystals, sulphur.

Bulking, or lack thereof, (of replaced material in hole) should be noted as this could point out possible collapsible grain structure.

The pebble, or even more commonly the gravel marker(s), should in any case be fully described on the profile, but could be elaborated upon in the notes, as it indicates the cut-off between transported and residual soils.

The depth at the bottom of the hole should be recorded and the comment always made as to whether this was at refusal of any type of auger used, or not and on what the machine has actually refused, if it did.

The type of machine used for excavation should also be noted e.g. Williams LDH 80 Auger, TLB-Case 580 G (4X4), or hand excavation, or was it an existing open face, etc.

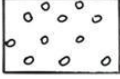
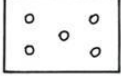
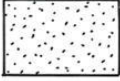
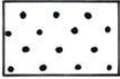
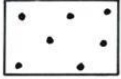
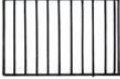
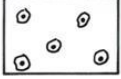
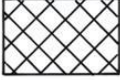
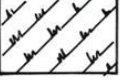
	Gravel		Gravelly
	Sand		Sandy
	Silt		Silty
	Clay		Clayey
	Ferricrete		Ferruginised
	Calcrete		Calcrete Nodules
	Silcrete		Silcrete Nodules
	Made Ground		Shattered Clay
	Permanent Water Table		Fissured and/or Slickensided Clay
	Perched Water Table		

Figure A.1. Standard Symbols for Soil Profiles (after Franki, 1995)

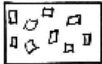
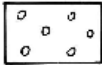
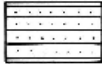
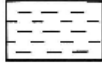
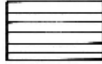
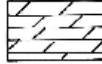
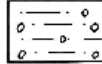
Sedimentary Rocks		Igneous Rock	
	Breccia	Plutonic	
	Conglomerate		Granite, Gabbro, Diorite, Norite
	Sandstone	Hyperbyssal	
	Siltstone		Syenite, Diabase, Dolerite
	Mudstone	Volcanic	
	Shale		Andesite, Rhyolite, Basalt
	Limestone	Metamorphic Rocks	
	Dolomite		Quartzite
	Peat		Schist
	Tillite		Slate
			Gneiss, Hornfels and other metamorphic rocks

Figure A.2. Standard Symbols for Profiling Rocks (after Franki, 1995)

SAPEM CHAPTER 6: APPENDIX B

ROCK PROFILING OF CORES, TEST PITS OR QUARRY FACES

The geological classification and identification of rocks is a very complex science requiring a high level of skill and experience. Any errors or oversights in this process invariably lead to claims by the contractor during the construction phase and it is thus a requirement that all logging be carried out by a professional and experienced engineering geologist or geotechnical engineer. Notwithstanding the above, a full geological appraisal may be unnecessarily detailed if the scope is only restricted to centreline soil on uniform geology on flat topography and some borrow pit investigations.

For bridge structures, cuttings, lateral support systems, quarry and deep soil/rock road prism surveys, **the detailed methods described in Section 3 of "Guidelines for Soil and Rock Logging in South Africa (2nd Impression)" should be followed.** This method prescribes the description of rock in the following order (MCWFDHR):

- Moisture
- Colour
- Weathering
- Fabric
- Discontinuities
- Hardness
- Rock Name

In addition, especially where the water table position from measurements is known, or when holes are drilled on topographical locations where wet conditions are to be expected during certain times of the year, the moisture condition (M), (e.g. "wet" below W.T.) for each layer should also be recorded before the colour (C) on the core log. The depth of the water table (if any) should be indicated.

In addition, the existence of any potentially deleterious secondary minerals such as clay, shale, mica, sulphides or soluble salts *in potential quarries*, must be identified and commented upon. If the presence of such minerals is suspected, it is considered prudent to carry out further microscopic/X-ray assessment of thin slides in order to more accurately identify and quantify potential problems.

As what follows is either a repetition of tables in the above-mentioned SAICE, AEG and SAIEG approved document, or are additional guideline descriptors as amended for SANRAL's own purposes, it is recommended that all investigatory site staff have copies of both documents with them on site for quality assurance purposes.

Table B.1. Colour

Term	Description
Speckled	Very small patches of colour: < 2 mm
Mottled	Irregular patches of colour: 2 – 6 mm
Blotched	Large irregular patches of colour: 6 – 20 mm
Banded	Approximately parallel bands of varying colour*
Streaked	Randomly orientated streaks of colour*
Stained	Local colour variations associated with discontinuity surfaces

* Describe colour thickness using bedding thickness criteria (e.g. thickly banded, thinly streaked, etc).

Table B.2. Weathering

Degree of Weathering	Extent of Discolouration	Fracture Condition	Surface Characteristics	Original Fabric	Grain Boundary Condition
Unweathered	None	Closed or stained.	Unchanged	Preserved	Tight
Slightly weathered	< 20% of fracture spacing on both sides of fracture	Discoloured, may contain thin filling.	Partial discolouration. Often unweathered rock colour.	Preserved	Tight
Moderately weathered	> 20% fracture spacing on both sides of fracture	Discoloured, may contain thick filling.	Partial to complete discolouration. Not friable except poorly cemented rocks.	Preserved	Partial opening
Highly weathered	Throughout	-	Friable, possibly pitted.	Mainly preserved	Partial separation. Not easily indented with knife. Does not slake.
Completely weathered (Residual soil)	Throughout	-	Resembles a soil.	Partially preserved	Complete separation. Easily indented with knife. Slakes.

Table B.3. Fabric or Grain Size Classification

Classification	Size (mm)	Recognition
Very fine grained	< 0.2	Individual grains cannot be seen with a hand lens
Fine grained	0.2 – 0.6	Just visible as individual grains under hand lens
Medium grained	0.6 – 2	Grains clearly visible under hand lens, just visible to the naked eye
Coarse grained	2 – 6	Grains clearly visible to the naked eye
Very coarse grained	> 6	Grains measurable

Table B.4. Discontinuity Spacing

Separation (mm)	Micro-Structure Spacing (foliation, cleavage, bedding, etc.)	Discontinuity Surface Spacing (fractures, joints, etc.)
< 6	Very intensely	Very highly
6 - 20	Intensely	Very highly
20 - 60	Very thinly	Highly
60 – 200	Thinly	Highly
200 – 600	Medium	Moderately
600 – 2000	Thickly	Slightly
> 2000	Very thickly	Very slightly

Table B.5. Discontinuity Surface Description

Joint filling	
Joint fill type	Definition (wall separation specified in mm)
Clean	No fracture filling
Stained	Colouration of rock only. No recognisable filling material.
Filled	Fracture filled with finite thickness
Discontinuity orientation	
Discontinuity inclinations (i.e. of joints, bedding, faults)	
Roughness of discontinuity planes	
Classification	Description
Smooth	Appears smooth and is essentially smooth to the touch. May be slickensided*.
Slightly rough	Asperities on the fracture surface are visible and can be distinctly felt.
Medium rough	Asperities are clearly visible and fracture surface feels abrasive.
Rough	Large angular asperities can be seen. Some ridge and high side angle steps evident.
Very rough	Near vertical steps and ridges occur on the fracture surface.

* Where slickensides occur, the direction of the slickensides should be recorded.

Table B.6. Rock Hardness

Hardness	COLTO Classification	Description	Range of Minimum UCS (MPa)
Very soft rock	R1	Material crumbles under firm blows of pick point. Can be peeled with a knife. SPT refusal. Too hard to cut triaxial sample by hand.	1 – 3
Soft rock	R2	Firm blows with pick point: 2 – 4 mm indentation. Can just be scraped with a knife.	3 – 10
Medium hard rock	R3	Firm blows of pick head will break hand held specimen. Cannot be scraped or peeled with a knife.	10 – 25
Hard rock	R4	Breaks with difficulty, rings when struck. Point load or laboratory test results necessary to distinguish between categories.	25 – 70
Very hard rock	R5		70 – 200
Extremely hard rock	-		> 200

The **Rock** Name is the last facet to be described in the MCWFDHR sequence to be recorded/described on the core log, two typical example formats are appended at the end of this Appendix.

The end product “Borehole Log” is not complete until the additional relevant data (obtained from the driller’s field sheets) has also been recorded and which is normally entered on to the left-hand side of the borehole log sheet. The core log (right-hand side) of the borehole log purely comprises a description of the recovered core. It is essential that the engineering geologist or geotechnical engineer provide not only a description of the material recovered in the core box, but an interpretation of the in situ condition of the material. For example, “recovered as a wash sample of granitic sand, interpreted as friable, very soft rock granite.” The entire borehole log includes the relevant data applicable to the actual drilling of the hole, (some of it quantified/analysed) viz. machine type, drill runs, core barrel sizes, casings, RQD determination, core recovery, sampling and in situ testing data, water loss and water rest levels etc., **all which are equally critically important inputs to be entered onto the borehole log by the profiler, to ensure an overall accurate end-product.**

The borehole log must reflect the name and professional registration of the logger.

BOREHOLE LOG												
DRENNAN MAUD & PARTNERS 68 RIDGE ROAD DURBAN			Project Site Job No. 7..... Logged by Date Machine Drilling Dates				Hole No. Sheet of Location Elevation X Co-ord. Y Co-ord. Orientation Total Depth					
			Contractor Driller									
Drilling Method and size	% Materials Recovery	R Q D %	Fracture Frequency	Sample and Test	Value	Depth Metres	Legend	DESCRIPTION SOIL Moisture, Colour, Consistency, Structure, Soil Type, Origin, Inclusions, Field Assessment, Classification. ROCK Colour, Weathering Fabric (Text, Struct. Disc) Rock Hardness Rock Type, Discontinuities, Field Assessment, Classification				
						0.5						
						1.0						
						1.5						
						2.0						
						2.5						
						3.0						
						3.5						
						4.0						
						4.5						
						5.0						
						5.5						
						6.0						
						6.5						
						7.0						
						7.5						
						8.0						
						8.5						
						9.0						
						9.5						
						10.0						

↓ Standard Penetration Test ~ End of Borehole
 ▽ Water Level --- Approximate Material Changes

○ Disturbed Sample
 □ Undisturbed Sample
 X Point Load Test in MPa

LAB TEST
 I Indicator T Triaxial
 C Consolidation R Recompacted
 S Shearbox ▮ Piezometer

SOUTH AFRICAN NATIONAL ROADS AGENCY LTD							Date started	5/11/2002	BH No.	MS 2
CONTRACT		MSIKABA - MTENTU/8100102: N2 WILD COAST TOLL ROAD					Date completed	11/11/2002	X-Coord	3463945
SITE		MSIKABA BRIDGE - SOUTH BANK					Water level	11.98m	Y-Coord	75593
CONTRACTOR		WEPPELMANN GEOTECHNICAL SERVICES (PTY) LTD					Logged by	SJH/RAB	Level	TBA
							Date	15/11/2002	Inclination	Vertical
DRILL RUN	DRILLING METHOD	CASING DEPTH	% CORE RECOVERY	% RQD	FRACTURE PR EQ.	TEST RESULTS	Depth (m)	GENERAL DESCRIPTION	PROFILE	REMARKS
1.50	Auger		100	-	-		1.07	SAND - Dry, charcoal grey becoming dark brown, loose to medium dense, silty fine to medium sand with coarse sand grains and siltels. Colluvium/topsoil.		
1.95	SPT		67	-		N=29	1.80	CLAYEY SILTY SAND - Moist (?), orange with grey blotches, fine (?) clayey silty fine to medium sand. Residual		
2.65	NWD4		100	-				SANDSTONE - Mottled pale grey, orange and red, highly weathered, coarse grained, very finely laminated, cross bedded and matrix supported, highly fractured, soft to very soft, Natal Group sandstone. Clay rich zones associated with core platy weathered zones.		
3.00	NWD4		100	-		N=41				
3.45	SPT		71	-						
4.80	NWD4		99	81			4.00	SANDSTONE - Pale grey with red staining, slightly weathered becoming unweathered, but slightly weathered around discontinuities, medium to coarse grained, cross bedded (60°), moderately to highly fractured, hard to mainly very hard, Natal Group sandstone.		PROVISIONAL
6.13	TNW		100	80				Discontinuities (bedding and joints) rough and undulating to stepped, often occurring as doublets with orange clay and red iron staining. Occasional bedding discontinuities contain rock flour or clay.		
7.70	TNW		99	80				8.20m Clay gouge (1mm) on rough, undulating joint surfaces.		
9.20	TNW		100	80		UL=0				
							10.00			

BH No. MS 2 - Page 1 of 3

EXAMPLES OF SPECIAL ROADBED TREATMENT TYPES

Roadbed Type	Description	Explanation
A1	COLTO Clause 3305(b) Three-pass roller compaction	
A2	COLTO Clause 3305(c) Preparing and compacting the in situ roadbed (ISRB) to 90% MOD AASHTO density	
B	COLTO Clause 3305 (c) As above but the in situ roadbed can be processed in situ and compacted on 90% MOD AASHTO density	
C1	COLTO Clause 3305 (d) In situ treatment of the roadbed by ripping the rock at roadbed level to be processed as BSL (bottom selected layer) according to COLTO Clause 3304 (b)	
C2	COLTO Clause 3305 (d) As above but blasting the rock at roadbed level to be processed as BSL	
D CUT OR FILL	This special treatment shall comprise of the following over and above benching in as required: (see Drawings) • Draining the roadbed in accordance with COLTO Clause 3305 (e) • Removing unsuitable material to a minimum depth of 400mm below BSL, even if in cut, in accordance with COLTO Clause 3305 (a) • Provisional geotextile (type..... or similar) at minimum depth of 650mm below BSL • 500mm (minimum) Compacted pioneer rock layer (provisional 250mm penetration) • Compacted blinding fill separation layer of 150mm thickness on top of pioneer layer • Fill layers, if in fill as specified • (Structural layers as specified)	For seasonal soggy conditions of limited depth (< 1 m)
E FILL	This special roadbed treatment shall comprise of the following over and above benching-in as required: (see Drawings) • Draining the roadbed in accordance with COLTO Clause 3305 (e) • Removing unsuitable material to specified depth (950mm) below fill layers (or in exceptional cases below BSL) in accordance with COLTO Clause 3305 (a) • Provisional heavy duty geotextile (type or similar) at reduced excavation level • 750 mm (minimum) Compacted pioneer rock layer (provisional 250 mm penetration) • 300 mm Sifted gravel filter blanket layer of top of pioneer layer • 150 mm Compacted blinding fill separation layer on top of pioneer layer • 150mm Compacted blinding fill separation layer on top of filter blanket layer • (Structural layers as specified)	For permanent soggy conditions overlain by ≥ 1 m of unsuitable soils
	This special treatment shall comprise of the following over and above benching in as required: (see Drawings) • Draining the roadbed in accordance with COLTO Clause 3305 (e) • Removing unsuitable material to specified depth (1950mm) below fill layer (or in exceptional cases below BSL) in accordance with Clause 3305 (a) • Provisional heavy duty geotextile (type or similar) at reduced excavation levels • 17500 mm (minimum) Compacted pioneer rock layer (provisional 250 mm penetration) • 300 mm Sifted gravel filter blanket layer of top of pioneer layer • 150 mm Compacted blinding fill separation layer on top of pioneer layer • 150 mm Compacted blinding fill separation layer on top of filter blanket layer • Fill layers, as specified • (Structural layers as specified)	For permanent soggy conditions overlain by ≥ 2 m of unsuitable soils