

SOUTH AFRICAN PAVEMENT ENGINEERING MANUAL

Chapter 7

Geotechnical Investigations and Design Considerations



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

Date of Issue: October 2014

Second Edition

South African Pavement Engineering Manual
Chapter 7: Geotechnical Investigations and Design Considerations

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Chapter 7

Geotechnical Investigations and Design Considerations



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BACKGROUND

1. Introduction

2. Pavement Composition and Behaviour

TESTING AND LABORATORY

3. Materials Testing

4. Standards

5. Laboratory Management

INVESTIGATION

6. Road Prism and Pavement Investigations

7. Geotechnical Investigations and Design Considerations

8. Material Sources

You are
here



DESIGN

9. Materials Utilisation and Design

10. Pavement Design

DOCUMENTATION AND TENDERING

11. Documentation and Tendering

IMPLEMENTATION

12. Construction Equipment and Method Guidelines

QUALITY MANAGEMENT

13. Acceptance Control

POST CONSTRUCTION

14. Post-Construction

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

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 7.

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 pavement investigations, including legal and environmental requirements, materials testing, and reporting on the investigations. 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. Chapters 6 and 7 are complementary.

Chapter 7: Geotechnical Investigations and Design Considerations covers the geotechnical investigations applicable to pavement structures, including embankments, cuts, structures and tunnels. Geophysical methods, drilling and probing, and stability assessments are discussed. Guidelines for the reporting of the investigations are provided. The personnel required for specialist geotechnical investigations are also recommended.

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

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

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.

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

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South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

TABLE OF CONTENTS

1.	Introduction and Planning	1
1.1	Objectives of a Geotechnical Investigation	1
1.2	Chapter Scope	2
2.	Competencies and Responsibilities	3
2.1	Consulting Engineering Company	3
2.2	Drilling and In Situ Testing Contractors	4
2.3	Testing Laboratories	4
3.	Geotechnical Investigations	5
3.1	Planning	5
3.2	Geophysical Testing	10
3.3	Drilling and Probing	10
3.4	Stability Assessments	10
3.4.1	Sub-Surface Investigations Related to Stability Assessment	11
3.4.2	Reporting, Scheduling and Timing	12
3.5	Procurement of Geotechnical Services	12
3.5.1	Consulting Geotechnical Engineering Services	12
3.5.2	Geotechnical and Drilling Contractors	12
4.	Embankments	13
4.1	New Embankments	15
4.1.1	Embankment Stability	15
4.1.2	Settlement of Embankments	15
4.1.3	Special Considerations	16
4.2	Existing Embankments	17
4.2.1	Toe Erosion	17
4.2.2	Settlement	18
4.2.3	Degradation	18
4.2.4	Translational Slips	20
4.2.5	Creep and Slide (Creeping Valley Slides)	20
4.2.6	Internal Erosion and Piping	20
4.2.7	Stability Failure (Rotational Slips)	21
4.3	Investigation Process	22
5.	Cuts	23
5.1	Cut Slopes in Soils	24
5.2	Cut Slopes in Rock	25
5.2.1	Rock Falls and Slides	26
5.2.2	Toppling Failures	27
5.2.3	Block Slides	28
5.2.4	Degradation	31
5.2.5	Investigation Process	33
5.3	Failure of Existing Cuts	33
5.3.1	Cut Slopes in Soils	33
5.3.2	Cut Slopes in Rock	37
6.	Subsurface Drainage	39
6.1	In Situ Subgrade	39
6.2	Cuts	40
6.3	Underneath Embankments	40
6.4	Design of Special Subgrade Treatment Types Underneath Building or Culvert Sites	41
7.	Structures	42
7.1	Intrusive Investigations for Bridge Upgrades	42
7.2	Modus Operandi and Reporting	43
8.	Tunnels	44
8.1	Stage 1: Desk Study and Site Reconnaissance (Pre-Feasibility)	45
8.1.1	Desk Study	45
8.1.2	Site Reconnaissance (Walkover Site Inspection)	47

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

8.1.3	Site Reconnaissance Report.....	49
8.2	Stage 2: Preliminary Site Investigation (Feasibility)	49
8.2.1	Preliminary Tunnel Report	49
8.3	Stage 3: Detailed Site Investigations and Design	49
8.3.1	Planning	50
8.3.2	Detailed Investigation Contract	50
8.3.3	Investigation Methods.....	50
8.3.4	Guidelines for Assessing Testing Requirements.....	51
8.3.5	Investigation of Old Mine Workings, Buildings and Structures	52
8.3.6	Design.....	53
8.3.7	Detailed Tunnel Investigation Report.....	54
8.4	Stage 4: Construction Stage Investigations.....	54
8.5	Stage 5: Post Construction Monitoring	55
9.	Composition of Test Data and Reporting.....	56
9.1	Preliminary Geotechnical and Materials Report.....	56
9.2	Detailed Geotechnical and Materials Design Report	56
9.3	Project Document	57
	References and Bibliography	58
Appendix A:	Aspects Covered in the Detailed Geotechnical and Materials Exploration and Design Report for Greenfield/Upgrade Projects	
Appendix B:	Bridge and Culvert Foundation Investigation	

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

LIST OF TABLES

Table 1.	Registration and Affiliations Requirements.....	4
Table 2.	Summary of Geotechnical Activities During Project Design and Construction Phases.....	8
Table 3.	Progressive Investigation Stages for Tunnelling Projects.....	45

LIST OF FIGURES

Figure 1.	Typical Flowchart for Road Prism, Structures and Tunnels Specialist Geotechnical Investigations.....	6
Figure 2.	Typical Road Embankment.....	13
Figure 3.	Topographic Embankment Types: Side Slope Embankments (from TRH10).....	13
Figure 4.	Topographic Embankment Types: Gully Embankments (from TRH10).....	14
Figure 5.	Topographic Embankment Types: Flat Embankments (from TRH10).....	14
Figure 6.	Bump at Bridge Approach.....	16
Figure 7.	Toe Protection by Construction of Gabion Wall.....	17
Figure 8.	Preventing Settlement on High Embankment.....	18
Figure 9.	Inclinometer Probe.....	19
Figure 10.	Prevention of Degradation and Collapse Settlement in High Embankment.....	19
Figure 11.	Slide or Slip (from TRH15).....	20
Figure 12.	Internal Erosion and Piping.....	21
Figure 13.	Stability Failure.....	21
Figure 14.	Example of a Road Cut in Rock.....	23
Figure 15.	Cut Slope in Soils.....	24
Figure 16.	Interceptor Drains.....	26
Figure 17.	Catch Fences and Canopies on Chapman's Peak Drive in Cape Town.....	26
Figure 18.	Applying Rock Fall Netting and Shotcrete to Cut Slope.....	27
Figure 19.	Toppling and Block Failures.....	28
Figure 20.	Steep Block Slide.....	29
Figure 21.	Slide on Unfavourable Bedding Plane.....	29
Figure 22.	Doweling as a Stabilization Method.....	30
Figure 23.	Gabion Gravity Wall to Retain Unfavourable Dip Strata.....	30
Figure 24.	Degradation of Sediments.....	31
Figure 25.	Enon Conglomerate near Knysna.....	32
Figure 26.	Corestones Falling from Slope.....	33
Figure 27.	Erosion of Cut Face due to Inadequate Interceptor Drain above Slope.....	34
Figure 28.	Netting System and Re-Vegetating.....	35
Figure 29.	Rotational Slip.....	35
Figure 30.	Mud and Vegetation Slide on Kaaiman's Pass.....	36
Figure 31.	Toppling Failure (from TRH18).....	38
Figure 32.	Interceptor Drain (from TRH15).....	39
Figure 33.	Drainage Blanket (from TRH15).....	40
Figure 34.	Wick Drains Under Fill.....	41
Figure 35.	Pedestrian Bridge Over the N1.....	42
Figure 36.	Scour around Bridge Piers.....	43
Figure 37.	Huguenot Tunnel.....	44
Figure 38.	Google Earth Satellite Image of Joints and Faults in Gneissic Terrain in Kamieskroon, Namaqualand.....	47
Figure 39.	Changes in Vegetation as a Result of Filled Pit.....	48
Figure 40.	Tunnel Boring Machine at Entrance to Tunnel at Gautrain's Rosebank Station.....	52

1. INTRODUCTION AND PLANNING

This chapter follows on from Chapter 6 and focuses on the geotechnical investigations for various road structures, cuts, embankments and tunnels and related design considerations and guidance. 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.

Geotechnical investigations and the associated design considerations are a very important aspect in the provision of roads. Some typical problems that may arise due to inadequate geotechnical investigations include:

- Unforeseen **changes in the excavation characteristics** and **usage of materials** in the works. This may result in major delays and cost escalation as arrangements and approvals for blasting hard materials are made.
- **Unforeseen founding or varying founding conditions** for embankments and structures. This may require, amongst other things, the establishment of expensive excavation plant such as draglines, and piling machines. This is likely to have a snowball effect when, for example, drainage structures cannot be constructed until the founding conditions are rectified, and embankments cannot be constructed until the structures are completed.
- **Foundation failures** requiring demolition and reconstruction of constructed works or on-going expensive maintenance activities. These costs can be astronomical to both the owner and user over the long term.

Old saying –

“One pays for the site investigation whether it is done or not”

The cost of prevention is much less than the cost of rectification



‘... and we can save 700 lira by not taking soil tests.’

1.1 Objectives of a Geotechnical Investigation

When carrying out any geotechnical investigation, be it of a simple nature and scope, or a more complex investigation using more advanced investigation techniques, the modus operandi is normally progressive in nature and the basic objectives are:

- First define the **engineering objective** and **total scope of work**.
- **Tailor the investigation** to:
 - Scope and type of project
 - Geology
 - Topography
 - Expected soil profile and ground water regime
- **Identify problem areas** at a sufficiently early stage.
- Assessing the **suitability of the site** for the proposed project, for example:
 - Route geology and soil conditions
 - Possible adverse geological conditions
 - Possible unstable ground conditions
 - Existing undermining
- Identify the measures necessary to ensure **stability of high embankments and deep cuts**, and to investigate accordingly.



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.

- Investigate individual sites for **suitable bridge** and **culvert foundations**.
- **Foresee and provide against difficulties** that may arise during construction owing to ground, ground water or ground moisture, and other local conditions, whether for new construction or upgrade purposes.
- Identify **risk and consequence of failure**.
- Facilitate an **adequate and economical design**.
- Identify and advise on the possible **need for further investigations** required during the construction stage.

1.2 Chapter Scope

The scope of this chapter includes:

- Competencies of **personnel, responsibilities** and **legal considerations** governing geotechnical exploration work.
- Geotechnical investigations for **structures and tunnels** associated with roadwork projects, and for the associated **foundation design** reports.
- Geotechnical investigations for **cuts and embankments**, and the associated design reports.
- **Early identification** of the required facets and sequence of **exploration** work, depending on the geology, the site and type of road or road structure project undertaken.
- **Early identification of problem areas** requiring the services of a specialist geotechnical engineer and/or a specialist engineering geologist or geophysicist may obviate the need for additional detailed subsurface investigations at a later stage.
- Appointment of a specialist **geotechnical engineer** and/or **engineering geologist** for specialized geotechnical investigations and designs for roadwork and associated road structure or tunnel projects.

The following are contained in the Appendices:

- Appendix A: Aspects Covered in the Detailed Geotechnical and Materials Exploration and Design Report for **Greenfield/Upgrade Projects**
- Appendix B: **Bridge and Culvert Foundation** Investigation



Standard Specifications

Note that when this chapter was written and updated, the 1998 version of the COLTO Standard Specifications was being used. However, these specifications are currently being reviewed. A revised version of the Standard Specifications is likely to be published in 2015 and is likely to be issued either by SANS or COTO.

In this chapter, reference is only made to the Standard Specifications, which currently refers to the 1998 COLTO version.

2. COMPETENCIES AND RESPONSIBILITIES

The competencies, responsibilities of the various parties involved are discussed in this section, including:

- Consulting engineers
- Drilling and in situ testing contractors
- Testing Laboratories

2.1 Consulting Engineering Company

The responsibility for the successful completion of any geotechnical investigation or assessment, design and documentation lies with the consulting engineering companies appointed for the project. Such companies are responsible to:

- Provide sufficiently knowledgeable and experienced, **professionally registered personnel** to plan, prepare, provide leadership and undertake the investigations and assessments.
- Have, or procure, the necessary experience, professional registration and knowledge for the **interpretation of the test data** and to **evaluate all the necessary geotechnical parameters** emanating from the investigations, for the design of the necessary foundations and/or support.
- **Manage** the various service providers appointed for the investigations to ensure that Code of Procedure guidelines, and best practice, are adhered to. Examples of possible service providers are:
 - Specialist geotechnical engineers
 - Engineering geologists
 - Geologists
 - Geophysicists
 - Geohydrologists
 - Drilling contractors
 - Specialized geotechnical in situ testing contractors and subcontractors
 - Accredited testing laboratories
- **Assess and evaluate** all the necessary soil, rock and ground water design parameters for geotechnical design and documentation purposes. Bear in mind that it may be the task of other appointed geotechnical design engineers or structural design engineers to carry out the design of the foundations or piles or lateral support systems, or tunnel support systems.
- Compile the necessary geotechnical investigation (site investigation) **design reports, drawings and project documents**.

On all geotechnical investigations it is expected that the professional staff and supervisory personnel have:

- **Sound knowledge** of engineering geology or geotechnical and pavement engineering.
- **Sufficient experience** in the identification of potential problematic practices, conditions or materials.
- **Ability to effectively investigate**, sample and request or instruct appropriate laboratory testing.

Personnel carrying out, leading, supervising and managing the various facets of a geotechnical investigations must be professionally registered and preferably also members of affiliated institutions as shown in Table 1, or similar foreign affiliations. Exceptions are allowed for persons-in-training, provided they are properly supervised by registered professionals, as described below.



When to Appoint a Specialized Geotechnical Engineer or an Engineering Geologist

- Where cuts and embankments are more than 3 metres deep
- For foundation investigations and tunnels
- Where the route traverses dolomitic formations
- Where the road or structures traverse landfills and/or undermined areas
- Where adverse geological conditions require special attention or special measures
- Where lateral support of road structure foundations is required, e.g., viaduct foundations on steep mountain or hill slopes

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

Table 1. Registration and Affiliations Requirements

Discipline	Registration Authority SA	Member Affiliation in SA
Geotechnical engineer	ECSA ¹	SAICE ³ Geotechnical Division
Engineering geologist	SACNASP ²	SAIEG ⁴
Geophysicist	SACNASP	SAGA ⁵
Geohydrologist	SACNASP	SA Groundwater Association
Pavement engineer/Pavement profiler	ECSA	SAICE Transportation Division or Geotechnical Division

Note

1. ECSA is the Engineering Council of South Africa
2. SACNASP is the South African Council for National Scientific Professions
3. SAICE is the South African Institute of Civil Engineers
4. SAIEG is the South African Institute for Engineering and Environmental Geologists
5. SAGA is the South African Geophysicist Association

All core or chip logging and geotechnical or soil engineering mapping and profiling must be carried out, officially checked and signed by a registered engineering geologist or professionally registered geotechnical engineer. In the case of core or chip logging or profiling, when proposed and officially approved by the employer, individual logging sheets may be compiled by a well-experienced, but as yet unregistered geotechnical engineer or engineering geologist (person-in-training). This profiling and related work is, however, to be officially supervised, checked and signed off by the supervising registered geotechnical engineer or engineering geologist.



Persons-in-Training

Logging of cores, chips and profiles can be carried out by geotechnical engineers or engineering geologists in training, provided the employer receives timely proposals and applications to this effect, and provided timely official approval is given.

2.2 Drilling and In Situ Testing Contractors

The Contractors tendering for geotechnical investigative work must be highly experienced in the particular field required. It is the responsibility of the contractor undertaking the investigation to:

- **Complete the work** on time and in accordance with the tender or quotation specifications.
- **Carry out the investigation** according to these guidelines and other recognised standards and procedures.
- Provide **adequate and reliable data** for interpretation purposes.
- Provide experienced staff on site to **supervise operations**.

2.3 Testing Laboratories

It is a requirement that the fieldwork, as well as laboratory materials sampling and testing, be carried out by a SANAS accredited testing company approved by the road authority. See Chapter 5: 1.1 for more on laboratory accreditation.

3. GEOTECHNICAL INVESTIGATIONS

3.1 Planning

A typical flowchart for road prism and specialist geotechnical investigations is shown in Figure 1. In practice, the investigations for structures, tunnels, cuts and embankments associated with a new or greenfields road project, are normally planned and carried out in conjunction with, or just after, the road prism and materials investigations. Information from road prism investigations is often used to assist in planning geotechnical investigations.

Exploration work should be as sufficient as the engineering conditions warrant, and as the total scope of works requires. It cannot be emphasized too strongly that thorough planning is a foremost requirement and utmost care and diligence is required during the early planning stages, as well as the detailed investigation stages. The primary aim is to prepare an adequate design and to safeguard against problems during construction and during the life of the facility.

The cost of adequate exploration is relatively low when compared with the total value of the project, and varies depending upon the project and the nature of the ground. An often-quoted cumulative figure is in the order of 1½% of the construction cost estimate.

Legal issues, environmental issues and safety precautions are critically important during all stages of a geotechnical investigation. The following documents should therefore be studied and be readily available at all times to the entire investigation team. Consulting companies should ensure that all members of the investigation team, including consultants, contractors and laboratory staff involved with the fieldwork, are knowledgeable with the contents of these documents.

- **SAICE Code of Practice**, "The Safety of Persons Working in Small Diameter Shafts and Test Pits for Geotechnical Engineering Purposes", 2007.
- The **legal and environmental requirements** and considerations elaborated upon in Chapter 1: 6, Chapter 6: 3 and Chapter 8: 2.5.
- **SAICE Code of Practice**, "Lateral Support in Surface Excavations", 1989.
- **Occupational Health and Safety Act** No. 85 of 1993 as amended, including the Regulations (2003).
- **TRH2**: Geotechnical and Soil Engineering Mapping for Roads and the Storage of Materials Data.

Considering the aims and objectives of investigations, the planning of the investigation should take many, or all, of the following factors into consideration:

- Definition of the **total scope** and the engineering objective.
- **Nature** of the proposed road project.
- **Geology and geomorphology** of the route or site(s).
- **Access** and remoteness of sites.
- Site **topography**, vegetation and drainage.
- The nature of **adjacent developments** beyond road reserves.
- Knowledge and data gathering of previous **geotechnical investigations**, for example, existing bridge foundations. Opinions and observations from local engineers, land owners and contractors.
- The identification of the various **soil and rock types** occurring in the area of the proposed road structure project, and representative soil profiles.
- **Evidence of problem soil conditions**, e.g., expansive or collapsible soils, possible shallow undermining, dolomites, dispersive soils and soft clays.
- Localised **moisture conditions** and ground water levels.
- **Upfront planning** for drilling or augering of trial holes, test pits excavation and obtaining undisturbed or disturbed samples for laboratory tests and in situ testing. These are required for the design of embankments, cut slopes, bridge and culvert foundations.

For successful eventual completion of any geotechnical investigation for structures and tunnels, a logical and systematic approach should be followed, as summarised in Figure 1.



Planning

Thorough planning is a foremost requirement of geotechnical investigations. The utmost care and diligence is required during both the early planning stages and the detailed investigation phases.



Terminology

New facilities comprise both *New construction* roads or structure works types as well as *Upgrading* road or road structure works.

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

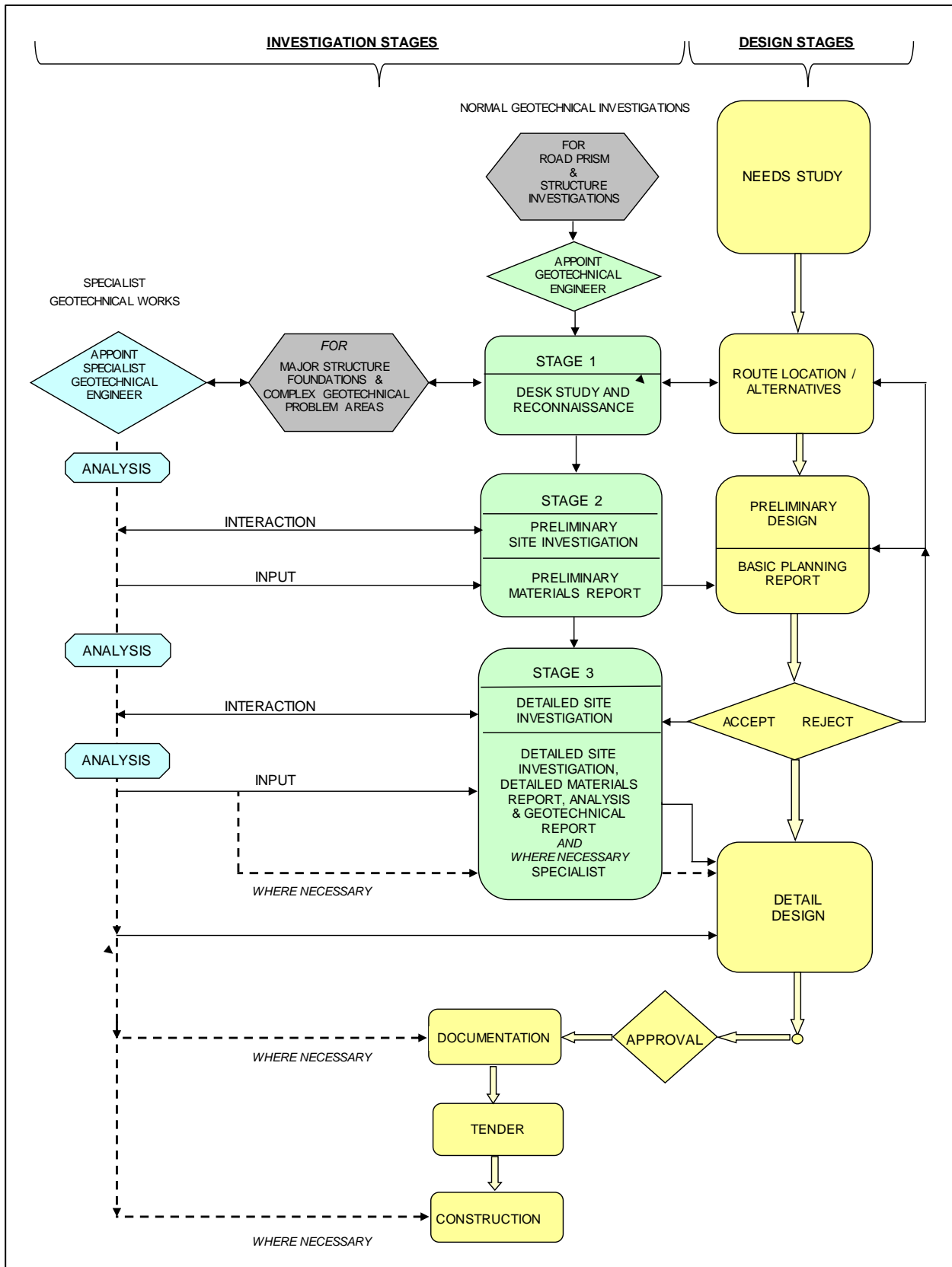


Figure 1. Typical Flowchart for Road Prism, Structures and Tunnels Specialist Geotechnical Investigations

Table 2 is included as a general guide to geotechnical engineers and engineering geologists to:

- Assist in stimulating the **upfront planning techniques**.
- To serve as a **quality checklist**, to ensure an eventual sensible and comprehensive Geotechnical and Materials Investigation and Design Report.

The compiler of the report should always bear in mind that the professionally evaluated geotechnical design parameters presented need to be used, digested and understood by other design engineers.

There can be up to four geotechnical investigation phases, of which the last phase occurs during construction. Monitoring the behaviour, deformation and/or structural integrity of existing geotechnical structures and assets (over the long term) such as lateral support systems, permanently anchored bridge or viaduct structure foundations, or permanently anchored road cut faces and road embankment slopes, all fall into this very important fourth phase. Special maintenance works are normally planned and contracted out to fulfil this very important requirement.

Sometimes, there is a fifth phase, which occurs after construction and during the design life of the facility. For example, in tunnel projects or anchored bridge foundations, stability or corrosion problems can arise during the design life. Should such problems arise, the employers or infrastructure owners should be informed.



Compiling the Geotechnical Investigation Design Report

The compiler of any of the reports must bear in mind that the report needs to be used, digested and understood by other Design Engineers.

Table 2. Summary of Geotechnical Activities During Project Design and Construction Phases

Purpose of Investigation	Techniques	Report Content
INITIAL ASSESSMENT REPORT, ROUTE LOCATION		
Geotechnical Reconnaissance	Desktop Study	Report
Walk-over investigation to: <ul style="list-style-type: none"> • Determination of general geology • Identification of potential geological or stability problems • Preliminary indications of foundation conditions • Preliminary indication of construction material sources • Identification of alternative sites and alignments • Interfacing with environmentalists 	<ul style="list-style-type: none"> • Collection of available information • Data recovery • Regional topographical, land usage, agricultural and geological mapping 	Initial Evaluation/Route Location Report <ul style="list-style-type: none"> • Layout plan • Regional engineering geological map (see Chapter 8: 2.2.1) with potential material types or sources • Schematic profiles • Record of existing information • Description of known geological conditions or problems • Recommendations for alternative route locations and further investigations
PRELIMINARY DESIGN		
Preliminary Geotechnical Investigation	Desktop Study	Report
Field Activities <ul style="list-style-type: none"> • Soil and rock mapping • Geophysical investigations • Test pitting • Core or auger drilling • Penetration tests • Sampling and laboratory testing 	<ul style="list-style-type: none"> • Soil and rock mapping • Analysis of test results 	Preliminary Geotechnical Report/Preliminary Materials and Geotechnical Report: Basic Planning Report <ul style="list-style-type: none"> • All the applicable information from the previous phase • Classification and description of foundation and construction materials • Record of investigation data, including problem areas • Discussion and interpretation of general test pit and borehole data, and materials sources • Recommendations for choice of location and type of bridges or structures • Recommendations for detailed design stage investigations



Scope of Investigations

In Table 2, the geotechnical investigations are very comprehensive, comprising up to five phases. In practice, however, programming considerations vary from project to project and physical conditions also vary from site to site. Therefore, several of these phases may happen concurrently, or not all phases are necessary for all projects.

Purpose of Investigation	Techniques	Report Content
DETAILED DESIGN AND TENDER DOCUMENTATION		
Detailed Geotechnical Investigation	Design	Report
<ul style="list-style-type: none"> • Soil and rock mapping • Geophysical investigations • Test pitting • Core or auger drilling • Borehole tests • Penetration tests • Disturbed and undisturbed sampling • Specialised laboratory and in situ testing 	<ul style="list-style-type: none"> • Stability analyses • Bearing capacity determinations • Design of special measures to address all identified areas in need thereof 	<p>Detailed Geotechnical Report/Detailed Materials Design Report and Geotechnical Report, Draft Design Documents and Plans</p> <ul style="list-style-type: none"> • Detailed engineering geological mapping and profiling • Quantitative and qualitative descriptions and results of detailed geo-investigations for bridge or other structure foundations, cuts and embankments and construction material sources including borrow pits and quarries; construction methods and alternatives. Pros and cons of each to be considered • Inclusion of all necessary geotechnical engineering design parameters, settlement estimation for bridge design engineers for each bridge, special measures/lateral support for each high embankment or each deep cut or other type of permanent lateral support structure required • Recommendations for foundation treatments, e.g., undercutting, stabilizing, grouting and lateral support • Recommendations for further geotechnical investigation and/or monitoring during construction phase
CONSTRUCTION		
Geotechnical Monitoring	Assessment	Report
<ul style="list-style-type: none"> • Monitoring foundation or slope treatments and behaviour via instrumentation and surveillance • Observation of behaviour of permanently anchored bridge foundations, lateral support systems and permanently anchored or bolted cuttings and embankments, during the Contractual Liability Period • Laboratory and in situ testing 	<ul style="list-style-type: none"> • Comparison of actual vs. predicted conditions 	<p>Construction Report</p> <ul style="list-style-type: none"> • Detailed mapping • Photos • Records, measurements and results • Conclusions • Further long term actions or recommendations
MAINTENANCE (typically every 8-10 years)		
Geotechnical Monitoring	Assessment	Report
<ul style="list-style-type: none"> • Same as above, but at intervals determined by site particular circumstances and as may be required over the operational life of the particular facility 	<ul style="list-style-type: none"> • Monitoring of permanent devices and/or instruments (mechanically and/or electronically, e.g., deflections, stresses, pressures and water flow), and ongoing verification of integrity of cuts, embankments and ancillary structures. 	<p>Special Maintenance and/or Integrity Reports</p> <ul style="list-style-type: none"> • Records, measurements and results • Evaluation • Recommendations for either immediate actions to be taken or longer term actions

3.2 Geophysical Testing

Geophysical surveys may indicate variations and anomalies such as faults, cavities or boundaries between different strata, which can be correlated with geological or man-made conditions. The information can then be used to interpolate between boreholes, thus reducing the necessity for more expensive and time consuming methods. The following methods are used for geophysical testing:

- Seismic refraction and seismic reflection techniques
- Resistivity surveys
- Magnetic surveys
- Gravimetric surveys
- Ground Penetrating Radar (GPR)
- Thermography
- Infrared photography and multi spectral scanning

Geophysical testing provides a non-intrusive means for determining:

- The **presence of rock** below surface soils
- The approximate **vertical depth** of rock head
- An approximation of rock **density**
- The presence and position of **fracture zones** or **faulting** in rock strata
- **Material changes**
- The presence of **subsurface cavities**

Chapter 6, Appendix 6B contains extensive discussion and details on Geophysical Testing.



Geophysical Testing

See Chapter 6: Appendix B, Section 3 for details on Geophysical Testing.

3.3 Drilling and Probing

Various drilling and probing techniques are available for determining material sources. These are described in detail in Chapter 6: 5.2.2 and Chapter 6: Appendix B and are not repeated here.

3.4 Stability Assessments

The identification of deep instability must be presented to designers as early as possible, so that alternative routes that avoid the instability can be investigated before additional design costs are incurred, especially before embarking on the Detailed Geotechnical and Materials Design Report stage. For new construction, alternative route options, which may be more practical, economical and avoid significant and expensive problems, must be considered. Instabilities that could justify potential realignment are:

- Portions of the route **passing over**:
 - Dolomitic or shallow undermined land
 - Thick active clays, collapsing sands or soft materials.
 - Existing underground services or features that cannot be economically relocated
- Possible **instability of structures** or tunnels/portals or deep cuttings or embankments located on problematic terrain.
- **Embankments or cuttings** that require special lateral support measures due to constraints such as geometrics.

In the case of stability assessment investigations for structures and/or tunnels on dolomitic land, such investigations are also normally carried out in progressive stages: firstly, the desk study, secondly, the geophysical stage, thirdly the borehole stage, etc. Some, or all, of these stages are required during the route location stage, to assess the feasibility and viability of the chosen route before the design has progressed too far. These investigative methods are documented in Council for Geoscience (2002 and 2007),



Dolomitic Sites

The methodologies relating to hazard and risk assessment on dolomitic land are adequately documented and are therefore not repeated in this manual. Refer to the

- "*Engineering Geological Site Characterization for Appropriate Development on Dolomitic Land*", 2002.
- "*Approach to Sites on Dolomitic Land*", 2007.

These are jointly published by the Council for GeoScience and the SAIEG, and endorsed by the Geotechnical Division of the SAICE.

These guidelines are superseded by SANS 1936.

See Chapter 6: 6.2 for more on dolomitic land.

Wagener (1985). It is essential that investigators for dolomite areas are adequately competent and experienced in dolomite work, as specified in SANS 1936 (Parts 1 & 2).

Slope stability of critical cuttings and embankments affecting structures and/or portal walls or tunnels, must also be investigated. Refer to the initial susceptibility to instability assessment guidelines and the stability of high embankments against sliding given in Sections 3.6 and 3.7 of TRH18 and Section 2 of TRH10. The detailed stage of this investigatory work normally only commences after the final establishment or confirmation of the chosen route and its horizontal and vertical alignments.

For structures to be founded on high embankments (greater than 10 metres), it is extremely important that before any field investigation commences, the embankment is classified on the basis of four simple parameters: topography, geology, climate and height. Staged, or progressively planned, evaluation and decision based investigation stages are then embarked on, details of which can be found in TRH10. If warranted, and provided the horizontal and vertical route alignment for the proposed road has been finalised, the initial road prism investigation (Chapter 6: 5), should be expanded to justify a more detailed stability investigation involving drilling, in situ testing, sampling, laboratory testing, core logging, and water table measurements.

3.4.1 Sub-Surface Investigations Related to Stability Assessment

Sub-surface studies represent an important phase of the stability investigation for roads, and are necessary for any evaluation of stability, settlement or heave. The depth to which the investigation must be carried out is a function of the magnitude of the applied load, uniformity of geology and soils in the area, and severity of the problem as reflected by cost or safety aspects.

For settlement considerations, the depth may be greater than generally required for slide stability problems. Wet, soft clayey and silty materials and materials with a collapsible grain structure are especially susceptible to settlement, even at a considerable depth below the embankment. The stretches of road pavement most vulnerable to heaving problems are on-grade sections and those with very low embankments.

In general, sub-surface studies must:

- Provide a description of the **character and geometry** of the underlying layer or layers.
- Identify and locate **weak or compressible (or heaving) strata**.
- Provide geotechnical parameters obtained from **in situ testing in boreholes** and using probes.
- Yield samples for testing the **geotechnical engineering properties** of the materials.
- Provide **in situ moisture**, water table and seepage data.
- Provide all of the data necessary for preparation of the **engineering solution**.

Cuts and embankments susceptible to instability are not only the deep or high ones. The various stages of investigation relating to critical embankments and critical cuttings are defined in Sections 4.3 and 5.2.5 and are also discussed in TRH10 and TRH18. The methodologies employed vary, depending on the stage, and on each particular situation. The methods include aerial photo interpretation, colour infrared photography for moisture studies and multi-spectral scanning (MSS) methods (TRH18). These techniques can be combined with construction material location as well. Modern remote sensing techniques are sometimes warranted for early slope stability studies, especially on large greenfields projects. An example is LiDAR, which is a three dimensional radar system that enhances 3-D topography.

Sufficient investigation of subsoil conditions below all embankments must be carried out to enable design procedures to minimise post construction settlement. Regardless of the initial susceptibility to failure, all embankments in excess of 10 metres in height must be designed for slope, horizontal slide and bulging stability considerations.

For road cuts considered as a source of construction materials, batter slopes are normally utilised to optimise the cut/fill balance, although adequate slopes must be maintained. Regardless of initial susceptibility to slope failure assessments, where the depth of a proposed cut exceeds 10 metres, special geotechnical investigations are necessary to prove the stability of such deep cut slopes. These include joint orientation and discontinuity surveys if in unweathered or weathered rock formations, and geotechnical design. Detailed descriptions, and profiles of the soil and rock encountered must be supplied, and special cognisance of the presence and implications of water must be made.



Batter Slopes

A batter slope is the backward slope of an embankment or retaining wall, or the slope of the cut.

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

The spacing and depth of boreholes and auger holes depends on the specific geological conditions. Because these critical investigation areas normally represent only a small percentage of the total investigation, special care should be devoted to them. At least two boreholes must be made beneath each major embankment, with intervals of 100 metres to 150 metres typical for long embankments, with probing in between for correlation purposes. Shorter intervals are used for short embankments. In problem areas, the spacing needs to be considerably reduced and may approach 15 to 20 metres when defining the extent of discovered compressible deposits.

The depth of boreholes must be related to the geological conditions present, as well as the width and height of the proposed embankment. On the basis of the depth to which significant stresses are produced by fill loadings, boreholes beneath embankments should extend to a depth at least equal to a half width, or to twice the average height of the embankment, unless incompressible layers are encountered at shallower depth. Boreholes for embankment stability investigations may be terminated at shallower depths when bedrock is encountered.

3.4.2 Reporting, Scheduling and Timing

In addition to the guidelines given in Section 9 and Table 2 for the various reporting stages of project development, for greenfields or new and/or upgrade road works projects, the following reports are generally also necessary:

- **Desk Study Geotechnical Report** is essential **prior to, or at**, route location stage.
- **Preliminary Geotechnical and Materials Report** is required **prior to** the compilation of the Basic Planning Report.
- **Detailed Geotechnical and Materials Design Report** is required approximately a month **prior** to the detailed design and documentation stage.

3.5 Procurement of Geotechnical Services

Services that are typically used for geotechnical investigations include geotechnical engineering consulting services and geotechnical or drilling contractor services.

3.5.1 Consulting Geotechnical Engineering Services

Certain road authorities' in-house geotechnical and structural engineers first do their own planning, aimed at accurately determining the total scope of geotechnical investigatory work. This includes the evaluation of results and to prepare the necessary Geotechnical Design Report. Following this, the road authority's tender procurement documents for the procurement of the geotechnical consulting engineer's services are prepared, to find a suitable professional to carry out the required geotechnical investigations and prepare the design reports.

Other road authorities appoint a suitable knowledgeable and reputable registered and trusted geotechnical engineering company, or a company with whom they normally work with to plan and carry out the necessary investigatory work and to compile the Geotechnical Design Reports.

3.5.2 Geotechnical and Drilling Contractors

The geotechnical engineer, who is to carry out the investigative work, must compile the proposed total scope of the work, together with its anticipated value and schedule. This must be discussed with the responsible employer or road authority's project manager and geotechnical engineer in a timely manner. Thereafter, tenders can be invited from geotechnical and drilling contractors, before contractors are appointed. This requirement applies to all geotechnical investigative work referred to in this Chapter, as well as Chapters 6 and 8.

Tenders for geotechnical site exploration work are requested using documents conforming to the standard requirements of the particular road authority. For example, SANRAL's latest pro-forma project document for sub-surface investigations, or for centre line and borrow pit investigations, together with its directives for the compilation of tender and contract documents could be used. These are issued by SANRAL on appointment. These could also be preceded by the Soil Engineering Map and Terrain Evaluation Report, especially for a greenfields project.

4. EMBANKMENTS

Embankments are when fills are placed over a section of land to elevate the ground level. The reasons for embankments include reducing the grade along a road or raising the roadbed out of problem areas. In hilly terrain, the materials for embankments are generally obtained from cuts (Section 5). A typical road embankment is shown in Figure 2.



Figure 2. Typical Road Embankment

Road authorities generally have standard plans and specifications describing their respective requirements and policies for the design and construction of embankments. These are particularly important when determining the footprint of the embankment and defining the area to investigate. In addition, there are many guidelines available to the engineer that address the design and construction of road embankments, including the TRH range. In the specific case of road embankments, TRH9 and TRH10 are pertinent, and should be consulted when planning investigations or designing embankments.

Road embankments are generally described by the topographical units wherein they are located, that is, as a side embankment (Figure 3), a gully embankment (Figure 4) or a conventional (symmetrically shaped or “flat”) embankment (Figure 5). Each embankment is generally treated as a single entity and the investigatory and test data are recorded on separate design sheets or files.

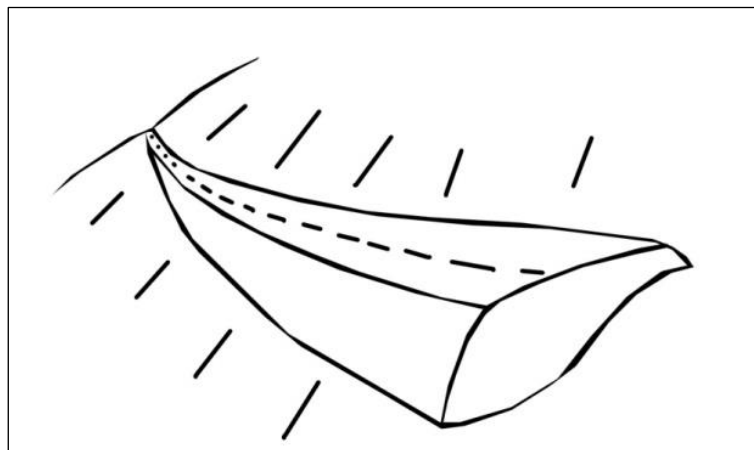


Figure 3. Topographic Embankment Types: Side Slope Embankments (from TRH10)



Embankments > 10 metres

Regardless of the initial susceptibility to failure, all embankments in excess of 10 metres in height must be designed for slope, horizontal slide and bulging stability considerations.



Investigating and Designing Embankments

More detailed information may be obtained from:

- **TRH9:** Construction of Road Embankments
- **TRH10:** The Design of Road Embankments

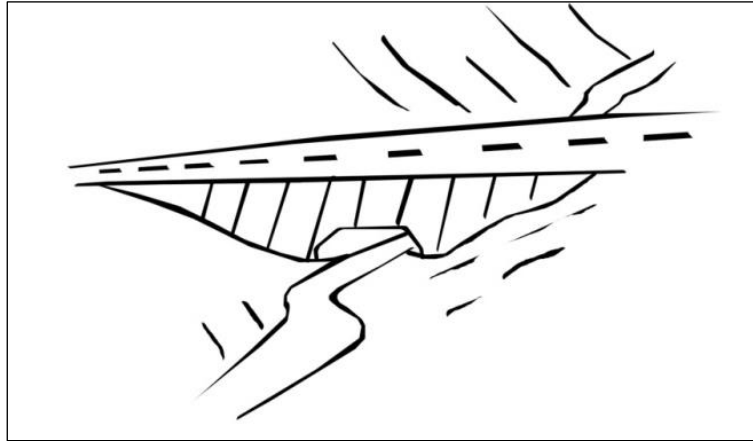


Figure 4. Topographic Embankment Types: Gully Embankments (from TRH10)

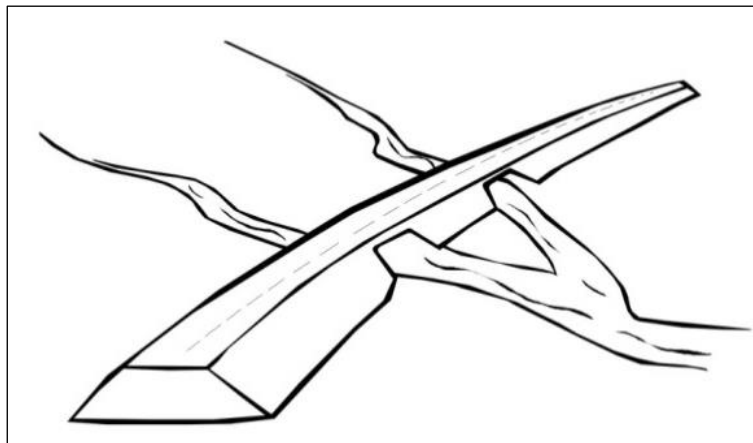


Figure 5. Topographic Embankment Types: Flat Embankments (from TRH10)

Provided that there are no problematic roadbed conditions (as described in Chapter 6: 6), and that suitable construction materials are readily available, conventional embankments can be investigated and designed under the guidance of suitably experienced engineers. However, where the vertical height of such embankments exceeds 10 metres, or where embankments are to be constructed traversing very deep gulleys, on steep side slopes, or where there are obvious signs of instability in the area, it is prudent to employ the services of an experienced specialist geotechnical engineer. This ensures that adequate investigatory, design and construction procedures are followed. This specialist will generally interact with the geotechnical engineer or leader of the investigatory team for the road prism investigations (see Figure 1 flowchart). The activities are generally conducted in a staged approach, running concordant with the main investigations:

- **Desk study** during which all available information is collected and assessed
- **Field reconnaissance** where note is taken of features relevant to the embankments and cuts being investigated
- **Investigative** phase
- **Analytic** and a **design** phase

Where required, supervision of such measures as prescribed by the specialist geotechnical engineer may have to be provided for either as a pre-construction exercise or as part of the main construction phase. Post-construction monitoring of such special measures may also be included in the specialist geotechnical engineer's brief.



Embankments > 10 metres

These embankments need to be carefully designed to limit long term settlement within the embankment, and to ensure good slope and foundation stability.

4.1 New Embankments

4.1.1 Embankment Stability

Generally, roadbed characteristics have a greater influence on the behaviour of embankments than the embankment itself as the materials quality and density are controlled. However, as the height of the embankment increases, the strength and density of the materials become more and more significant. Most road authorities therefore require that all high embankments exceeding 10 metres in vertical height be designed to:

- Ensure **limited long term settlement** within the high embankment itself
- Ensure a minimum **factor of safety (FOS) of 1.5** for slope and foundation stability
- A **probability of failure** acceptable to the employer or client.

Embankment stability assessment requires prior determination of the quality of available construction materials, the determination of the strength parameters, setting density requirements, settlement verification and batter slope design, including long term erosion protection and storm water measures. This involves various methods of analyses by the geotechnical engineer.

Similarly, the strength and moisture condition of the subgrade materials beneath the proposed embankment, and its compressibility and permeability, need to be established so that accurate settlement predictions and stability analyses can be carried out. In situ evaluation of shear strength can be made by way of field tests such as:

- **Vane shear tests:** The tests are performed at any depth by first drilling to the required depth, cleaning the bottom of the hole and then pushing the selected vane into the stratum to be tested. A torque is then applied and the peak value is used to calculate the shear strength of the soil.
- **SPT Test** (see Chapter 6: 5.2.2). Correlations between the SPT "N" value and undrained shear strength and the compressibility of soils are readily available.
- Menard **Pressuremeters** and the self-drilling pressuremeter (camcometer) also provide means of determining the shear strength of soils and soft rock.
- **Penetrometers:**
 - **Hand held/pocket penetrometer:** The instrument is pushed by hand to the calibration mark and the maximum reading is recorded on the scale. This is commonly done on the sidewalls of large diameter auger holes.
 - **Dynamic cone penetrometer (DCP):** Correlations exist between DCP N values, CBR values, and bearing strength (q) (see Chapter 6: 7.4.5 and Chapter 10: 7.3)
 - **Dynamic probe super heavy (DPSH)** testing for settlement estimation purposes
- **Probes:** The CPT and CUPT tests (see Chapter 6: 5.2.2) provide a means for measuring the undrained shear strength of fine grained soils through the entire soil profile. This is very useful to pick up changes in subsurface strata such as differing coefficients of permeability, which may be of great significance.

Laboratory shear strengths may be determined on both disturbed samples (laboratory compacted specimens) and undisturbed samples obtained from test holes (see Chapter 6: 8). Test methods include shear box testing (quick, undrained tests and slow, saturated drained tests) or undrained and drained triaxial testing, where a number of options exist such as differing confinement pressures, differing loading rates, or measuring pore pressure changes. Shear box tests involve inducing shear failure in a cylindrical soil specimen by sliding the top of the shear box over the bottom. Triaxial tests are discussed in Chapter 3: 4.6.

4.1.2 Settlement of Embankments

As an embankment is constructed, the vertical stresses on the underlying soils increase. Deformation or consolidation occurs as a result of the escape of air or water from the voids and the moving of the solids closer to each other. The amount of consolidation occurring for a unit increase in pressure in a soil is defined as the soil's compressibility. The vertical displacement that occurs with the resultant reduction in volume is called consolidation settlement, the rate of which is dependent on the permeability of the soil. Consolidation or settlement that takes place over a short period of time, e.g., loading during construction, is termed primary settlement. Settlement that takes place over a long time is termed secondary settlement. Secondary settlement in deep organic alluvium of very low permeability can be almost infinite in duration!

Embankment settlement can have a significant impact on the performance of both the road pavement in terms of riding quality and



Settlement

- **Primary settlement** occurs over a short period of time, i.e., during loading in construction.
- **Secondary settlement** occurs over a long time. In deep organic alluvium of very low permeability, the secondary settlement can be almost infinite in duration!

water runoff. It also affects the long term integrity of the embankment and associated structures, i.e., bridges and drainage structures, pipes and even cables and pipelines. Where such settlement is differential, these detrimental effects are compounded. Note for example, "bumps" at bridge approaches, which results in impact loading on the bridges, as illustrated in Figure 6.



Figure 6. Bump at Bridge Approach

Modelling and predicting embankment settlement is generally carried out by specialist geotechnical engineers. Knowledge of the in situ permeability of the subsoils is necessary. Field measurement of permeability is carried out through the installation of piezometers or pumping tests in boreholes. Piezometers measure water pressures. Settlement can also be predicted from SPT tests, CPT and CUPT tests, Menard Pressuremeters and the self-drilling pressuremeter (camcometer). See the previous section.

Laboratory determination of the consolidation characteristics of both disturbed (remoulded) and undisturbed soils can be made using the one dimensional consolidation test, the oedometer. However, these are often conservative as many of the effective drainage paths in the materials are included in the small samples tested.

To ensure successful embankments, it is necessary to appoint the specialist geotechnical engineer at an opportune time so that the special field testing, sampling and laboratory testing can be planned and conducted in unison with the conventional road prism investigations (Chapter 6: 5). It is often useful to pre-load embankments to accelerate settlement. Early identification of the problem allows this to be commenced in a timely manner.

4.1.3 Special Considerations

Special considerations for geotechnical engineers when dealing with embankments are:

- **Substandard or non-conventional construction materials:** Where large volumes of cut materials do not meet the standards for fill and costs of spoiling render phased or slow construction or special placement and encapsulation viable, the geotechnical engineer may be tasked with considering various design and construction alternatives utilising such materials.
- **Toe protection:** Where the toe of an embankment is close or adjacent to a water course, special toe protection measures may need to be incorporated into the design of the embankment to prevent toe erosion in the long term. Such protection may extend a considerable height above the toe.



Oedometer Tests

The oedometer test is a one-dimensional consolidation test used to determine consolidation characteristics. The test however, has its limitations as the sample is confined whereas in situ the material is not laterally confined.

- **Side Embankments:** Where long side embankments occur and clear lines of drainage are not evident, it may be prudent to design sub-drainage systems so that the embankment does not act as a water retention structure.
- **Gulley Embankments:** Abrupt drop-offs in bedrock on the sides of gulleys, or where the depth of transported materials makes the interception of water flow on the bedrock interface difficult.
- **Retention structures:** Where the optimal slopes cannot be achieved due to steep crossfalls of existing slopes, or any other constraints and retention structures such as crib wall, gabion structures or retaining block walls are required, these should be designed for long term performance. If the embankments are major in size (> 10 m) they should be designed and constructed under the guidance of a geotechnical engineer.

4.2 Existing Embankments

Problems with existing embankments manifest in various ways, including:

- Toe erosion
- Settlement or differential settlement
- Degradation of materials
- Translational slips (shallow displacements)
- Creep and slide (creeping valley slides)
- Internal erosion and piping
- Stability failure (rotational slips)

4.2.1 Toe Erosion

Toe erosion probably leads to the highest incidence of all embankment problems and failures. This is especially a problem where an embankment lies adjacent to a water course subject to periodic or flash flooding. The removal of material from the toe area results in loss of support and is followed by progressive side slope collapse. Typically, longitudinal cracking occurs on the upper reaches of the slope, progressively moving into the road shoulder and traffic lanes, depending on the steepness of the slope and the extent of the erosion. Remedying such damage poses major problems and may include reconstruction of the outer edge of the embankment with some special precautionary measures to prevent future occurrences and to stabilize over-steep slopes. Such precautionary measures can be anchored gabions, reinforced earth walls or soil nails. An example of gabion wall construction to limit toe erosion is shown in Figure 7.

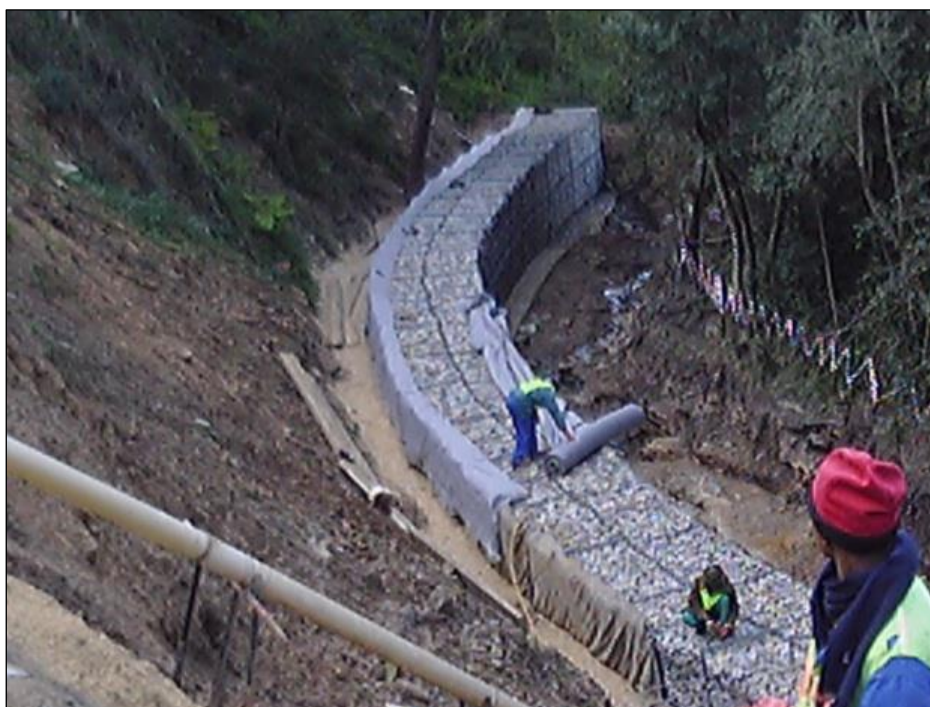


Figure 7. Toe Protection by Construction of Gabion Wall

4.2.2 Settlement

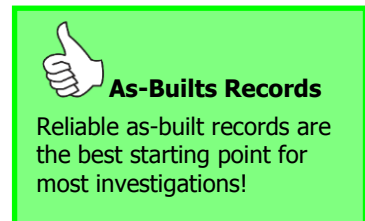
Settlement occurs gradually as the moisture and air migrates out the material, the material consolidates, and the grain structure of the material realigns. This results in a denser material, with the surface gradually lowering.



Figure 8. Preventing Settlement on High Embankment

Some older embankments have settled to such an extent that the drainage pipes and structures have disappeared into the subsoils! In many instances, such settlement of abutment embankments for example, also places additional loads on piled foundations to bridge structures, may sever electric and fibre optic cables, and sever water and other pipelines. If lasting remedial measures are to be implemented, and damage to structures and services prevented, it is necessary to establish:

- **Causes** of settlement
- **Current** stage reached
- Potential for **further settlement**
- **Rate** of settlement



Various methods for monitoring, investigating and determining remedial actions are available to the geotechnical engineer, as listed below. Reliable as-built data is, however, always the best starting point for such investigations.

- **Monitoring:** settlement gauges, surveys, inclinometer surveys using an inclinometer probe illustrated in Figure 9
- **Investigatory:** rotary drilling, probing, down the hole testing
- **Remedial methods:** jet grouting, curtain grouting, compaction grouting, installation of additional piles, drainage enhancements, flatter slope

Collapse settlement occurs in embankments that are not compacted adequately, generally as a result of insufficient moisture and/or insufficient compaction effort, similarly to natural collapsible soils. On wetting up, densification occurs (with or without external load, its own mass is usually sufficient to cause collapse) and failure of the embankment usually follows. Adequate control of the compaction is essential to avoid such problems. A picture of such an embankment has been included in Figure 10.

4.2.3 Degradation

The degradation of materials in embankment slopes with the passage of time can be problematic. Rapidly weathering tillites, dolerites, basalts and mudrocks have resulted in incidences of severe longitudinal cracking and even deformation of significant proportions along the eastern and north eastern areas of South Africa. Solutions may include stabilizing moisture regimes, encapsulation and sometimes even removal and replacement of some of these materials. The solution chosen must be supported by sound analysis, including determining risk by the geotechnical engineer.

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

A good example of a combined case of degradation and collapse settlement is the 30 metre high embankment near Grahamstown along the N2. The problem has been arrested by stabilizing moisture regimes and adding compacted benches to lower portions of each side slope. This is illustrated in Figure 10, and is the same high embankment as in Figure 8.



Figure 9. Inclinometer Probe



Figure 10. Prevention of Degradation and Collapse Settlement in High Embankment

4.2.4 Translational Slips

Translational slips, sloughs or shallow displacements are generally rainfall induced following sustained periods of precipitation. They are generally shallow, parallel to the embankment slope and occur along the wetted front, usually at the interface between the topsoil and vegetation and the compacted fill layers. An example of a slide or slip is given in Figure 11. These slips need to be repaired early, as with time tension cracks develop upslope and eventually into the road pavement, due to loss of support. Solutions include water management and, in the worst case scenario, reconstruction of the outer edge.

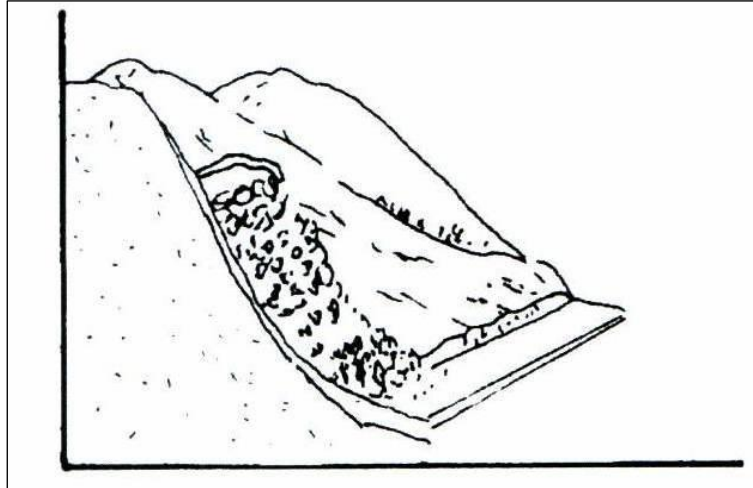


Figure 11. Slide or Slip (from TRH15)

4.2.5 Creep and Slide (Creeping Valley Slides)

Creep and slide problems are also known as creeping valley slides. These slides are a common mode of distress in gully type embankments in rugged topography. The embankments may be founded on transported materials such as alluvial wash, colluvium or even old landslide debris, which are sometimes marginally stable. When assisted by moisture movement along the soil/bedrock interface, slow downslope creep takes place. In South Africa, these slides have such small movements that they are not normally visually discernible. Solutions include:

- **Physical restraint**, such as
 - Anchored pile retaining walls
 - Buttress walls
- **Water management**, for example
 - Cut off drains
 - Sub-horizontal drains
 - Buttress drains

These solutions require in depth analyses and modelling to determine the most appropriate engineering solution. In some cases in South Africa, bridging the entire area has been necessary.

4.2.6 Internal Erosion and Piping

Internal erosion and piping failures occur when the material used to construct the embankment is dispersive, erodible or likely to slake. Any uncontrolled water flow through the embankment can result in removal of material and the development of voids, leading to collapse of the embankment. An example of this is Town's Hill along the N3 near Pietermaritzburg, which failed in December 1977. The piping and slope failure is shown in Figure 12. Specialist advice is necessary for the rectification of such problems.




Figure 12. Internal Erosion and Piping

4.2.7 Stability Failure (Rotational Slips)

Stability failure or rotational slips in an existing embankment are generally the result of some unforeseen event causing local saturation and thus high pore water pressures at a point in the embankment or in its foundation. An example from the side of a road is shown in Figure 13. These are more prevalent in embankments constructed from fine grained cohesionless soils and sands. The causes of these failures may include:

- Removal of **vegetation**
- Leaking **pipes**
- Failure of **drainage systems**
- **Migration of water** within the embankment or its foundation on falling grades
- Abnormal sustained **precipitation**

The failure surfaces may be circular in homogenous materials or non-circular in non-homogenous soils. Remedial solutions include restraint, such as retaining structures, or water management such as cut off and sub-horizontal drains.

 **Problem Embankments**

The investigation into the causes of embankments failures and identifying appropriate solutions and alternatives requires fieldwork. This may include some, or the full spectrum of, investigations described in "Road Prism Investigations" Chapter 6: 5.

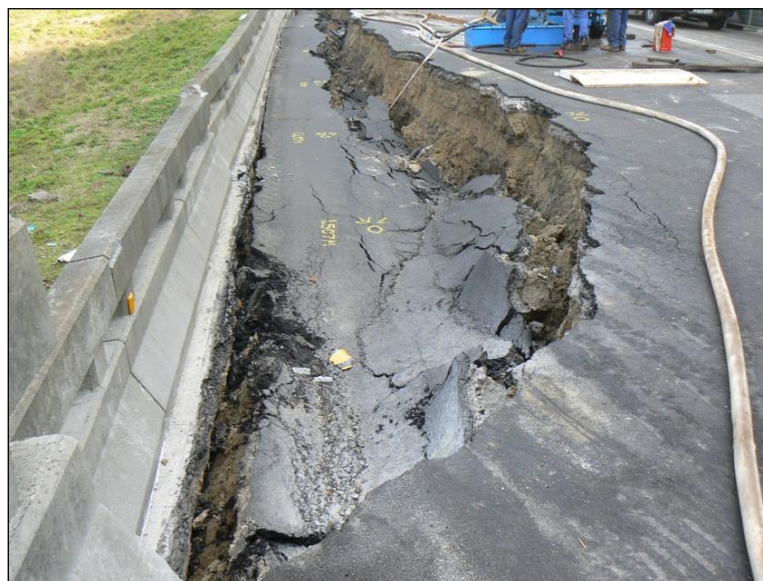


Figure 13. Stability Failure

4.3 Investigation Process

Investigating the causes of failures in embankments and determining engineering options and alternatives requires fieldwork. This may include some, or the full spectrum of, investigations described in this chapter. These investigations should be conducted by an experienced geotechnical engineer.

Generally, after being appointed to investigate a particular failure or failures, the geotechnical engineer carries out a phased approach as for normal road prism investigations (Chapter 6: 5). This ensures a rational, well planned investigation, tailored and limited to the specific needs. Such an approach comprises:

- **Desk study** wherein all available information is collected and studied.
- **Site reconnaissance** where the extent of the problem and possible causes are identified.
- **Detailed investigation**, including (as required)
 - Test pitting
 - Drilling
 - Probing
 - Pore water pressure monitoring
 - Monitoring of movements
- **Analysis**, development and design of a **remedial solution**.
- **Documentation** and possibly site supervision.
- **Post construction** monitoring.

In most cases, the remedial works for an embankment failure include the repair of the road surface and drainage systems. These are sometimes outside the scope of normal activities of the geotechnical engineer, and the supervision may thus be confined to the geotechnical aspects of the works.

Periodic inspection of existing embankments by an experienced geotechnical engineer or technologist should ideally be part of any road authority's management system.



Periodic Inspection of Embankments

Periodic inspections by an experienced geotechnical specialist or technologist should ideally be part of any road authority's management systems.

5. CUTS

Road cuts are necessary where the ground level is too high and needs to be lowered. The construction of road cuts exposes the subsurface soil and rock stratum. An example of a road cut is shown in Figure 14. A typical profile may include a topsoil horizon, a transported soil overlying residual soils and highly weathered soft rock grading into hard, unweathered rock. Most deep cuts are composite, comprising more than one of these soil or rock types. To complicate matters further, there may be different rock types present in successive strata, e.g., igneous intrusions, local metamorphism of the materials and even fracturing and faulting. Of particular concern may be cuts where the nature of the material varies not only vertically but horizontally within the cut.



Figure 14. Example of a Road Cut in Rock

As for road embankments, the various road authorities have standard plans and specifications laying out their respective requirements and policies for the design, construction and maintenance of road cuts. These are particularly important to determine the footprint of the cutting and define the area to be investigated. There are also many guidelines available to the engineer addressing the design and construction of road cuts, including TRH18, which should be consulted.

The engineering problems that can be expected with cuts are many and generally increase with the depth of cut. For this reason, most road authorities require that cuts deeper than 10 metres in vertical depth be investigated and designed by an experienced geotechnical engineer. This is to ensure the long term stability and a slope stability factor of safety (FOS) greater than 1.5. This is, however, not a blanket requirement as there will be instances where cuts as shallow as 3 metres require specialist attention due to adverse conditions, sometimes only evident on excavation of the cut. In some cases, widening of some much deeper cuts can be carried out without much more than examination of the current condition and its past performance.



Cuts > 10 metres

These cuts need to be carefully designed to ensure long term stability and a sufficient factor of safety.

Each cut should be regarded as a single entity and all information regarding that cut, albeit very little information in the case of shallow cuts in uniform materials, must be gathered and reported separately.

For the geotechnical engineer to analyse a cut slope, an accurate profile of subsurface materials is required and the engineering properties of each material need to be known. In addition, the groundwater regime needs to be established. In Section 3 and Chapter 6: 5, the different methods of investigations to determine these properties and conditions are described. It may also be necessary to obtain the services of an experienced engineering geologist to carry out specific tasks such as the identification of faults and fracture zones, characterising the various rock types for strength and durability, carrying out joint analyses, and determining the potential for planar and wedge failures for rock.

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

It is evident that the most economical and rational approach is to carry out the geotechnical engineer's field investigations, in situ testing and sampling, during the routine road prism investigations. This is also convenient from a sample handling and transportation perspective.

Where necessary, the geotechnical engineer must witness the investigations and carry out the works that require his/her expertise. The laboratory testing of sampled materials generally comprises routine testing of materials, such as soil particle distribution analysis, the determination of the soil constants, CBR and UCS determinations. Some tests, such as consolidometer, shear box, triaxial and permeability testing, require the services of specialised laboratories. Thin section and X-ray diffraction analysis of rock samples for mineral identification generally require geological expertise. The geotechnical engineer needs to follow the relevant road authority's procurement guidelines.

For convenience, and clarity of discussion, cuts are hereinafter classified as cut slopes in soils and cut slopes in rock.



Investigating and Designing Cuts

More detailed information may be obtained from TRH18: **The Investigation, Design, Construction and Maintenance of Road Cuttings.**

5.1 Cut Slopes in Soils

An example of a cut slope in soils is shown in Figure 15. Instability of soil slopes is generally attributable to:

- **Steep slopes**
- Unconsolidated **loose material**
- Adverse **groundwater** conditions
- Changes in **groundwater** conditions
- Unexpected **surcharges**
- **Erosion** by surface runoff exacerbated by abnormal sustained heavy precipitation

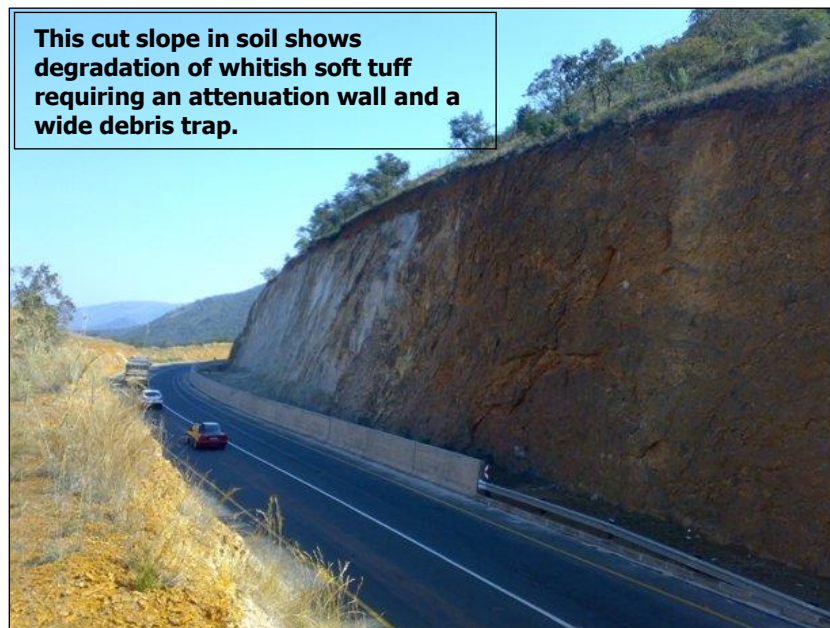


Figure 15. Cut Slope in Soils

Cut slope failures manifest in the form of:

- **Creep**, when slopes are close to the angle of repose and where movement is relatively slow. An example of toe creep is illustrated in Figure 12.
- **Rotational slips**, where the failure surface may be circular or non-circular in the case of non-homogenous materials.
- **Translational slips**, where movement takes place along the interface of layers of different or inadequate strength, discontinuities or along wetted fronts. In extreme cases, the materials may become so wet that a flow or a mud-rush develops (Figure 11).

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

Failure can also occur when the area within which the cut is to be excavated is marginally stable and the excavation process in essence removes lateral support. Stress relief follows with movements stretching upslope, beyond the area of the cut. The experienced geotechnical engineer will be able to identify such signs and indicators from the field reconnaissance and take these into account in the investigations, analysis and design.

Knowledge of overburden or soil thickness, groundwater conditions and the in situ materials properties (material types, density, and shear strength) enables the modelling of the proposed slope by the geotechnical engineer. Slope stability analyses are generally performed using software packages, of which many are available. Bishop's Simplified Method is generally used for analysing circular surface failures while Janbu's Generalised Method is favoured by some for planar or non-circular slip surfaces (Bishop, 1955; Janbu, 1954)

In view of the variability of the material properties, probabilistic methods of analysis are used by most practitioners. This allows the evaluation of the sensitivity of more than one design parameter and its contribution to slope stability. For example, the effect of variations in the shear strength, cohesion and moisture conditions on the overall stability of the slope can be evaluated.

The results of these analyses enable the geotechnical engineer to design the steepest slope to produce the probability of failure target, or to a factor of safety (FOS) > 1.5. Where this is impractical, possibly because of cost, road reserve limitations or other physical constraints, the engineer must design adequate retention measures or other measures to improve the stability of the soil slope, such as drainage of the phreatic surface situated within the soils in the slope.

Many of the problems associated with slopes in soils only become apparent once construction has commenced. There should, thus, always be provision for obtaining the advice of an experienced geotechnical engineer so that, when necessary, appropriate steps can be taken to rectify the situation before the problem compounds. The kinds of problems that could become apparent are:

- Localised **seepage**, see Figure 12 from Town's Hill, Kwazulu-Natal
- Signs of **previous movement**
- **Stress relief** movements
- **Crack** formation
- **Bulging** of the slope



Phreatic Surface

This is the subsurface zone of soil or rock in which all pores and interstices are filled with fluid.

5.2 Cut Slopes in Rock

To adequately investigate, analyse and design cuts in rock, an understanding of the mechanisms of failures in rock slopes is required. Failures in rock slopes can take many forms including:

- **Rock falls** and slides
- **Toppling failures**
- **Block slides** from planar and wedge failures
- **Degradation** through weathering

The causes of the failures are many, including:

- Loss of **vegetation**
- **Excavation** method
- Unfavourable **geological conditions**
 - Fracture zones
 - Faulting
 - Igneous intrusions
- Nature of the **rock materials**
 - Structure
 - State of weathering
 - Jointing
 - Bedding
- Water pressures developing along discontinuities
- Unfavourable dip of strata
- Undercutting of dipping strata

- Stress relief in deep cuts
- Erosion
- Absence, or inadequate capacity, of an impermeable and effective upper storm water interceptor drain. Examples of an inadequate and an adequate interceptor drain are shown in Figure 16.



Figure 16. Interceptor Drains

5.2.1 Rock Falls and Slides

5.2.1.1 Natural Slopes

Rock falls and slides in natural slopes above road cuts or embankments remain a difficult challenge for the geotechnical engineer, especially in steep topography and when large in extent. Such rock falls and slides generally occur as a result of progressive weathering or loss of support due to erosion or vegetation loss, usually exacerbated or caused by sustained precipitation. Injudicious use of explosives during construction may also trigger such movements. Successful solutions have been obtained with:

- **Catch fences** strengthened by cables and poles to intercept and retain falling or rolling rocks, see Figure 17.
- **Reinforced canopies** to protect traffic and convey slide debris over the road, also illustrated in Figure 17.



Figure 17. Catch Fences and Canopies on Chapman's Peak Drive in Cape Town

5.2.1.2 Constructed Cut Slopes

In constructed cut slopes, rock falls or slides may occur in fracture and fault zones. The geotechnical engineer will recognise the potential for such occurrences during the field reconnaissance stage and may require geological assistance and aerial photographs to determine the extent. Ravelling of fractured rock may be kept at bay by rock fall netting nailed to the surface or in shotcrete, and mesh solutions with adequate provision for drainage, as illustrated in Figure 18.



Figure 18. Applying Rock Fall Netting and Shotcrete to Cut Slope

5.2.2 Toppling Failures

Toppling failures are more frequent in natural slopes and are generally in steeply dipping or highly jointed bedded strata such as sandstones, shales and metamorphics, which have laminated or foliated structures, such as schists. An example of a toppling failure, is shown in Figure 19. Toppling may also occur at the crest of a constructed cut slope as a result of loss of lateral and vertical support, sometimes exacerbated by pore water pressure development in the joints. This may be a result of the erosion or degradation (weathering) of adjacent or underlying strata that can be exacerbated by adverse jointing. Determining the potential for toppling failures in the design stage is difficult, especially if there are no outcrops. It is often only apparent during and after construction. An experienced engineering geologist may be able to deduce the potential of such problems from the discontinuity patterns on rock outcrops and on exposed rocks in test pits. The use of stereographic projection methods to characterise the nature of a jointed rock mass on which joint surveys have been conducted may assist in predicting the likely occurrence of wedge, toppling and block slides.



Figure 19. Toppling and Block Failures

5.2.3 Block Slides

Block slides may be the result of:

- **Undercutting and intersecting** of dipping strata
- **Intersecting discontinuities** in the rock mass

5.2.3.1 Dipping Strata (Planar Failures)

The undercutting and intersecting of dipping strata are probably the greatest single cause of cut failures, examples of which are shown in Figure 20 and Figure 21. The experienced engineering geologist or geotechnical engineer should recognise the potential from the desk study, using regional geology and site reconnaissance stages including land form and topography, and the study of rock outcrops and existing cuts. If the potential is not identified in these stages, it should be detected during the preliminary investigation stage. It may even be necessary to realign the road to the other side of a valley to avoid such problems.

The inclination of dipping strata can be assessed from joint orientation studies of existing outcrops, studies on rock exposed in test pits and bulldozer slots, and by core orientation during rotary drilling. This is a specialised exercise requiring the skills of both a competent drilling contractor and an experienced engineering geologist. It is for such reasons that most road authorities specify that core logging is only done by experienced engineering geologists.

Where the intersection of dipping strata in a cut face is evident and cannot be avoided, various options are available to provide a safe slope in both the short and long term. These include retaining structures such as:

- Reinforced concrete walls
- Gabion walls
- Concrete buttresses
- Doweling, bolting or anchoring laminated or closely bedded strata, as illustrated in Figure 22
- Covering with shotcrete to prevent spalling and delay weathering (see Figure 18)



Core Logging

Most road authorities specify that core logging is only done by experienced engineering geologists.

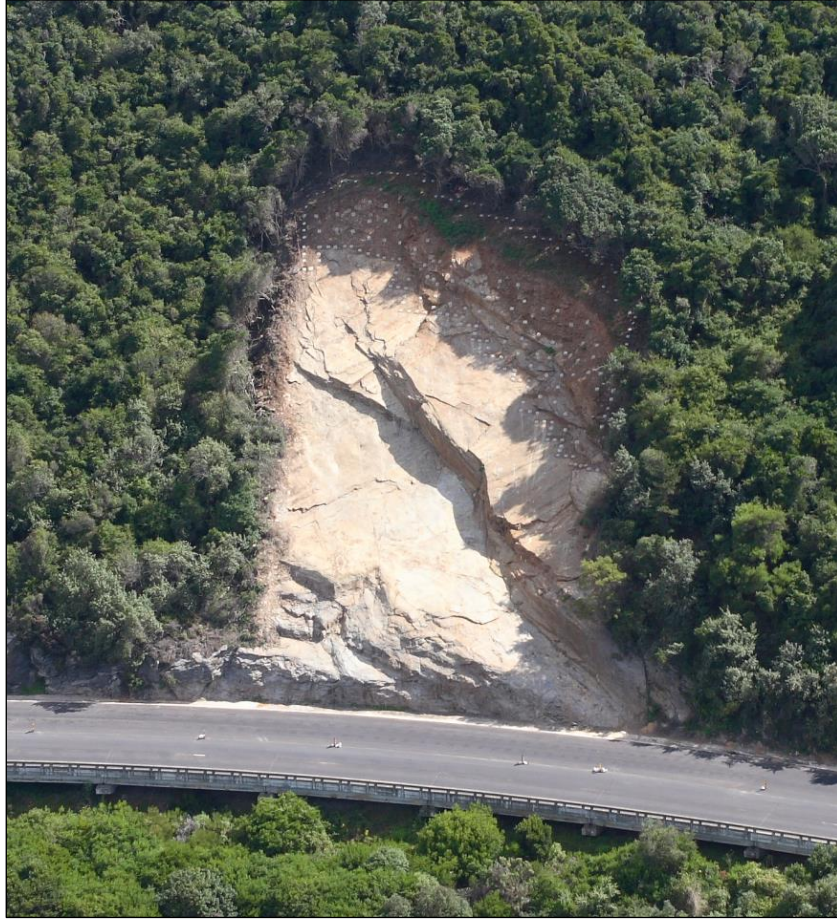


Figure 20. Steep Block Slide



Figure 21. Slide on Unfavourable Bedding Plane



Figure 22. Doweling as a Stabilization Method



Figure 23. Gabion Gravity Wall to Retain Unfavourable Dip Strata

The retention of free drainage is crucial to the stability of such slopes. Most of the measures include installing drainage holes to prevent pore water pressures developing, and to lower the water table.

The failure mode in dipping strata is essentially planar. In carrying out plane failure analysis, the following parameters are required by the geotechnical engineer:

- Rock joint **shear strength**
- **Continuity** of rock joint
- Dry and wet **density** (total unit weight) of the sliding mass
- **Angle of friction** of the sliding surface
- Depth of **tension crack**
- **Cohesion** along rock joint

The assessment of the inclination of the core recovered from drilling, the quality of the drilling, recovery of joint filling material and the physical characteristics of the rock are obtained from the preliminary and detailed drilling investigations. The geotechnical engineer's own experience and knowledge is needed to assign the appropriate range of values to the variables for a probabilistic analysis of failure for each of the remedial options.

5.2.3.2 Intersecting Discontinuities (Wedge Failures)

Where two daylighting discontinuities intersect behind the cut face, the potential exists for a wedge of rock resting on these discontinuities to slide down along the line of intersection, if this is steeper than the angle of friction. A

block (wedge) failure is illustrated in Figure 19. Water in the joints can also provide uplifting forces, enhancing such potential. Joint surveys by an experienced engineering geologist and the use of stereographic projections indicate whether this is likely in the proposed cut. Such a survey is initially carried out on rock outcrops and possibly on exposed rock in test pits and/or bulldozer slots. Further investigating jointing in the rock, as it is exposed during the excavation process facilitates the design and execution of stabilizing measures, such as rock bolting and dowelling. Prior recognition of such requirements is, however, necessary from both a safety point of view and to providing the necessary expertise, plant and equipment to carry out these measures without delaying construction unnecessarily.



Stereographic Projections

These show the slopes and orientation of the geology on a map.

The expert drilling and logging of cores, especially regarding to the spacing, orientation, condition and joint filling of recovered cores, is an essential input to the analysis of possible wedge failures. The use of orientated integral core drilling can provide invaluable information on the orientation or nature of fractures of the rock.

Other parameters that may be required by the experienced geotechnical engineer for determining the potential for wedge failures in the proposed cut are similar to planar failures described above. Again, a probability of failure approach, where the input parameters are varied to represent the variability in real projects, indicates the sensitivity of the stability of the cut to each of the design parameters.

5.2.4 Degradation

Degradation of the materials in a rock cut can take place through weathering (decomposition), stress release, liquification of the cementing agents in sediments and pedogenic materials, and slaking or exfoliation of sedimentary rocks. The early identification of degradation due to exposure in cut faces can lead to preventative actions that could result in a significant reduction in maintenance costs and even prevent failure. An example of degradation of sediments is shown in Figure 24.

Typical examples of rocks that have the potential to degrade are Karoo sediments, conglomerates and basic crystalline materials.



Figure 24. Degradation of Sediments

5.2.4.1 Karoo Sediments

Karoo Sediments are generally comprised of interbedded sandstones, shales and mudstones.

- Exposed mudrocks (**shales and mudstones**) often undergo slaking and disintegration, leaving the more resistant sandstones and indurated shales unsupported in the cut slope, leading to rock falls and toppling failures with time. Often the cut slope is too steep and the mudrock fragments spill over into the drains and shoulders of the road.
- Shales of this origin are infamous for their **slaking** tendencies. In a cut slope, this results in ongoing breakdown of the constructed rock face and upslope creep of the crest of the cut.
- Shales and mudstones are infamous for their behaviour in the roadbed. In many situations, they require blasting to loosen and excavate, but **rapidly weather to silts and clays** in the roadbed, especially if a free draining state is not maintained during construction.



Slaking

Slaking is a phenomenon whereby mudrocks (especially) swell and lose their strength when their stresses are relieved from a reduction in confinement, and when exposed to air and water.

Early recognition by the geotechnical engineer or engineering geologist ensures that sufficient width is provided for a debris trap outside the side drain, and also for preventative measures to be designed (such as shotcreting) to delay or prevent weathering.

5.2.4.2 Conglomerates

Some of the naturally cemented sediments that require blasting and heavy ripping to excavate, resulting in near vertical cut slopes have performed well over many years. However, as time passes, many such slopes become concave. As the bottom reaches of the cuts are invariably wetter, with time, and sometimes exacerbated by adjacent developments channelling more water onto the road reserve and over the crest of such cuts, the cementing agent (mostly iron) softens and collapse occurs. Examples of these are the Enon Conglomerates in the Knysna and Plettenberg Bay areas, which is illustrated in Figure 25.



Pedogenic Materials

Pedogenic materials are formed by a chemical process where either transported or residual soils are altered to a cemented granular structure, resulting in the engineering properties being altered. The cementing agent and degree of cementation can vary. Calcretes and ferricretes are the most common pedogenic materials.



Figure 25. Enon Conglomerate near Knysna

To mitigate these failures, steps are taken to curtail water flowing down or penetrating into the cut slope from the top. Additional measures to reduce the likelihood of such collapse posing a hazard to road users include lined interceptor drains at the crest of slopes, physical barriers, drop-zones or even shotcreting. A well-designed interceptor drain at the crest of a cut slope is illustrated in Figure 16.

5.2.4.3 Basic Crystalline Materials

Many of the basalts and dolerites in South Africa are prone to rapid weathering (Orr, 1979). On exposure to the atmosphere these materials deteriorate rapidly, visible as the deposition of fine material at the foot of the slope. The weathering also causes a loss of the matrix around large corestones (or spheroids), which eventually fall from the slope as illustrated in Figure 26. Application of mesh and shotcrete is usually the best solution, but the problems need to be identified before, or during construction, and excavation.

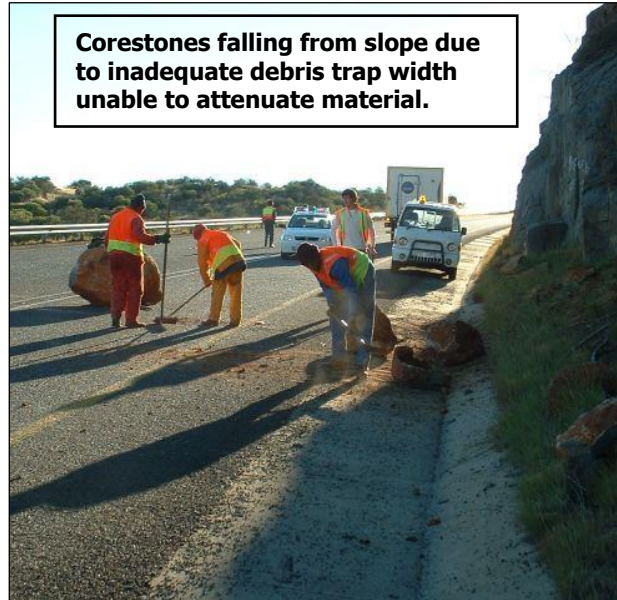


Figure 26. Corestones Falling from Slope

5.2.5 Investigation Process

As with the investigation of large (high) embankments, the experienced geotechnical engineer's investigation needs should be programmed and coordinated to take place under the routine road prism investigations, wherever possible. This also provides the means and opportunity for the execution of these works and facilitates interaction between the geotechnical engineer and/or leader of the routine investigations and the experienced geotechnical engineer. They also provide for the ancillary needs, such as traffic accommodation, sample storage and transport. The kinds of investigations the geotechnical engineer is likely to require are:

- Investigate **groundwater** conditions
- In situ testing to determine **permeability** of the subsoils
- In situ testing to determine **strength** parameters
- Disturbed and undisturbed **sampling** for routine and specialised testing

5.3 Failure of Existing Cuts

In this section, typical problems in existing cuts are discussed, first for cuts in soils and then for cuts in rocks.

5.3.1 Cut Slopes in Soils

Problems in cut slopes in soils include:

- Erosion
- Creep
- Materials degradation
- Ravelling
- Stability failure (rotational slips)
- Translational slips

5.3.1.1 Erosion

Erosion in existing cut slopes occurs from:

- **Excessive runoff** from above the slope crest due to either the absence, or inadequate capacity, of lined interceptor or cut off drains, as illustrated in Figure 27
- **Interceptor drains** filled with debris and not cleaned
- **Leaking** services
- Heavy, sustained **rainfall**



Figure 27. Erosion of Cut Face due to Inadequate Interceptor Drain above Slope

The extent of damage is exacerbated by the presence of dispersive or erodible materials (see Chapter 6: 6.7). Severe erosion, as may occur after abnormal rainfall, may render portions of a slope unstable or susceptible to translational slides, and in such cases may require special measures to reinstate the slopes. Many repairs by maintenance staff are unsuccessful, and the situation sometimes degrades to such a state that major remedial measures are required. Solutions may include:

- Provision of adequately lined **interceptor or cut off drains**
- Repairing **leaking services**
- **Re-top soiling** and re-vegetating the slope
- Applying **soil retention systems** such as biojutes and netting systems

5.3.1.2 Creep

Creep describes the situation where soil slopes are somewhat steeper than their angle of repose and the soil particles slide over each other to reach a state of equilibrium. Creep is usually limited to the upper edges of a slope and is slow. But, it is accelerated by deep wetting. Creep is very common in fine grained materials of low cohesion, such as sands. Following heavy rainfall, the situation could transform into a translational failure.

5.3.1.3 Degradation of Materials

Materials degradation takes place through weathering (decomposition), stress relief and by exposure to the elements, as described in Section 5.2.4. Where severe, the geotechnical engineer needs to address the problem.

5.3.1.4 Ravelling

Ravelling in soils occurs as a result of the removal of the finer particle support for larger particles by rain or wind, which then roll down the slope. Where severe, the geotechnical engineer needs to address the problem. Solutions vary from re-top soiling and re-vegetating the slope to applying soil retention systems, such as biojutes and netting systems (Figure 28), held in place by wooden pegs or soil nails, dowels or galvanised steel pins.



Figure 28. Netting System and Re-Vegetating

5.3.1.5 Stability Failure (Rotational Slips)

Stability failures or rotational slips vary in severity from minor, causing partial road closures, to catastrophic, rendering a road unusable for many months. An example of a rotational slip is shown in Figure 29. These failures may happen overnight, with little warning to alert road users. Road officials or maintenance staff may, however, recognise signs of imminent failure and raise the alarm. These signs include:

- **Cracking** in the road or shoulder
- **Cracking in the slope** above the cut or in the cut off/interceptor drain
- **Humps** forming in the cut slope
- **Material displacements**, into the side drain or roadway
- **Sag** development in the roadway or shoulder
- **Water seeping** or piping out of the cut slope
- **Trees falling** over or leaning away from the vertical
- Increased **animal activity**, movement away from the affected area

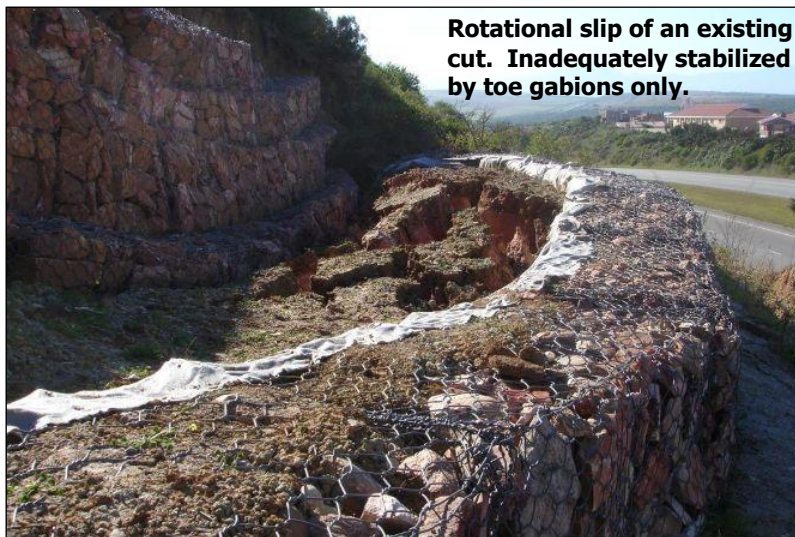


Figure 29. Rotational Slip

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

The first reaction to any such occurrence or signs of imminent failure should be to safeguard the users of the road by immediately erecting the necessary road signs and closing the road to traffic. The routine road maintenance manager or relevant road authority should be contacted immediately, and will arrange immediate inspection by their engineering staff. SANRAL requires a monitoring action to be performed when such an event takes place and have special slope monitoring forms for this purpose. Following this, a geotechnical engineer may be appointed for an assessment of the failure and an investigation into the causes and likely remedial solutions.

The geotechnical engineer will, from his field inspection and the available information, be able to form a quick assessment of the type of failure, its extent and probable cause, and recommend what action should be taken to remedy the situation. An investigation may be needed to verify assumptions, to determine the extent of the movements, to determine what conditions to allow for in modelling the failure and to determine the ground water, soil density and soil strength parameters to use in any analyses.

Such investigations take the form of those outlined for the investigations for new cuts (Section 4.2.7). Because the cost of a road closure to the economy can be significant, most road authorities will have a contingent amount in the annual budget for the investigation and repair of such failures. Some road authorities even have an accelerated system in place for obtaining approval to proceed with the procurement of services in emergency circumstances.

5.3.1.6 Translational Slips

These are slips where movement takes place along the interface of layers of different or inadequate strength, or along wetted fronts. Invariably these movements take place after abnormal and/or sustained rainfall. These are sometimes referred to as rain induced instability, and the failures are generally shallow and parallel to the original slopes. Various researchers have investigated this phenomenon, and correlations have been made with rainfall intensity, duration and the time lapse before movement occurs. In some cases, movements took place after 3 days while in other cases after only 8 days of continuous rainfall. The material grading, thickness, density, permeability, upslope catchment area and vegetation all influence the moisture penetration, rate of movement and time before equilibrium is breached. Where the materials become saturated, a slide or a mud-rush may develop. An example from Kaaiman's Pass between George and Wilderness is shown in Figure 30.



Figure 30. Mud and Vegetation Slide on Kaaiman's Pass

5.3.2 Cut Slopes in Rock

Cut slopes in rock include:

- **Ravelling**
- **Rock falls**
- **Rockslides**
 - Wedge failure
 - Planar failure
- **Toppling failure**

5.3.2.1 Ravelling

Ravelling describes the situation where rocks become dislodged from the rock face. The causes range from stress relief to weathering and erosion, and root wedging, exacerbated by the entry of water into open joints. Ravelling is generally addressed under ongoing maintenance. However, where severe, ravelling can be controlled by measures such as shotcreting, or utilising rock fall netting pinned to the slope by dowels, steel pins or rock bolts. See Figure 18 for rock fall netting and shotcrete.

5.3.2.2 Rock Falls

Rock falls affecting existing rock slopes generally occur in the natural slopes above constructed cuts in rock. They are generally triggered by an event, or sequence of events, such as loss of vegetation or gradual loss of support through weathering, erosion and downpours, sometimes of high intensity and/or long duration, or seismic events. An example of a rock fall is given in Figure 20.

Rock falls are particularly evident in the Karoo Formations where sandstones and siltstones are underlain by, or interbedded with, lesser resistant mudrocks and shales. Remedial measures include:

- **Rock bolting** and/or dowelling to secure blocks
- Protecting soft, weathering susceptible strata by **shotcreting**

5.3.2.3 Rock Slides

Rock slides are generally the result of planar or wedge type failures.

(i) Wedge Failures

Wedge failures in existing slopes occur where two daylighting discontinuities intersect behind the cut face, and a wedge of rock resting on the discontinuities slides down along the intersection. Such failures can be triggered by extreme precipitation or seismic events, or ongoing weathering and opening of joints from thermal changes and stress relief. The reaction to an occurrence depends on the extent and consequences of the failure. That is, how large the wedge is, whether it affected the road, the verge or side drain, and whether the safety of the travelling public was endangered. Such reaction may therefore vary from clearing the debris to road or lane closures, and is usually followed by joint orientation surveys and analysis by a geotechnical engineer. Remedial measures could include concrete buttresses, rock bolting and even the installation of cable anchors. An example of a wedge failure is given in Figure 19.

(ii) Planar Failures

Planar failures occur along planar surfaces including bedding planes, joints and planes of movement in metamorphic rocks, particularly with cleavage, laminated or schistose (flaky layer) structures. The most common planar type failure in existing rock cuts occurs when dipping strata are undercut or when such strata are intersected in a rock cut. Movement occurs when the plane along which failure occurs is steeper than the angle of friction. Rising pore water pressures, which provide uplifting forces thereby lowering the friction along the failure surface, are generally the trigger of such movements.

Remedial measures may include the securing of in place rock slabs that remain on the slope, for example, concrete buttresses, doweling or bolting laminated or closely bedded strata, and covering with shotcrete to prevent spalling and delay weathering. The retention of free drainage is crucial to the stability of such slopes. Most of the remedial measures include installing drainage systems to prevent pore water pressures developing and to lower the water table.



Periodic Inspection of Cuts

Periodic inspection of existing cuts should be an essential part of any road authority's management systems. Systematic and regular maintenance of drainage systems, repair of erosion and minor sloughing (translational slips of topsoil), as well as recognising symptoms of potential failures should be included. These measures can prevent a substantial number of failures in existing cuts.

In carrying out plane failure analysis the following parameters are required by the geotechnical engineer:

- Rock joint **shear strength** (cohesion and friction angle)
- **Density** (total unit weight) of the sliding mass
- **Angle of friction** of the sliding surface
- Depth of **tension crack**
- Continuity of **rock joints**
- **Orientation** of fractures

5.3.2.4 Toppling Failure

Toppling failures in existing constructed rock cuts generally occur at the crest of cuts. A toppling failure is illustrated in Figure 31. They usually occur in bedded or jointed strata such as sandstones, shales and metamorphics which have laminated or foliated structures, such as schist. They can also occur in other formations such as dolerites, or any materials where the centre of gravity of individual blocks falls outside of the base of the block. Toppling occurs as a result of loss of lateral and vertical support, sometimes exacerbated by pore water pressure development in the joints. This may be a result of the erosion or degradation of adjacent or underlying strata, sometimes exacerbated by adverse jointing. Remedial measures include rock bolting and/or dowelling to secure blocks, and protect soft, weathering susceptible strata by shotcreting.

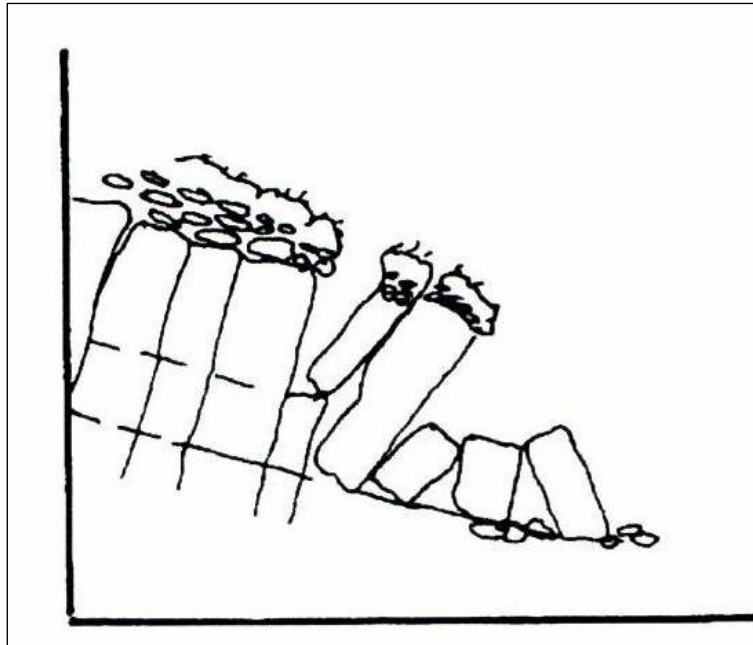


Figure 31. Toppling Failure (from TRH18)

6. SUBSURFACE DRAINAGE

An effective subsurface drainage system cannot be designed without a well-planned comprehensive investigation consisting of a desk study and a field investigation. Methods and aids during the initial reconnaissance stage include using maps and remote sensing, for example, aerial photo interpretation, followed by the normal physical field investigations. Due allowance should be made for seasonal fluctuations in the moisture regime.

Subsurface drainage in road and road structure construction can be divided into three general categories:

- In situ subgrade
- Cuts
- Underneath embankments

6.1 In Situ Subgrade

The most common application of subsurface drainage is to control the ground water in the road subgrade and below the surface bed levels of buildings, either by intercepting in-flows or encouraging out-flows. Methods to control groundwater include:

- Longitudinal and/or diagonally spaced **interceptor drains**, illustrated in Figure 32.
- **Ground water** lowering, in extreme cases.
- **Geotextile** enclosed sloping **drainage blankets** for interception of general seepage under the top of subgrade and at cut-fill transitions, as illustrated in Figure 33.



Drainage Information

More detailed information may be obtained from:

- SANRAL: **Drainage Manual**, Chapter 9
- TRH15: **Subsurface Drainage for Roads**
- TRH18: **The Investigation, Design, Construction and Maintenance of Road Cuttings**

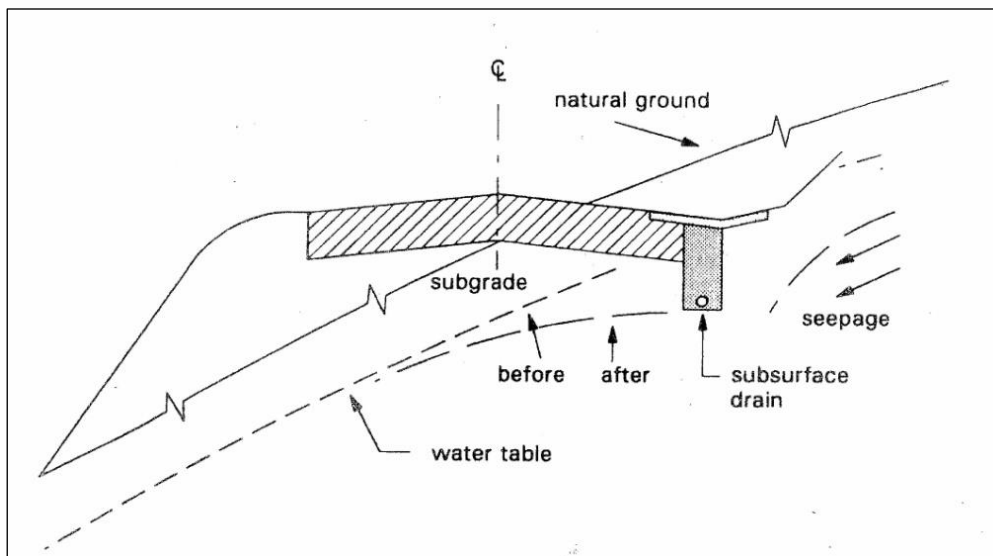


Figure 32. Interceptor Drain (from TRH15)



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.

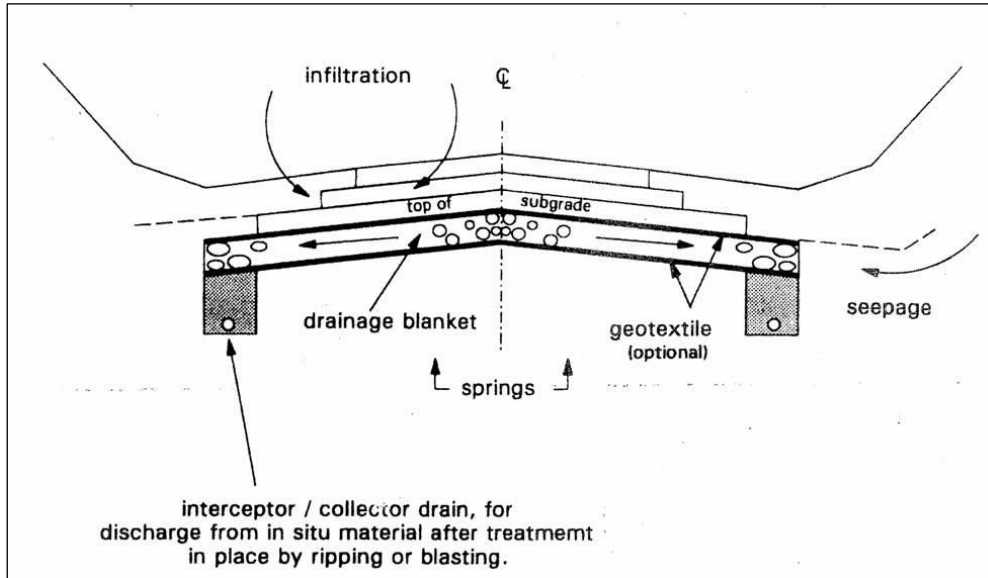


Figure 33. Drainage Blanket (from TRH15)

6.2 Cuts

The investigation and control of groundwater is thoroughly dealt with in Section 5, where investigations into the stability of cuttings are discussed.

It is important to drain the road pavement within a cut or the surface bed of buildings to be placed within a cut. Pore water pressures caused by the available head in the adjacent cut or from the adjacent uphill road may lead to pavement distress. Provision for subsurface drainage must therefore be made in the road foundation in cuttings. The provision of permanent subsoil drains below the surface or next to the pavement layers in cuttings normally also goes hand in hand with the provision of lined side drain surface drainage systems next to the paved road, in conjunction with sealed shoulders.

6.3 Underneath Embankments

The general problems of embankment stability and settlement are considered in Section 4. Cases may arise where road structures or buildings associated with a road project need to be founded on constructed embankments.

Following the initial normal shallow centreline soil survey during the preliminary or detailed design stage, the detailed geotechnical investigations for embankments must be adequately planned to allow the necessary design calculations for typical solutions. To avoid settlement and/or instability of embankments built on soft wet formations, drainage of the roadbed is normally the first operation, followed by the removal of unsuitable materials thereafter, if possible. Depending on the subsurface circumstances found on individual sites, special drainage measures have to be designed. These include:

- For high embankments, complicated vertical **wick drains** (Figure 34) or **sand piles** installed below ground level in conjunction with geotextile wrapped sand or gravel horizontal drainage blankets (Figure 33). The settlement versus time should be monitored during construction.
- Introducing **transverse** and **longitudinal temporary drainage trenches** in a clayey subgrade with a pioneer layer, or rock fill compacted in situ, prior to the embankment construction.
- Where embankments are to be constructed on sloping natural terrain, **drainage blankets** (Figure 33) used with **longitudinal collector drains** installed parallel to the slope or on benches, with rock toes at the bottom, should be considered.

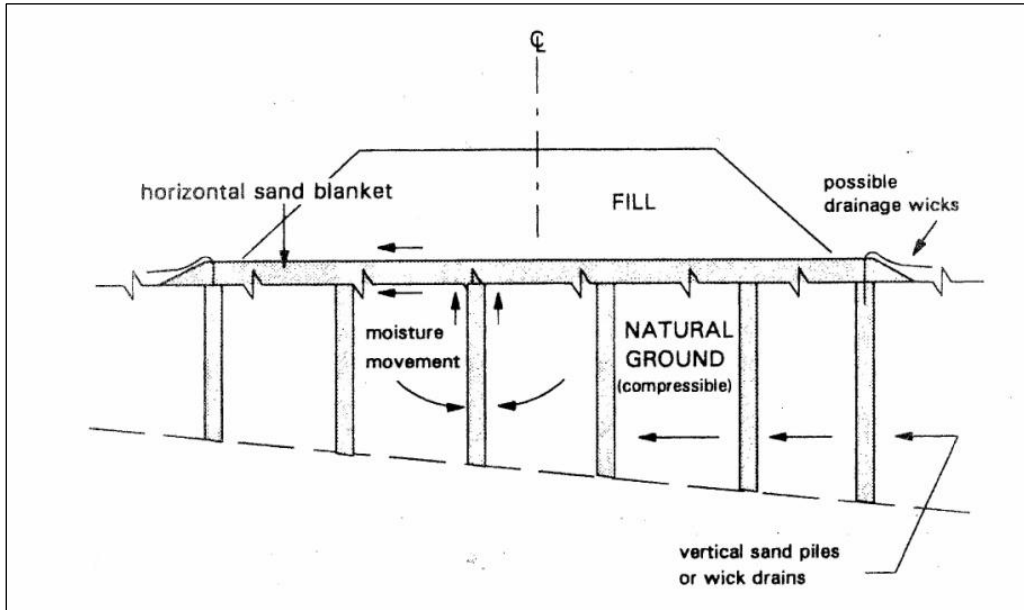


Figure 34. Wick Drains Under Fill

6.4 Design of Special Subgrade Treatment Types Underneath Building or Culvert Sites

Typical examples of special roadbed treatment types are discussed and presented in Chapter 6: 6 and further examples are included in Chapter 9: 2.

All portions of problematic subgrades identified underneath culvert and building sites should be categorised into uniform sections. Each uniform section should receive either the standard roadbed treatment, or a special roadbed treatment as specified by the geotechnical and pavement design engineers. These special roadbed treatment types are therefore not be the standard types as referred to in the Standard Specifications, but a combination of specially designed operations and methods. For example:

- **Dynamic compaction methods** (deep or shallow) over thick compressible fills, followed by conventional earthworks and a three-pass roller compaction.
- A long period of **pre-wetting heaving clays** at subgrade level that are left in place below the road embankment.
- On a **heaving clay subgrade**, a combination of several precautionary measures may be required. For example, removing the dessicated partly saturated clay layers and replacing with compacted inert materials.
- For a high **embankment on swampy ground**, before constructing the embankment a combination of several precautionary measures might be required involving several construction operations, such as a geogrid mattress or geotextiles, in combination with natural sand blankets.
- The construction of a **dump rock pioneer layer**.

The Detailed Geotechnical and Materials Design Report should clearly elaborate on the details of such special measures, as specified in Chapter 6: 9.

7. STRUCTURES

Structures associated with a road project include bridges, bridge culverts, gantries, retaining walls, tunnels and tunnel portals, and facilities such as toll administration and booth buildings. A pedestrian bridge over the N1 is shown in Figure 35. Geotechnical investigations for structures are primarily concerned with the soil and structure interaction, determining the load, deformation and bearing capacity characteristics of subsurface materials on which the structures are founded. Aspects which require investigation include the technical desirability, as well as practical considerations governing:

- Bridge and bridge **abutment interaction**
- **Selection of piles, caissons or spread footings** for structural support
- Considerations resulting from **driving resistance** of different types of piles, particularly where close to buildings or sensitive underground services
- Pattern and intensity of **pressure distribution** beneath structure footings
- Likely and permissible **settlement** of the structure
- **Lateral support** issues
- **Scour** around bridge piers due to river hydraulic action. An example of this is shown in Figure 36.



Figure 35. Pedestrian Bridge Over the N1

In addition, other critical items such as: problems excavating in restricted areas, which may require shoring or sheet piling; special provisions for flooding, water seepage or uplift pressures; and, unusual conditions for rock blasting, must be investigated, interpreted, evaluated and reported.

7.1 Intrusive Investigations for Bridge Upgrades

Intrusive investigations apply to bridge upgrade projects and are primarily aimed at verifying the as-built depth and details of existing foundations. Normally, it is not possible to decide fully on the required type and scope of testing for bridge foundation upgrade exploration in advance of the commencement of the exploration work, since initial results generally influence the eventual exploration requirements. However, all proposals for bridge foundation widening or upgrade investigations must first be discussed with the relevant road authority's geotechnical and bridge engineers, prior to commencing any work.



Investigating Structures

More detailed information may be obtained in Chapter 7 of SANRAL's updated **Code of Procedure for the Planning and Design of Highway and Road Structures** in South Africa, which is included in Appendix A.



Figure 36. Scour around Bridge Piers

7.2 Modus Operandi and Reporting

The modus operandi for planning, scoping, responsibility, acquisition of tenders, methodology and execution of geotechnical investigations for structures are fully documented in Chapter 7 of SANRAL's Code of Procedure for the Planning and Design of Highway and Road Structures in South Africa and also in Annexures 18.2 and 18.3 thereof. All of this has been included at the end of this Chapter as Appendix B.

The compilation and interpretation of test data and reporting is carried out in accordance with Section 9.

8. TUNNELS

The need for a tunnel is generally apparent at the route location stage of a road project. In view of the high costs of constructing a tunnel, it is likely to be the dominant cost element of the project. As tunnelling costs vary widely due to ground conditions and constraints arising from existing infrastructure in the vicinity, it is essential to locate the most economical site, as well as favourable line, level and positions for shafts and portals. This enables the appraisal of the technical and economic merits of alternative schemes and alignments.

The 3.9 km Huguenot Tunnel, shown in Figure 37, through the du Toit's Kloof mountains on the N1 between Paarl and Worcester is the longest road tunnel in Africa.



Figure 37. Huguenot Tunnel

The site investigation must establish, in three dimensions:

- **Geological** structure
- **Character** of the strata
- **Groundwater** conditions
- Presence of **adverse geological conditions** on the site

This requires examining existing information, carrying out field investigations, in situ and laboratory testing of samples taken, and analysis of information and test data. The investigations must also locate any existing underground works, services and other man-made features which may affect, or be affected, by the construction of the proposed tunnel.

As with the other investigations covered in this manual, a systematic, staged approach is



Tunnel Terminology

Adit: Horizontal entrance to a tunnel

Azimuth: Horizontal angle measured clockwise from a defined north base line or meridian.

Chimneying: Process of internal erosion of ground working its way upwards through decomposed material as a result of high rates of gravitational groundwater inflow.

Invert level: Bottom level of the inside of the tunnel

Overbreak: Over-excavation of rock broken out in excess of the neat tunnel line

Portals: Entrances and exits of the tunnel

Regolith: Layer of loose rock resting on bedrock

Stand-up time: How long the ground safely stands by itself at the point of excavation

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

recommended. At each stage, the uncertainties about the site are reduced and the next steps indicated. For tunnelling however, investigations continue through the construction stage as indicated Table 3. The titles of the stages suggested in SAICE's Site Investigation Code of Practice (2009) are shown in brackets in Table 3.

Table 3. Progressive Investigation Stages for Tunnelling Projects

Stage 1: Desk Study and Site Reconnaissance (Pre-Feasibility)
<ul style="list-style-type: none">• Assembly of available information including topographical and geological maps, reports, plans and records of structures and underground services• Geological, geotechnical and hydrological enquiries• Aerial photographs• Site reconnaissance (walkover site inspection)• Interpretation of information collected, needs assessment for preliminary site investigation
Stage 2: Preliminary Site Investigation (Feasibility)
<ul style="list-style-type: none">• Works, sufficient to:<ul style="list-style-type: none">– Confirm the feasibility– Narrow route options– Consider the preliminary design– Establish the ball park cost of the project– Provide direction to the planning of the detailed site investigation• Investigations may include initial hydrological studies, geophysical investigations, selected open excavations, drilling of boreholes and some testing• Preliminary Report that summarises work done, records information gathered, includes preliminary site assessment and recommendations for the next stage
Stage 3: Detailed Site Investigation and Design (Design)
<ul style="list-style-type: none">• Extensive drilling and sampling programme with in situ and laboratory testing• Open excavations, test adits, pilot tunnelling, rock bolt testing, grouting tests• Investigation of old mine workings, recording condition of buildings and structures• Detailed Tunnel Investigation Report comprising<ul style="list-style-type: none">– Factual information including borehole logs, test data, groundwater information, plans and sections– Discussion and interpretation of findings of test results, expected ground behaviour and possible problems– The proposed design with supporting drawings and plans– Recommendations for investigations in the construction stage
Stage 4: Construction Stage Investigations
<ul style="list-style-type: none">• Recording ground conditions as excavation proceeds• Probing ahead of the face, drilling and in situ testing• Trials for grouting, rock bolting and shotcrete, monitoring movements• Monitoring structures and buildings
Stage 5: Post Completion Monitoring
<ul style="list-style-type: none">• Continued monitoring as determined by the design requirements

8.1 Stage 1: Desk Study and Site Reconnaissance (Pre-Feasibility)

8.1.1 Desk Study

The desk study must include the following:

- Geological information
- Hydrological Information
- Underground services and structures
- Mine shafts and quarries
- Landfill sites
- Air photographs
- Topographical maps
- Satellite imagery
- Ortho photographs

(i) Geological Information

Plans, maps, borehole and geophysical data can be sourced from the Council of Geoscience. The 1:250 000 regional geological maps of South Africa are available. More detailed geological maps at a 1:50 000 scale are available for certain urban areas. These maps are supplemented by explanation booklets which provide useful background information on the formations encountered in various areas. National, regional and local authorities, local museums and libraries as well as the geology departments of universities may also be consulted. Local civil consultants may also provide data obtained from underground engineering projects.



Council for Geoscience

The following can be sourced from the Council of Geoscience:

- Plans
- Maps
- Borehole
- Geophysical data

The possibility of seismic and tectonic activity must be established. The level of amplification induced in structures by seismic events is primarily influenced by the nature and magnitude of the seismic impulse, e.g., the magnitude and epicentre of an earthquake. However, the dynamic stiffness properties of the rock mass, regolith and the structures also have an influence.

The frequency response curves for use with structures founded on various strata are best handled by competent seismic engineers well versed in these aspects. Pinto (2003) and the SANS 10160 National Standards (2008) are good references. For the provinces of Gauteng, Northwest, Mpumalanga, Limpopo and Free State affected by mining activity, the effects of mining induced seismicity must also be taken into account, as this results in predicting much higher seismic design accelerations.

The four volumes on the Engineering Geology of South Africa by A.B.A. Brink (1979, 1981, 1983 and 1985) form an invaluable source of general and, in some cases, site specific information on the geology of southern Africa. These volumes focus on the engineering properties and behaviour of construction materials.

(ii) Hydrological Information

Hydrological information is obtained from water authorities and hydrologists. The possible effect of tunnelling and investigations on, for example, aquifers, should be investigated.

(iii) Underground Services and Structures

Copies of plans and records showing underground services such as sewers, pipes, tunnels wells, cellars, basements and foundations should be obtained, especially when shallow tunnels and cut and cover tunnels are envisaged. This is also necessary for bored tunnels, to assess the effect of settlements on existing works. Of special note are the position, depth and method of backfilling.

(iv) 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, 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 and physical condition. Mining activities below tunnel level may have disturbed the overlying rock, while flooded workings and loose fill above tunnel levels must be considered. The presence of mine gases and subsidence could also present hazards. Future mining or quarrying activities, which could involve blasting near the proposed tunnel, also need to be established.

(v) Landfill Sites

The location of filled in pits is important because they are generally loose, and may be unstable and water bearing. Industrial and domestic landfills are a source of toxic substances, dangerous gases as well as deleterious substances. Details and plans should be obtained from the relevant authorities.

(vi) Aerial Photographs

For new roads and road tunnels, aerial photographs generally need to be commissioned and should include stereo pairs. Expert interpretation assists in identifying geological features such as faults, outcrops, volcanic intrusions and karst formations. Vegetation, land use, drainage lines and land forms provide useful indicators of subsurface geology and geomorphologic activities. Overlapping stereo pairs of aerial photographs, usually at a scale varying between 1:10 000 to 1:50 000, may be obtained from the Department of Land Affairs.



Aerial Photographs

Overlapping stereo pairs of aerial photographs, usually at a scale varying between 1:10 000 to 1:50 000, may be obtained from the Department of Land Affairs. Chief Directorate: Surveys and Mapping of the Department of Land Affairs, Aerial Photo Division
Photographs are available for online ordering.

(vii) Topographical Maps

Topographical maps are available for most areas in South Africa at a scale of 1:50 000 either in hard copy or electronic format. Much information may be gleaned from GPS systems, for example Garmin's Garmap suite of street, topographic and waterways maps, or online-based information systems such as Google Maps and Google Earth.

(viii) Satellite Imagery

The availability of online satellite images of all portions of the earth makes this tool particularly useful, especially during the initial stages of a project for identification of major geological or topographical features. Whilst basic images are available to all, high resolution images may have to be purchased. Digital images may be exported in electronic format for use in reports or as background information on plans or maps. An example of an image from Google Earth is shown in Figure 38.

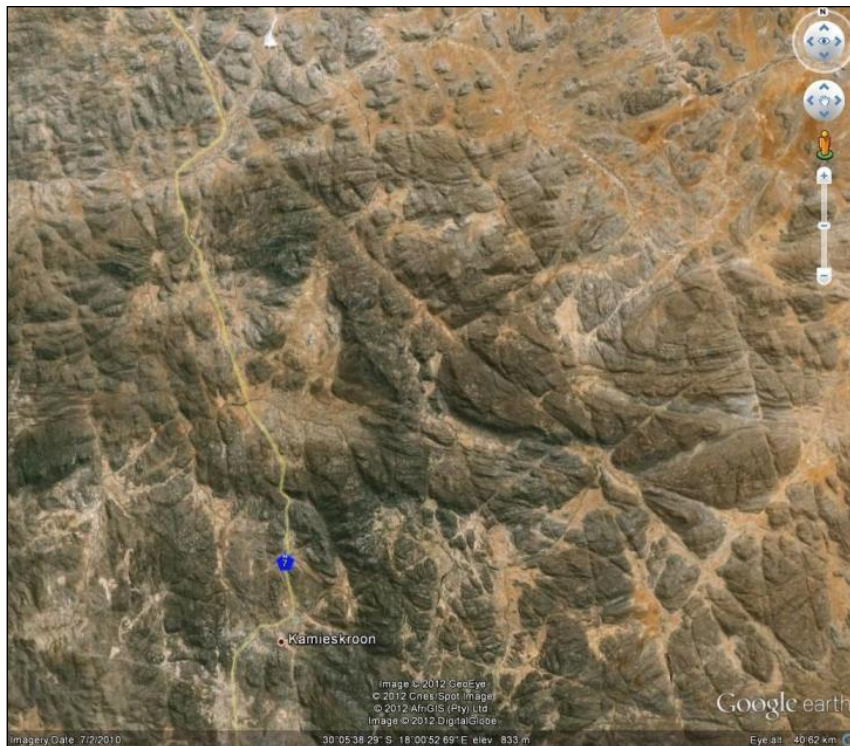


Figure 38. Google Earth Satellite Image of Joints and Faults in Gneissic Terrain in Kamieskroon, Namaqualand

(ix) Ortho Photographs

These are available at a scale at 1:10 000. Unlike aerial photographs, ortho photographs have been corrected for distortion over the full area of the photograph. Contours from these and similar maps are useful to create a first-order digital terrain model (DTM) of the site.

8.1.2 Site Reconnaissance (Walkover Site Inspection)

In carrying out a reconnaissance of the corridor along possible tunnel alignments, it is essential to map rock outcrops, the position and dip of boundaries and faults, and other geological features. Particular attention should be paid to land use and topographical features. Attention should also be given to general accessibility. Long established local land owners must be engaged in discussion.

(i) Land use

The following features in an urban, rural or agricultural environment should be identified:

- **Urban Environment**
 - Position and description of buildings and structures
 - Evidence of subsurface structures

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

- Pipes and tunnels that may be affected by tunnelling, whether by drilling and blasting or boring
- Industries that have the potential to spill, such as, filling stations and chemical works on or near the line of the tunnel
- **Rural environment**
 - Evidence of any subsurface structures, such as pipelines
 - Mining and quarrying as may be indicated by spoil heaps, stockpiles and excavated pits
 - Inspection of nearby road and railroad cuttings, borrow pits and quarries may provide confirmation of regional geology
- **Agricultural**
 - Changes in vegetation or crops, which could be as a result of filled pits, as illustrated in Figure 39.
 - Changes in stratigraphy
 - Subsurface moisture conditions



Figure 39. Changes in Vegetation as a Result of Filled Pit

(ii) Topographical Features

- **Surface and land forms** may provide indications of:
 - Instability
 - Shallow holes
 - Changes in slope
 - Landslides
 - Subsidence
 - Depressions
- **Springs, subsurface water** channels

Particular attention should be paid to the possible portal areas. The survey should ideally be preceded by Aerial Photo Interpretation (API) to identify points of geological interest or importance. Photographic records of all significant observed features are essential.

If the site is not readily accessible due to remoteness, security concerns or socio-political sensitivity, the site reconnaissance (walkover) survey would then probably form part of the Stage 2: Preliminary Investigation Stage (Feasibility Stage).

8.1.3 Site Reconnaissance Report

The compilation of this report should be in accordance with the employer's requirements and/or the guidelines given in Section 9.

8.2 Stage 2: Preliminary Site Investigation (Feasibility)

The desk study and reconnaissance (walkover site inspection) is the focus of the preliminary site investigation. This stage facilitates the selection of a preferred route, estimates costs and decides on the nature and cost of the third stage, the detailed investigation. Stage 2 investigation generally involves:

- Limited number of boreholes
- Auger holes
- Open excavations
- In situ profiling and sampling
- Selected laboratory testing
- Geophysical investigations (see Section 3.2)

The same procedures for the procurement of specialised services and tenders outlined in Section 3.5 should be followed. Some special considerations may also be necessary. The client may require that a feasibility investigation is planned to allow project budget costing with defined accuracy, e.g., $\pm 15\%$. This phase probably provides the most information per unit of input and typically comprises no more than 10% of the cost of the total geotechnical investigation. Provided well-indexed maps and the necessary references are available, this preliminary investigation stage should ideally take no more than 10% of the total time expended.

Apart from the limited intrusive methods (test holes and pits), the preliminary investigation poses no damage to the environment. Care must be exercised when undertaking intrusive investigations to limit damage to the environment. This is particularly applicable at this stage where the investigation may be for site selection purposes only, and one or more of the sites investigated will not be developed.



Intrusive Investigations for Tunnels

Care must be exercised when undertaking intrusive investigations to limit damage to the environment. This is particularly applicable when the investigation is for site selection purposes only, and one or more of the sites investigated will not be developed.

8.2.1 Preliminary Tunnel Report

The information gained from the desk study, the reconnaissance or walk over inspection, and the preliminary site investigation should be summarised in a preliminary report. This includes a provisional geological map and longitudinal section with notes on the likely range of characteristics of each geological formation, likely groundwater conditions and any other special hazards. The feasibility of the tunnel should be discussed and, if positive, the alignment and design options discussed. It should also lay out the direction along which the detailed investigation should be planned, indicating where special investigations and expertise (such as underground inspections of mines) may be needed. The location of the tunnel portals is of particular concern as it is usually in these areas the weathered and unstable materials are encountered. The report should also draw attention to hazards to site investigators, such as unstable slopes, contaminated areas and dangerous gases. Occupational Health and Safety issues must be strictly attended to at all times.

This report is generally included in the Basic Planning Report for the project, which is generally subject to approval prior to commencement of the detailed design stage. The reporting guidelines given in Section 9 should be followed.

8.3 Stage 3: Detailed Site Investigations and Design

The detailed site investigations and design stage is the most important phase as the factual data is converted into design parameters and guidelines. The cost of this phase, even though it is the most important, is usually less for cases when favourable or non-problematic geological conditions are encountered. Typically, less than 10% of the total professional time is expended on this phase. The exception is when challenging ground conditions are, or are likely to be, encountered, or when challenging structures are involved. For these situations, empirical or 'recipe' design approaches are insufficient and the geotechnical engineer must resort to advanced analyses, numerical methods and large scale trials to determine appropriate design parameters or construction solutions.

8.3.1 Planning

The investigation must establish the geological structure, succession and character of the strata present. Where problem areas exist, appropriate measures must be catered for to determine the character and magnitude. The investigation should thus establish:

- **Extent**
- **Depth** properties and **nature** of all the soils and rocks present in the zone of interest
- **Interfaces** between soils and rocks
- **Groundwater** conditions
- **Unstable** or caving ground
- Rock **faults, fracture zones**, fissuring, jointing and bedding surfaces
- **Weathering** levels
- **Igneous intrusions**
- **Cavities** in soluble formations such as limestone or dolomites

Further to obtaining information required for the location and design of the tunnel, shafts and portals, information is also required for construction purposes, including:

- Selecting the **method of excavation** and **construction**
- Predicting **stability** and **timing** of support installation
- Predicting type of **support**
- Predicting and controlling **water conditions**
- Predicting **overbreak**, assessing the need for special expedients
- Ensuring the **safety** of the works and workers

Areas of uniformity, suited to particular methods of tunnelling, should be established. The selection and investigation of portal positions, generally in hillside or valley locations, must be carefully carried out as these can be in difficult ground conditions. Unloading during excavation may result in instability, fracture or ground movements where unstable surface deposits are located.

In planning these investigations, the requirements of the Occupational Health and Safety Act (OHS, 1993), the National Environmental Management Act, (NEMA, 1998) as well as other pertinent legislation covering the environment and other legal issues as described in Chapters 1: 6 and Chapter 6: 3 must be considered. Large projects may also warrant the appointment of a full time site safety officer. The consultant must be aware of the specific safety requirements of the particular client.

8.3.2 Detailed Investigation Contract

The same procedures for the procurement of specialised services and tenders detailed in Section 3.5 should be followed. In preparing the required documentation, the specific project specifications need to be comprehensive and make due allowance for necessary changes as the investigation and information appraisal proceeds. The contractor should be required to appoint a geotechnical engineer or an engineering geologist competent in all aspects of the investigatory work, to work in close liaison with the engineer's representatives.

8.3.3 Investigation Methods

The following investigation methods are used for tunnel investigations:

(i) Rotary Core Drilling, Core Recovery and In Situ Testing

Boreholes should be sited at each portal, shaft and key positions to interpret geological features, such as faults. These may be identified during the preliminary investigation stage from aerial photo interpretation, geophysical testing and field reconnaissance. Further boreholes are sited to interpolate between points and to fill any gaps. As a three dimensional understanding of the site is required, some of the holes are off-axis. Boreholes should extend to at least two tunnel diameters below the proposed invert level. Where boring appears feasible, further boreholes should be located clear of the tunnelling line to avoid interference with tunnel construction. Where cut and cover operations are envisaged, holes should be within the excavated strip. Inclined holes are necessary to provide the required information, especially in dipping strata.

Good core recovery (> 90%) is required, necessitating the use of split double tube or triple tube core barrels. In soft ground, provision should be made for continuous undisturbed sampling.

The presence or absence of groundwater is a critical factor in tunnelling, particularly when tunnels are driven beneath rivers or lakes. Moderate inflows can slow progress and be expensive to control. High inflows can destroy face stability, result in mud rushes and chimneying. Water table measurements and seasonal variations should be made utilising piezometers. Note should be made of all water strikes and of artesian conditions. Groundwater flow characteristics can be determined by pumping tests. In examining the feasibility of dewatering or lowering groundwater tables, the effect of these on ground settlement, neighbouring structures and on groundwater supplies should be considered.

Accurate borehole locations on site and as marked on plans is essential. Borehole survey techniques should be used at intervals to check inclination and azimuth. Where piezometers are not installed, all boreholes and penetrations should be backfilled by tremie grouting. Comprehensive drilling and in situ testing records are necessary.

In situ testing in soft ground conditions may include pressuremeter, dilatometer, vane shear, SPT's, CPT, CUPT and other probings. In situ testing in rock includes packer tests.

(ii) Trial Pits

Trial pits are generally used in soft ground at portal, shaft and shaft positions as well as for shallow tunnelling. They allow direct profiling and undisturbed sampling as well as in situ testing, such as penetrometer and jacking tests. Careful consideration must be given to the positioning of trial pits as they can cause difficulties during construction. All holes need to be backfilled with suitably compacted materials. The safety measures provided in SAICE's "Code of Practise: The Safety of Persons Working in Small Diameter Shafts and Test Pits for Civil Engineering Purposes" (2003) must be adhered to at all times.

(iii) Large Diameter Boreholes

Headings or shafts allow deeper in situ inspection, testing and sampling at crucial positions. These provide vital information such as stand up time in potentially unstable formations. They may also allow for rock bolt testing and in situ stress measurements in rock as described in Section 8.4 "Construction Stage Investigations" of SAICE's 2003 Code of Practice.

(iv) Field Trials

Field trials remove some of the uncertainties regarding interpretation of test data. Examples are:

- **Short trial tunnels**, driven to assess actual tunnelling conditions and the suitability of support measures such as rock bolting, shotcrete and mesh, steel arches and grouting.
- **Pilot tunnels** along the line or parallel to the proposed main tunnel. These enable full scale assessment of tunnelling conditions and in situ testing to enable the design of tailor made support, as well as providing access to allow for multiple headings, whilst providing an escape route in the event of an emergency.

These methods are, however, both costly and time consuming. Their application is largely a function of the size and complexity of the tunnel project.

8.3.4 Guidelines for Assessing Testing Requirements

8.3.4.1 Tunnelling in Soils

Laboratory testing of soils includes classification tests as well as strength, consolidation and permeability tests.

In granular soils, stability and support are largely a function of ground water flow. Early indications can be gained from water rest levels and permeability tests, but more reliable measurements require the installation of piezometers. Particle size distribution and porosity are inputs to assess the suitability of various stabilizing methods, such as dewatering, ground freezing, slurry, bentonite shields or grouting.

In cohesive soils, stability and support are largely a function of the in situ shear strength. Measurements of shear strength can be carried out by in situ vane tests, and in stiff firm clays, by laboratory triaxial tests on undisturbed samples.

8.3.4.2 Tunnelling in Rock

The stability of the rock is a function of the rock mass and rock material properties. Rock mass properties can only be determined by core logging, down the hole photography, borehole to borehole geophysical methods and field trials. Laboratory testing to assess material properties include:

- Unconfined or **triaxial** compression tests, particularly where rock is weak relative to overburden pressures. These are also useful for support considerations.

- Tensile and indirect **tensile tests**, which are also useful for support considerations.
- In situ measurement of **ground stresses** using photo-elastic cells or pressuremeters, dilatometers and Goodman Jacking in soft rock. These are also useful for support considerations.
- **Creep, swell or slake tests**, particularly in argillaceous rocks.
- **Mineralogical analysis** for swell potential.

Excavation of rock tunnels is generally carried out by drilling and blasting, or by tunnel boring machines, such as that shown in Figure 40. For drilling and blasting, unconfined compression tests, and quartz content or direct abrasiveness tests are useful in determining drill speeds and tool consumption. Tests to determine the practicality and economic viability of tunnel boring methods include:

- **Strength** tests, such as point load and UCS tests
- **Hardness** tests, such as shore hardness, cone indentation and Schmidt hardness
- **Abrasion** tests
- **Groove cutting** tests and machine-ability tests, which simulate cutting tool action
- **Petrographic analysis** to assess geological factors, such as faults, limestones behaving like dolomites, high silica cementing and variability mitigate against the use of tunnel boring machines.



Further Reading on Tunnels

A good reference for Tunnels is West, Carter, Dumbleton and Dumbleton (1980), **Site Investigations for Tunnels** for additional information.



Figure 40. Tunnel Boring Machine at Entrance to Tunnel at Gautrain's Rosebank Station

Chemical analysis of groundwater in both soil and rock should be carried out to check for substances deleterious to the lining, e.g., sulphate content and pH level. Contaminants may well indicate their source, for example, industrial or sewage effluent.

8.3.5 Investigation of Old Mine Workings, Buildings and Structures

Where the existence of abandoned old mine workings in the vicinity of the proposed tunnel is established, but the exact position is not accurately known from the information obtained, boreholes may need to be drilled. Once penetrated, the condition can be assessed with borehole cameras. Accessible workings should be explored with the cooperation of the mining authorities, to provide the geotechnical engineer with information and advice to enable decisions on whether workings should be backfilled, the methods to employ and the tunnelling method to be used. Underground workings may only be entered by a certified mining engineer.

Existing buildings and structures in the vicinity of the tunnel alignment should be inspected and the condition thereof recorded and photographed. In many cases, the as-built foundation plans and/or underground basement plans of buildings should also be searched and studied.

8.3.6 Design

This is the most important phase, as the factual data is converted into design parameters and guidelines.

8.3.6.1 Design Philosophy

In the design of tunnels, the limiting equilibrium or working stress philosophy is traditionally followed. This relies on a global lumped factor of safety against failure, and occasionally for serviceability. More recently, geotechnical design has followed structural design in adopting partial factors of safety and a limit states design approach. The choice as to which approach is followed may be specified by the client, left to the choice of the designer, or regulated. Eurocode 7 is regulated in the UK since 2010 (Eurocode, 2004).

The selected design philosophy generally allows for an “observational method approach”. This involves developing a base design using the most likely values for the geotechnical parameters, based on the information available, and not necessarily using a conservative selection based on variation in the data. The designer has to identify the shortcomings in the data and in the predicted geotechnical behaviour. These lead to the derivation of a plan of monitoring during construction to identify critical limits to trigger the implementation of predetermined contingency actions, for which provision is been made. Some clients are, however, sceptical of such an approach.

8.3.6.2 Design Parameters

In the selection of appropriate design parameters, the specialist geotechnical consultant has to consider the type of tunnel, applied loading, dynamics, settlement criteria and the nature of the geology, i.e., stratigraphy and stress history. These parameters should also account for: the in situ state of the geo-materials, for example normally consolidated or over consolidated; and soil-structure interactions, such as, drained or undrained behaviour; and, strain levels.

There are two classes of geotechnical design parameters, fundamental and specific:

- **Fundamental parameters:** These are dependant only on the properties of the material constituents and are independent of the in situ state and structure of the material. They are typically determined from basic testing on disturbed or reconstituted samples. Sophisticated analysis and design calculations are required to take account of stress history, applied stress paths and the effects of structure and fabric. The critical state or steady state effective angle of friction represents an example of a fundamental strength parameter.
- **Specific parameters:** These, in addition to the material constituents, are influenced by the in situ state and the structure or fabric of the material. These parameters are typically determined from specialised testing that model the structural loading on high quality undisturbed samples that preserve the in situ state of the material. The resulting parameters represent all the behavioural aspects associated with the in situ material under the intended loading. These parameters can, therefore, be used in relatively simple design calculations. An example of such a parameter is the tangent Young's modulus of a material, determined from a triaxial test on an undisturbed sample, loaded with an appropriate stress increment.

Identifying points of changes in ground or water conditions requiring changes in design are of major importance. Such areas may be very small in extent, but they are of no lesser significance to the safety of the users, the integrity of the construction, or the functionality.

Characteristic values of design parameters are derived using statistical methods and defined confidence levels. Due cognisance must be taken of the sample size. The more limited the amount of information, the less reliable the statistical interpretation. Where large volumes of data are generated, it is appropriate to represent the data using statistics such as sample size, average value, standard deviation, and percentiles, and to identify outliers. These statistical values are particularly useful in carrying out sensitivity analyses during the design process. Statistical data can best be presented graphically and can, at least, provides some indication of the nature of the distribution of the data.

Considerable experience is, however, required when using statistical concepts in geotechnical engineering. Simple averaging of values does not properly account for the variability of the parameter, or for parameter dependencies. It is common practice to model natural phenomena using the normal probability distribution. This assumption simplifies the manipulation of statistical data and the prediction of confidence levels where the average and median values coincide. Geotechnical data, however, do not always conform to a normal distribution, and even if it does, the distribution is likely to be “flat”, that is with a large amount of variability.

It is essential that the consultant liaises with the rest of the design team during this phase of investigation to ensure that appropriate design parameters are determined, and that these parameters are understood and correctly used by the designers.

8.3.7 Detailed Tunnel Investigation Report

The guidelines given in Section 9 should be used to compile the report, and should also include:

- **All the information** gained from **earlier investigations** as well as borehole reports, log sheets, test results and geological plans, and sections showing their positions together with all strata and groundwater levels encountered in the boreholes. Symbolic codes and colours should be used to distinguish between different soil and rock types, see Figures 8 and 9 in Chapter 6: 5.2.3. The soil and rock types must be fully described, and areas of inferred geological structure shown with an indication of the degree of confidence of the interpolations.
- **Additional information** such as plans showing:
 - Services, structures, and condition reports
 - Position and condition of underground mineshafts and workings, and measures needed to stabilize them
 - Presence and characteristics of groundwater, mine gases and other hazardous substances
- **Consulting engineer's interpretation** of the investigation results and expected ground conditions. Due consideration must be given to possible problems in tunnelling, controlling groundwater and providing temporary and permanent support.
- **Proposed design** and supporting plans and drawings. The observed, measured and inferred conditions and properties on which the design is based must be given, highlighting any special, relevant geotechnical features. The classification of the ground into zones of similar ground and water conditions, and construction and support methods is similarly important.
- **Recommendations for investigations** during the construction stage.

SAICE's Site Investigation Code of Practice (2009) should also be consulted for more information.

8.4 Stage 4: Construction Stage Investigations

It is essential that predictions made on the ground structure and materials are confirmed as construction proceeds. This includes continuous updating of geological sections, recording water inflows, joint spacing and orientation, regular sampling and testing of rock or soil samples, and other relevant data such as overbreak occurrences.

Probing ahead, by drilling short distances ahead of the tunnel face, gives advance warning of undiscovered fault and fracture zones, material changes and hazards, such as, water bearing fissures. This also provides a means of treating materials ahead of the drive.

The construction of test adits allows the execution of in situ stress measurements to determine lining requirements. These measurements include uniaxial tests using flat jacks, biaxial tests using doorstopper cells and Leeman/CSIR cells for triaxial stress measurements. Continual deflection or convergence measurements, rock bolts and grouting tests, as well as shotcrete trials, are regularly conducted to determine their efficacy for both primary support and the final lining. Ongoing monitoring of structures, buildings, as well as the ground surface in the corridor of the tunnel, is a further necessity.

Post construction reports and records must include:

- **All test and geological data**
- **Construction experience** in the ground conditions encountered
- **Equipment** and methods employed
- **Hazards and difficulties** encountered, and measures adopted to address these.

The importance of this phase cannot be over-emphasised as the whole of the tunnel structure is exposed during construction. Many recommendations made in the geotechnical reports may have to be altered or even reversed based on the evidence, which becomes available during construction. If conditions on the exposed site turn out to be more favourable than indicated by the site investigation, the design may possibly be altered, with significant cost savings.

The ongoing assessment of actual conditions and analyses with those predicted is, and must, remain an integral part of the whole design approach, as is post construction monitoring described in the next section.

The Construction Report compiled by the supervising engineers on completion of the construction project should include a specific section or volume covering the construction of the tunnel, problems encountered, solutions executed, as-built records, plans, geological sections, logs, and, test and monitoring data.

8.5 Stage 5: Post Construction Monitoring

Post construction monitoring is carried out to monitor the behaviour of the completed tunnel and to validate long term or post construction design assumptions. It also provides an ongoing verification of the tunnel's integrity. It may take the form of routine recording of instruments by operational staff or surveys by competent persons covering a wide spectrum of measurements and inspections as described below. The particular tunnel and its site specific features dictate the level, degree and frequency of such monitoring.

Measurements may take the form of a simple survey of targets attached to critical elements, or, sophisticated electronic measuring devices embedded within or onto a structural member. These typically include deflection and convergence measurements and are taken at regular intervals at areas where less favourable conditions were encountered. Deflections may continue over a number of years, but should stabilize as a new state of equilibrium is reached. In many cases, the final deflection measurements only occur after many years of service. Hence, budgets and measures must be put in place in the design and construction stage such that these long-term measurements may be made.

A variety of sensors are available including strain gauges, extensometers and pressure transducers. In those areas identified as requiring a high level of monitoring, the output from such electronic devices can be linked to a cellular device that transmits data in real time to a centre or a person, or even to a remote warning device.

A rational approach is to have the results of the ongoing monitoring assessed by the designer and the geotechnical engineer for the first few years of service. Thereafter, the monitoring data could be assessed against suitable parameters, with periodic overviews at longer intervals.

The assessment of the data collected during ongoing monitoring provides useful data, which may bring about cost-saving modifications on future projects, or may suggest changes to the design process that form the basis of updates to codes, standards and guidelines. Whatever the reason, the value of post-completion measurements cannot be overstated.



Post-Construction Measurements

The value of post-construction monitoring cannot be overstated. The information can lead to cost-saving measures for future projects and can provide data with which to update codes, standards and guidelines.

9. COMPOSITION OF TEST DATA AND REPORTING

This section stipulates the requirements for the composition of test data and reporting for the geotechnical investigations planning, design, tender and construction purposes. This section is relevant to this chapter and to Chapters 6 and 8.

The stipulations given in Sections 9.1 to 9.3 below reflect the requirements of SANRAL, but provide good guidance for reporting for other authorities or clients. The various clients or road authorities using or prescribing this manual, may perhaps also have different or additional requirements as to what needs to be covered in the various reports. Also, the level of detail to be included in the reports and tender documents must be determined by the client or road authority.

The format in which to report both laboratory and field test results is not covered in this chapter. Each road authority has their stipulations that must be followed. For each project, contact the applicable road authority to determine the required formats.



Reporting on Laboratory and Field Testing

The format in which to report testing is not covered in this chapter. Each road authority has their stipulations that must be followed. For each project, contact the applicable road authority to determine their required formats.

9.1 Preliminary Geotechnical and Materials Report

Prior to submission of the Basic Planning Report for greenfields or new projects, a Preliminary Geotechnical and Materials Report is submitted and approved. This report contains information influencing the Basic Planning Report, and, should, therefore, be approved in advance of submission of the Basic Planning Report.

The following aspects should be commented on in the Preliminary Geotechnical and Materials Report:

- **General geology and geomorphology** of the area, and their effects on the geotechnical and materials design, stability and road location. Also, the generally expected excavatability classes must be discussed, as specified in the Standard Specifications. If portions of the route are underlain by dolomite or undermined ground, these must be identified.
- **Broad nature of the materials resources** available within the area directly next to the route, and specifically within the road reserve, and their possible influence on the basic planning. For example, is selected subgrade, subbase or base course material likely to be available from the road prism, or from existing or potential borrow sources not too far from the road reserve? Or, will material need to be imported from commercially owned sources.
- Availability of **material sources** of hard aggregate for concrete and upper pavement layers, and suitable sand and gravel. Where these resources are in short supply, expropriation may be desirable at this stage and should be recommended, if necessary.
- Possible **material characteristics** that may affect the geometric grading. For example, the presence of dolomite formations, possible shallow undermining, expansive soils, deeply weathered soils, lack of weathered materials or soft saturated soil conditions.
- Proposals for **safe batter slopes**, expectations on shrinkage or bulking factors, and possible bridge foundation types based on the results of existing data and preliminary **drilling and augering investigations**. The proposed batter slopes, based on stability conditions during the basic planning, may eventually have to be flatter, depending on geometrical alignment and volumes required due to geometric design requirements.
- Likely **subsurface ground water conditions** and the possible influence on the road pavement design are discussed.
- Likely **traffic load spectrum**, and the possibility of growth due to future economic developments, or attracted traffic are reported. A provisional **pavement design** and alternatives (without detailed analysis thereof) are proposed. A cost benefit analysis of the proposed pavement designs is supplied.
- Preliminary **list of bridges, large culverts** and other important structures is provided in kilometre sequence.

9.2 Detailed Geotechnical and Materials Design Report

Aspects to be covered in the Detailed Geotechnical and Materials Design Report, and the recommended indexing for greenfields and upgrade projects, are given in Chapter 6 and in Appendix A of this Chapter. In the case of tunnels, an additional detailed report must be prepared along the guidelines given in Section 8.3.7.

SANRAL requires two copies, in draft form, are first submitted to the responsible road authority's project manager or geotechnical engineer with a covering letter, and copied to the regional manager for purposes of discussion and approval, prior to the finalisation thereof.

The programme for the submission and approval of these reports should be as agreed and recorded in the relevant agreement for consulting engineering services for the project. Submission of the report should nevertheless be sufficiently in advance of the compilation of tender documents, to limit possible changes from delaying to the programmed tender date.



SANRAL's Reporting Requirements

The reporting stipulations in this section reflect the requirements of SANRAL. They also provide good guidance for reporting for other authorities or clients.

9.3 Project Document

The project document details provided here are specifically from SANRAL's "Volume 6 – Geotechnical and Materials Investigation and Utilisation". For greenfields works, and upgrade projects, these particular project documents must include the separately bound Detailed and Final Geotechnical and Materials Design Report(s) referred to in Section 9.2, and Chapter 6: 9. Where applicable, Dolomite Stability Reports are also included. These documents are often referred to as the "Tender Documents".

For cross checking purposes, the essential information listed below is included in this document, but not necessarily in the sequence given:

- Generalized **geology** chapter describing the road construction aspects of the area traversed by the proposed route in terms of engineering geology.
- **Physiography** chapter describing average minimum and maximum temperatures, rainfall, topography and drainage, land use, vegetation and water resources.
- **Road prism or centre line investigation.** An engineering description of all road construction soil or rock types traversed by the route, and which cuttings are proposed for use as borrow pits or quarries inside the road reserve.
- **Special drainage**, or other precautionary measures required to ensure the stability of the road prism are described and detailed. For example, construction on dolomitic land.
- **Cuts and embankments** are tabulated and discussed, and their stability measures recommended. Also, the proposed use and excavation potential of materials encountered in cuts is provided. Where cuttings are used as sources of construction materials or crushed and screened aggregate, provide details and include on the key plan.
- **Soil survey** sheets indicating the required roadbed preparation types, either the standard types or any specially designed roadbed treatment types proposed. Characteristics of the material occurring within and below the road prism are discussed. These sheets prepared at AO-size must be reduced to A2 or A1 size for inclusion in the tender or contract documents.
- **"Key plan"** indicating the position of the proposed borrow pit or quarries, or cuts to be utilised as sources of materials for the pavement layers, in relation to the road centre line. Test results for all centre line and proposed borrow pit, quarry or cuttings, are included, guidelines for which are in the Chapter 6: Appendices.
- **Construction materials** are included in a chapter summarising the utilisation of materials from the road prism, cuttings, borrow pits, quarries and sand sources as specified in Chapter 8 and in Chapter 6: Appendix A. The characteristics and materials utilisation of each proposed borrow pit, quarry or cutting, together with their proposed method of working the source, must be described. Comments regarding the availability of cement, including the various types of cement, quality of water, and sand for use in concrete, asphalt or soil stabilization, also included.
- All important new **structures and bridges**, or bridges to be widened as part of an upgrading programme, are listed or tabulated in kilometre sequence, including recommendations for their founding. Details, including cost considerations, advantages and disadvantages, as well as typical settlement analyses for each alternative foundation or pile foundation evaluated are also included. These are generally taken from the Final Detailed Geotechnical and Materials Design Report. All test results, soil profiles, borehole logs, and in situ testing results are included as Appendices.
- The **pavement investigation and pavement design** aspects as specified in Chapters 6 and 10.
- **Traffic** data and analyses.

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

REFERENCES AND BIBLIOGRAPHY

- BISHOP. A.W. 1955. *The Use of the Slip Circle in the Stability Analysis of Slopes*. **Geotechnique**, 7(1): 7-17.
- BRINK, A.B.A. 1979, 1981, 1983, 1985. **Engineering Geology of Southern Africa**. Volumes 1 to 4.
- BRITISH STANDARDS. 1981. BS 5930: **Code of Practice for Site Investigations**. British Standards Institution. London.
- COLTO. 1998. **Standard Specifications for Road and Bridge Works for State Road Authorities**. Committee for Land and Transport Officials. Pretoria.
- COUNCIL FOR GEOSCIENCE. 2002. **Engineering Geological Site Characterisation for Appropriate Development on Dolomitic Land**. DRAFT. Council for Geoscience and South African Institute for Engineering Geologists.
- COUNCIL FOR GEOSCIENCE. 2007. **Approach to Sites on Dolomitic Land**. Available from www.geoscience.org.za.
- DME. 2004. **Environmental Management Programme**. Regulations 48 to 51 of Govt. Gazette # 26275 of 23 April 2004. Department of Minerals and Energy.
- DME. 2002. **Environmental Management Programme**. Regulation 52 submitted in support of application for a prospecting right or mining permit in terms of The Minerals and Petroleum Resources Development Act (Act 28 of 2002). Department of Minerals and Energy.
- ELGES, H. *Problem Soils in South Africa – State of the Art. Dispersive Soils*. **The Civil Engineer In South Africa**, Vol. 27 No. 7 July 1985.
- EUROCODE 7. 2004. **Geotechnical Design. Part 1 General Rules, Part 2 Design Assisted by Laboratory Testing and Part 3 Design Assisted by Field Testing**. European Committee for Standardization. CEN.
- JANBU. N. 1954. **Stability Analysis of Slopes with Dimensionless Parameters**. Harvard Soil Mech. Serv. 46:81 pp.
- NEMA. 1998. **National Environmental Management Act**. Act 107 of 1998.
- NETTERBERG. F. 1979. *Salt Damage to Roads - An Interim guide to its Diagnosis, Prevention and Repair*. **Journal for the Institute of Municipal Engineers of South Africa (IMIESA)**, 4(9), 13-17.
- OHS. 1993. **Occupational Health & Safety Act No. 85 of 1993**, As Amended.
- ORR, C.M. 1979. *Rapid Weathering Dolerites*. **The Civil Engineer in South Africa**. July 1979. pp 161-167.
- PINTO, P.E., Lupoi, A., Franchin, P. and Monti, G. 2003. *Seismic Design of Bridges Accounting for Spatial Variation of Ground Motion*. **ACI International Conference on Seismic Design of Bridges**. San Diego. 2003.
- SAICE. 1989. **Code of Practice: Lateral Support in Surface Excavations**. South African Institution of Civil Engineering, Geotechnical Division.
- SAICE. 2002. **Guidelines for Soil and Rock Logging in South Africa**. South African Institution of Civil Engineering, Geotechnical Division.
- SAICE. 2003. **Code of Practice: The Safety of Persons Working in Small Diameter Shafts and Test Pits for Civil Engineering Purposes**. South African Institution of Civil Engineering, Geotechnical Division.
- SAICE. 2009. **Site Investigation Code of Practice**. 1st Edition. South African Institution of Civil Engineering, Geotechnical Division.
- SACS. 1980. **Stratigraphy of South Africa**. Geological Survey of South Africa, Handbook 8. South African Committee on Stratigraphy.
- SANRAL. 2011. **Updated Code of Procedure for the Planning and Design of Highway and Road Structures in South Africa**. South African National Roads Agency Limited.

South African Pavement Engineering Manual

Chapter 7: Geotechnical Investigations and Design Considerations

- SANRAL. 2006. **Drainage Manual**. 5th - Edition fully Revised. South African National Roads Agency Limited. ISBN 1-86844-328-0.
- SANS 1936. 2009. **Development of Dolomite Land Part 1: General Principles and Requirements** (ICS 07.060; 93.020) and **Part 2: Geotechnical Investigations and Determinations** (ICS 07.060:93.020). SABS webstore www.sabs.co.za.
- SANS 10610 Series. 2008. **Basis of Structural Design and Actions for Buildings and Industrial Structures**. South African National Standards. Pretoria. DRAFT. SABS webstore www.sabs.co.za.
- SCHWARTZ, K. 1985. *Problem Soils in South Africa – State of the Art. Collapsible Soils. The Civil Engineer In South Africa*, Vol. 27 No. 7 July 1985.
- TRH2. 1996. **Geotechnical and Soil Engineering Mapping for Roads and the Storage of Materials Data**. Technical Recommendations for Highways. ISBN 0 7988 1776 8. CSRA. Pretoria (available for download www.nra.co.za)
- TRH9. 1992. **Construction of Road Embankments**. Technical Recommendations for Highways. ISBN 0 7988 2272 4. CSRA. Pretoria (available for download www.nra.co.za)
- TRH10. 1994. **The Design of Road Embankments**. Technical Recommendations for Highways. ISBN 1 86844 093 1. CSRA. Pretoria (available for download www.nra.co.za)
- TRH15. 1994. **Subsurface Drainage for Roads**. DRAFT. Technical Recommendations for Highways. ISBN 1 86844 155 5. CSRA. Pretoria (available for download www.nra.co.za)
- TRH18. 1993. **The Investigation, Design, Construction and Maintenance of Road Cuttings**. Technical Recommendations for Highways. ISBN 1 86844 094 X. CSRA. Pretoria (available for download www.nra.co.za)
- VAN DER MERWE, D.H. 1964. *The Prediction of Heave from the Plasticity Index and the Percentage Clay Fraction. Transactions*. SAICE, Volume 6.
- WAGENER, F. 1985. *Problem Soils in South Africa – State of the Art. Dolomites. The Civil Engineer in South Africa*, Volume 27 No. 7 July 1985.
- WEST, G., Carter, P.G., Dumbleton, M.J. and Dumbleton, L.M. 1980. **Site Investigation for Tunnels**. Lake.
- WESTON, D.J. 1980. *Expansive Roadbed Treatment for Southern Africa. Proceedings for 4th International Conference on Expansive Soils*. Denver.
- WILLIAMS, A.A.B, Pidgeon, J.T., Day, P. 1985. *Problem Soils in South Africa – State of the Art. Expansive Soils. The Civil Engineer In South Africa*, Vol. 27 No. 7 July 1985.



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 7: APPENDIX A

ASPECTS COVERED IN THE DETAILED GEOTECHNICAL AND MATERIALS EXPLORATION AND DESIGN REPORT FOR GREENFIELD/UPGRADE PROJECTS

A.1 Introductory Executive Summary

- Appointment: The terms of Reference describing the Consulting Engineer's Commission and Scope and Programming of Geotechnical Investigative Works.
- General Description of Project.
- Summary of Problem Areas, Design Recommendations and Special Construction Requirements.

A.2 Physiography

Location and general nature of terrain. Also cover or cross refer to Environmental Management Plan if already dealt with separately. Some of these sections may be dealt with together, e.g., Topography and Drainage

- Topography
- Drainage
- Climate
- Vegetation
- Land use
- Infrastructure

A.3 Geology

- General geology of area (Refer to Geological Plans, Soil Survey Maps, Sections, etc.)
- Detailed geology and geomorphology along route
- Influence of geology and geomorphology on design and construction
- Effect of geology and geomorphology on availability of construction materials
- Geologically unstable areas (e.g. sinkholes, natural slopes shallowly undermined land, etc.)

A.4 Road Prism Investigation

This section should contain a detailed description of the route with regard to cuts, fills, and the identification of problem areas. (Refer to Chapter 6, Section 4). Include numbering of cuts and fills and problem areas with associated important stake values. It should also describe the identified problem areas in which instance, unless similar conditions are encountered, each area must be described separately, e.g., fills over swampy areas or sections of the route underlain by dolomite or shallowly undermined land.

A.4.1 Soil Survey and Subsurface Investigations

(i) Description of Investigations

NB : If portion of route is underlain by dolomite, cross-refer to the separate Dolomite Stability Investigation Report carried out during the Route Location/Preliminary Geotechnical and Materials Investigation Report stage. Include this preceding report into the Detailed Geotechnical and Materials Design Report if possible.

Mention when the various detailed investigations took place and by whom they were undertaken.

State the number of test pits dug or the number of auger holes drilled, the number of boreholes drilled and cored, the number of disturbed and undisturbed samples taken and for what purpose. Elaborate on the geophysical exploration methods used. Refer to plans, sections, etc., showing positions of all test pits, boreholes, etc. Also mention where the test results, logs, plans, etc., are bound in the Report. Use the prescribed forms/formats specified in this Manual.

(ii) Results of Soil Survey

This section should include geotechnical evaluation and discussion on:

- Moisture conditions and water tables. Tabulate marshy/vlei areas along route.
- Construction materials (suitability thereof) available from boxed-out excavations within road prism. When it comes to cuttings, discuss suitability and tests results for various materials encountered.

- Location and extent of unsuitable founding material below fills, warranting C.4.2 (ii).
- Identification, depth(s) and quantities of suitable topsoil along the route.
- Identification and quantities of unsuitable (spoil) materials along the route and in cuttings. NB: Clayey topsoil/overburden sources can be utilised meaningfully for topsoiling/reinstatement of the environment and landscaping purposes respectively.
- Excavatability in cuttings (more fully elaborated upon in C.4.3 below)
- Proposed *special* treatment types for roadbed/in situ subgrade, as referred to in Chapter 6, Section 4 , and as indicated on the AO-Soil Survey Plans vs. km distances
- Proposed *standard* road bed treatment types as discussed in Chapter 6, Section 4, and as also indicated on the AO-Soil Survey Plans vs. chainages.

Refer to test results, tables, plans, chainages, etc. where relevant. Use the prescribed forms.

C.4.2 Stability Assessments and Proposals

(i) Dolomitic Land or Shallowly Undermined Land

Appropriate reference should be made here to any preceding Dolomite Stability Investigation Report(s) prepared (during the early stages of the investigation) and such reports could be appended to this Detailed Geotechnical & Materials Investigation and Design Report.

(ii) Embankments

- Discuss the stability of the embankments considering founding conditions, potential lateral sliding, anticipated settlement (type, extent, period), or heave. NB: Consider behaviour of existing embankments/road fills as appropriate.
- If special measures are required to improve the stability of certain embankments, discuss for each the embankment geometry the proposed measures, e.g., the removal of unsuitable materials, special sub-surface drainage measures, monitoring of seepage, the construction of pioneer layers, the provision of reinforcement, rock toes and rock fills, the need for impact rolling, progressive construction and/or surcharging, required on-going monitoring, possible lateral support systems required, etc. Elaborate on proposed systems to be considered, e.g., Reinforced Earth (NB patented trade name – rather use other term such as “Soil reinforcement” otherwise other suppliers complain), piled anchored walls, etc. Refer to test data, borehole information, include calculations, provide plans and geological cross sections, typical details, sketches and preliminary breakdown of additional costs as necessary.
- Recommend drainage measures and required culvert class, etc. List precautionary measures relating to storm water handling.
- Recommend slope batters.
- Recommend erosion control measures and options.
- Provide stability analysis outputs where appropriate.
- Discuss the various proposed in place subgrade treatment types envisaged for the various embankments and also indicate this on the Soil Survey Plans vs. km-distances. (See C.4.1 (ii) above). Explain/indicate typical details for each type on the Soil Survey plans.

(iii) Cuttings

- Tabulate and discuss the geometry of all new (also upgrade projects) cuttings and pro-actively specify the surface and subsurface drainage requirements in terms of Chapters 4 & 5 of TRH 18: 1993. NB: In the case of upgrade projects, also consider experience gained from history of the existing cuttings, via available Slope Management System.
- By considering individual cases and site specific geology, recommend rock fall control (TRH 18:1993 Chapter 5.6.1) for cuttings susceptible to this phenomenon. (NB: In the case of upgrade projects, also consider available incident data obtained from existing Slope Management System.)
- Recommend permanent erosion control measures.
- Discuss the general stability of the cuttings considering geological features, in situ materials, moisture conditions, water table and the recommended permanent drainage measures. Recommend safe and maintainable batter slopes.
- Discuss proposals to enhance the stability of certain cuttings, e.g., special drainage measures, flatter or benched slopes, special methods of excavation (see C.4.3. below also), permanent rock bolting or active anchors, other retaining systems such as local gabions or concrete retaining block walls, bolted meshing, with or without guniting, required on-going monitoring, etc. Refer to test data, joint orientation surveys, borehole information,

provide plans and geological cross sections, typical details and sketches, as well as preliminary breakdown of additional costs as necessary. NB: Do not forget experience gained from the history of existing cuttings.

- Provide stability analysis outputs where appropriate.
- Discuss the proposed in place subgrade treatment envisaged for each cutting, and indicate this on the Soil Survey Plans versus the km-distance.

A.4.2 Classification of Excavation

- Tabulate per cutting, divide into depth zones as may be applicable, insert specified excavation classification (e.g. in accordance with COLTO). Provide proposed definition and preliminary assessment of bulking factors, etc. (Refer to test pit/auger hole and /or core borehole positions and logs, provide plans, geological cross-sections, seismic data, or other geophysical exploration methods if applicable, etc. as necessary).
- Then, tabulate the proposed classifications per cutting for tender documentation purposes. (Tabulate volumes, i.e., in situ cut volumes as well as percentage of each class of excavation, these volumes adjusted to compacted fill, or layer work volumes, for tender quantification purposes, or for possible use of the Mass Earthworks (cut to fill) proportion thereof, in the Mass Haul Diagram referred to below.)

A.5 CONSTRUCTION MATERIALS

(i) General Introduction

Elaborate on the various types of materials required for the specific project in hand.

(ii) Usable Material from Road Prism (Refer to C.4.1 (ii) where necessary)

Discuss efforts attempting to attain balance of earthworks, referring to Mass Haul Diagram as applicable and where necessary. Discuss origin and quantities of spoil, proposed spoil areas, etc.

Summarise quantity and implications of usage including stockpiling or spoiling of surplus effect on balance of earthworks, costs, effect on construction program, etc., absolute proposed usage of the various in situ materials based on the results discussed in C.4.1(ii).

(iii) Borrow Pits (Refer to Chapter 8)

Discuss the positions, practical haul distance, quantity, quality and suitability of the materials. Elaborate on the general shortcomings/good attributes of the various materials and how these can best be put to use, e.g., by modification/stabilization. Use the prescribed forms referred to in sections C.8 to C.10 in this Appendix. Discuss the environmental issues associated with the borrow pit and any special measures that may have to be implemented during their exploitation. Refer to test data, borrow pit plans, etc. where necessary. Indicate where the test data are bound in the report. Any implications and/or limitations with respect to future closure of the borrow pit according to the standard Environmental Management Plan (EMP) should also be included.

For commercial sources, list name of source, location, product range, material test results, quantities available and contact details.

(iv) Rock Quarries (Refer to Chapter 8)

Discuss the position, quality, quantity, suitability, method of working, and other aspects for each proposed quarry. Use the prescribe forms referred to in sections C.8 to C.10. Mention environmental issues associated with the quarry and any special measures that may have to be implemented during their exploitation. Refer to test data, plans, sketches, etc. and also mention where the data is bound in the report. Copies or references to copies of the approved EMP should be included in the report together with discussion on any associated cost implications.

For existing as well as potential commercial sources, each quarry must be listed together with product range, the relevant location and owner contact details. Refer to test data and any other relevant information that may be bound elsewhere in the report.

(v) Sand Sources (Refer to Chapter 8)

As for C.5 (iii) and (iv) above.

(vi) Water Sources

Discuss aspects such as:

- Location of sources

- Owner details
- Seasonal availability (perennial; non-perennial)
- Quantity available
- Water test results (salinity, potability, etc)
- Suitability for specific applications

Refer to results and evaluation of any testing undertaken.

A.6 Pavement Design

(i) General Introduction

(ii) Traffic Surveys and Growth Projections (refer to data)

(iii) Alternative Pavement Designs and Calculations

(iv) Cost-Benefit Analyses

(v) Influence of Terrain, Drainage, Geology and Construction Materials on Pavement Design

(vi) Summary and Proposed Pavement Design for:

- Freeway
- Ancillary roads

(vii) Summary of Schedule of Quantities Together with Cost Estimate

A.7 Structures

NB: The Geotechnical Investigation and Design Report shall be signed by both the compiler and the geotechnical engineer who planned/supervised the investigation, evaluated the results, prepared the geotechnical/foundation design parameters and recommended the most appropriate foundation type.

The Geotechnical Investigation Design Report shall also be a Design Report, i.e. the report shall provide clear guidance by the geotechnical engineer to the structural/bridge engineers, enabling the selection of the most appropriate solution and foundation type for the structure/bridge envisaged and the allowable differential settlements. The responsible geotechnical engineer shall evaluate and elaborate in the report on alternative foundation systems and/or solutions, if ground conditions or depth to a competent founding horizon suggest such a possibility. Settlement and load capacity analyses should be summarised in the report. The design report shall thus not only contain all of the necessary soil (and/or groundwater) parameters required for the design of the proposed foundation, (or pile type) for each bridge/major culvert/minor culvert, but also for the respective approach embankments. It should be realised that in some cases the detailed designs of foundations/piles/abutments are to be carried out by another geotechnical engineer who was not originally involved in the geotechnical investigation.

The report shall be compiled under the headings and in the sequence listed below:

- Introduction
- Description of the site(s) *
- Geology, soil profile and water table *
- Investigations carried out *
- Geotechnical evaluation *
- Evaluation of alternative foundation systems/types *
- Recommendations *
- References
- Annexures

NB: The items marked * shall be dealt with under the heading of **each structure** for which investigations have been conducted.

[The Geotechnical Investigation Design Report including appropriate Appendices as directed by the Project Manager, needs to be bound into Volume 6 of the tender documents. The Volume 6 report, together with the inspection of the site, shall provide the contractor with sufficient information to reasonably anticipate any problems which may occur during the execution of the works. This will enable the contractor to tender a realistic price for the construction of the work and to select the most appropriate equipment and techniques].

The aspects covered under the above-mentioned headings shall include, but not be limited to, the following, as relevant:

(i) Introduction

- Terms of reference and description of the project, with specific reference to the structures involved.
- Description of the stage, as described in Chapter 6 and the purpose for which the investigation was conducted.

(ii) Description of the Site(s)

- Location of the site(s)
- Accessibility of the site(s)
- Trafficability of the site for construction equipment
- Listing of sources from which data is available or was obtained
- Description of regional geology, geomorphology, vegetation, drainage and other general features of importance

(iii) Geology, Soil Profile and Water Table

- Formation(s) underlying site
- Typical soil profiles described
- Water table information
- Geological cross-section provided if applicable

(iv) Investigations Carried Out

- Name(s) of firm(s) responsible for the field work (consultant, contractor).
- Name(s) of person(s) responsible for the interpretation of the geophysical work and for the profiling and/or core logging.
- Date(s) on which the work was conducted.
- Description of the types of field work undertaken number of pits, auger holes or boreholes and probes, and equipment used.
- Laboratory testing programme on soils/rock (including groundwater quality testing w.r.t. possible effect on concrete).

(v) Geotechnical Evaluation

- Discussion of "stability classes" (if on dolomite formation).
- Evaluation of the soils encountered, identifying their stability or potential problems they may present e.g., tendency to heave, collapse, settle.
- Evaluation of hard rock geology (if encountered) identifying the type, quality, strength, degree of weathering, fracturing, excavatability classes. Mention reference used to arrive at excavation classes.
- Provide geotechnical/foundation design (or pile design) parameters etc.
- Potential for boulders and other obstructions to be encountered in deep seated foundations.
- Discussion of problems experienced during investigation or to be expected during construction.
- Discussion/evaluation of groundwater table(s) and expected variations.
- Discussion of field and laboratory testing (including chemical tests) carried out i.e.,
 - Evaluation of results obtained and comments on their reliability.
 - Evaluation of in situ testing results/geophysical investigations.

(vi) Evaluation of Alternative Foundation Systems/Types

- Maximum tolerable total settlement(s) and maximum tolerable differential settlement(s) applicable to the various bridge foundation components, as obtained from bridge design engineer.
- Discuss and evaluate alternative foundation types with pros and cons to be considered by bridge or structural engineers.
- Motivate preferred foundation (or pile) type.

(vii) Recommendations

- Excavatability classes (i.r.o conventional foundations and caissons, or for piling).
- Founding options to be considered (in the light of (vi) above).
- Estimated safe bearing pressure and predicted foundation settlements (differential and total) for the respective materials/depths on which founding could be considered.
- Recommended founding depth and allowable bearing pressure at that depth.
- Precautionary protective measures against corrosion of concrete/steel in foundations.
- Recommended pile type (if piling seems essential/economically viable).
- Recommended design parameters, e.g., friction values and rock socket parameters for the design of piles.
- Specified FOS to be designed for piling; and applicable pile design code.
- Recommended supplementary geotechnical investigations to be conducted or to be allowed/budgeted for during construction phase (if any).
- Construction problems anticipated.

(viii) References

- List reference used for the classification of materials in respect of soil condition and rock hardness and excavatability classes.
- Others as applicable to the investigation, evaluation, or to the recommendations.

(ix) Annexures

- Locality plan to appropriate scale
- Results of geophysical investigations (if any)
- Borehole, auger hole and test pit logs (with coordinates and elevations)
- Photographs of borehole cores recovered
- Laboratory test results/in situ testing results
- Geological cross-section(s) drawings (if appropriate)
- Drawings to scale, for each bridge/major culvert or other structure, showing the location(s) including levels of all positions investigated, physical features of the site and setting out points in relation to proposed bridge foundation layout(s).

A.8 Laboratory Test Data

Reporting (w.r.t. the Road Prism Exploration, borrow pits, quarries and commercial sources) shall only be carried out using the standardised series of reporting sheets. In special instances, e.g., foundation indicators, consolidation, shear box, triaxial tests, etc., modified laboratory test sheets will be accepted, i.e., where no standard form exists. All pavement materials designs should be recorded on the standard D3, etc. forms used for the As Built Materials Books.

Individual results recorded on forms emblazoned with a commercial laboratory's name and logo **will not be acceptable** for inclusion in the Reports and Project Documents.

Seismic data should be tabulated and also reported/shown on the Centreline Soil Survey Long Section/Plan drawings.

A.9 Subsurface Investigation Data

Standard boreholes log sheets must be used for all boreholes and auger holes. An example thereof is bound in Chapter 7, Appendix B. Any laboratory test results on soil or groundwater samples retrieved from trial holes, which cannot be reported on these sheets, should be presented on appropriate sheets.

A.10 Drawings

The following drawings should be included in the Detailed Geotechnical and Materials Investigation Report:

- Key plan
- Geological plans and sections
- Soils map (if required)
- Centreline soil survey long section/plans
- Long sections, cross sections of deep cuttings * and high embankments * (See NOTE below)

- Layout plan(s) of proposed quarries/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

NOTE: If certain cuttings and/or embankments were subjected to supplementary detail geotechnical investigations (over and above, the normal road prism exploration) in order to arrive at Stability Assessments and Proposals (in terms of Section C.4.2. of this Appendix), additional plans and sections indicating the position of these supplementary investigation positions and explaining the various soil/rock horizons encountered/investigated including water-table(s), etc., should be presented including preliminary plans/sections depicting the stability proposals/sequence of construction features, etc.

Also, if material from cuttings is to be used as sources for pavement layer materials, plans indicating the position and number of the cutting as well as the exact location and coordinates of test pits/auger holes, or core boreholes are required. **The source remains a cutting and should not be renamed a borrow pit.**

SAPEM CHAPTER 7: APPENDIX B

BRIDGE AND CULVERT FOUNDATION INVESTIGATION

Note: THESE EXTRACTS ARE FROM ROAD AUTHORITY SANRAL'S CODE OF PROCEDURE FOR THE PLANNING AND DESIGN OF HIGHWAY AND ROAD STRUCTURES IN SOUTH AFRICA (FEB. 2002), WHICH IS CONSIDERED TO REPRESENT GOOD PRACTICE

NOTE: The following pages in this Appendix B are extracts from Chapter 7 and Annexures 18.2 & 18.3 of the SANRAL Code of Procedure dated February 2002.

Note that some of the content has been updated (*in italics*) as well as additional guidelines included here and there (*in italics*), to align it with the report writing guidelines as outlined in Chapters 6 and 7 of this SAPEM manual.

B.1 Geotechnical Investigations

B.1.1 Introduction

NB: This entire Appendix needs to be read in conjunction with Chapter 7, Section 2 and/or Chapter 6, as the specific project type or case in question may require.

This abstract generally sets out the procedure for Geotechnical Investigations for Structures other than Tunnels.

The purpose of geotechnical investigations in this case is to provide an accurate assessment of subsurface conditions for all types of highway and road structures, including toll-buildings, etc., forming part of a particular project. The geo-investigations are therefore aimed at arming the Geotechnical Engineer/Engineering-Geologist in arriving at the various soil/rock/groundwater parameters/properties necessary for settlement and/or stability prediction and other soil/structure interactions cum design. In other words, for them to consider in a technical sense and then to select and recommend suitable foundation types for adequate and economic foundation designs for each and every facility. Also the bridge versus approach embankment interaction, bridge abutment settlements and slopes need to be looked into, etc.

It is essential that *thorough upfront planning* be done by the responsible Geotechnical Engineers/Engineering-Geologist, the investigative work then be carried in a competent manner, soil and rock profiles, groundwater conditions are described in detail using standard terminology, the necessary samples be recovered, the results are reported in full, the geotechnical evaluations and calculations are prepared by experts and the validity of the information is not disclaimed by such professionals.

The eventual preparation of a comprehensive and reliable Geotechnical Investigation and Design Report to be included in the Tender Documents. It also needs to provide guidance to Contractors in assessing risks, with the preparation of tenders and with the execution of the work.

In cases where existing works are to be modified and/or extended, *the information obtained from the original investigations shall be used to plan additional investigations, if any.* Where investigations are contemplated for New work, enquiries should be made to ascertain whether any previous investigations have been carried out in the area. Certain local authorities maintain data banks and much valuable information can be obtained from such sources.

Depending on circumstances, investigations may extend from superficial visual inspections to sophisticated surface and subsurface testing. These will have to be agreed with the Client at the appropriate stage of work.

B.1.2 Scope of Investigations

The scope of investigations contemplated for the stages described in Chapter 6, Section 1.3, is given as a guide. *These stages are mostly applicable to new "Greenfield" projects and therefore the scope of investigations for any specific project will thus have to be modified in conjunction with the Client to suit the specific project, the circumstances and conditions.*

B.1.2.1 Preliminary Investigation and/or Route Location Stage

The subsurface conditions shall be assessed by visual inspection of local ground conditions, examination of the available geological records and information contained in the section dealing with '*Preliminary Geotechnical and Materials Report*' in this manual.

At Sites for Bridges with deck areas exceeding 750 m², the extent of the investigation should be *of a sufficient scope and nature so as to reveal whether problematic founding conditions are present or not.*

B.1.2.2 Preliminary Design (Basic Planning) Stage

Exploratory subsurface (drilling) investigations on the centre line of the road shall be carried out for those major bridges and culverts at which problematic founding conditions are expected.

B.1.2.3 Detail Design and Documentation Stage

It is essential that a general geotechnical investigation of foundations for structures, based on the findings of the preliminary (basic) design of the road, be completed before the conceptual design of any structure is contemplated. Based on these results, conceptual designs could be prepared. It is possible that during the preparation of the conceptual designs it will come to light that *detailed* information with regard to the foundation conditions is lacking. In this event, a further phase of the foundation investigation should be entered into during which parameters that have a direct bearing on the proposed designs may be determined.

Thus, depending on the information that is available on the foundations and the extent of the planned works, a three-stage foundation investigation might be required. These stages would consist of a preliminary stage, a general investigation stage and a detail investigation stage.

B.1.3 Quotations and Tenders

The Geotechnical Engineer shall discuss the proposed investigations with the Client before commissioning any work on behalf of the Client. After agreement has been reached on the work to be undertaken and whether geophysical investigations are required, the engineer shall obtain at least three quotations for such geophysical investigations (refer to Section D.7.5.3), and he shall submit a report including his recommendation to the client for a ruling.

After the geophysical investigations have been completed the engineer shall prepare draft tender documents for the detailed investigation which will include some or all of the following: exploratory holes, in situ testing, laboratory testing, survey to set out and pick up positions and levels of exploratory holes, profiling holes, logging cores and photographing of cores. The draft documents shall be submitted to the Client for approval before tenders are obtained for the work.

In the case of SANRAL projects, documentation shall be based on the *SANRAL Pro Forma document for Geotechnical Investigations, with the FIDIC General conditions for construction for building and engineering works designed by the Employer (1999)*.

The new Standard Specification for Subsurface Investigations (2010) and any other specific Project Specifications shall apply. Open tenders shall be invited for the work unless the estimated value of the work is considered by the client to be too low to justify calling for open tenders. In such cases, contractors selected with the approval of the client, shall be invited to quote for the work.

B.1.4 Responsibility for Investigations and Designs

Geotechnical Investigations, *the ensuing geotechnical evaluations and foundation design recommendations* should ideally be carried out and prepared by knowledgeable and experienced Geotechnical Engineers (Registered Professional Engineers).

The logging/profiling of test holes/joint surveys of open rock faces, etc., should ideally be done by Engineering-Geologists (Registered Natural Scientists) or by Registered Geotechnical Engineers who are experienced in the type of investigative fieldwork envisaged.

B.1.5 Extent and Sequence of Investigation

This section describes the general procedure only and does not prescribe in detail how the investigations should be undertaken.

The investigation normally takes place in a number of phases. (*Refer to D.7.2 above*). The phases include a desk study, site reconnaissance, preliminary field work, detailed investigation and verification of conditions during construction. In certain instances, the process may be iterative, with some phases being repeated prior to final site selection and commencement of detailed investigation.

The Geotechnical Investigation shall be planned to obtain the necessary information at minimum cost. In planning an investigation it is important to consider the cost of the foundation and the sensitivity to foundation movement of the structural system being supported.

The following is a guide to the information which may be obtained in the various phases:

B.1.5.1 Desk Study

- Topographical maps and aerial photographs should be consulted to gain information on the general topography and prominent features.
- Geological and soil maps should be consulted to gain information on the basic geology and soils.
- Local authorities and other organisations should be approached to establish whether they have knowledge of investigations conducted in the area or have records available. The Greater Johannesburg Metropolitan Council, for example, maintains a comprehensive data bank.
- The Government Mining Engineer should be approached for information on mining operations where such operations are known to have been undertaken.
- The study of overlapping aerial photographs through a stereoscope will usually be of value in identifying geological features such as faults, dykes, geological boundaries, rock and soil types, rock exposures, drainage patterns, etc. These features are often not apparent in the field.

B.1.5.2 Site Reconnaissance

A site reconnaissance should be undertaken to gain geotechnical information for visible features, establish the suitability of various geophysical testing methods and investigate accessibility for drilling equipment.

Features such as boundary fences, gates, rail tracks, transmission lines, telephone lines, water pipes, electricity cables, exposed rock, exposed material in cuttings and quarries, depressions, sinkholes, springs, boreholes, changes in natural vegetation and damage to structures should be recorded.

B.1.5.3 Geophysical Investigations

Wherever practicable, *for example on sites underlain by dolomite, where it is an essential part of the investigation*, a geophysical investigation shall *first* be undertaken and *may* comprise a seismic or resistivity, or gravimetric, or electromagnetic evaluation of the subsurface conditions of sufficient extent and depth to assist in the selection of the most *appropriate and* economic detailed investigation, as well as in the *positioning* of the bases. It should be noted that a proper geophysical investigation can substantially reduce the number of boreholes required at any site. Recommended geophysical methods are summarized in Annexure 18.2.

B.1.5.4 Detailed Investigations – Exploratory Holes

B.1.5.4 (a) Purpose

The purpose of exploratory holes is to permit visual examination, testing of the in situ material and for the recovery of samples *to appropriate depth*.

B.1.5.4 (b) Choice of Equipment

In most instances, advantages are gained from using similar equipment, both in terms of type and capacity, for the detailed investigation as will be used for the construction of the foundations. For example, where augered piles are *expected* to be installed and circumstances permit, it is preferable to include the use of a large diameter auger rig similar to that which will be used for the installation of piles. This will provide a direct indication of the problems likely to be experienced during construction. Conversely, the use of a backactor for the excavation of test pits holds distinct advantages on a site where *it is certain that* shallow spread footings are envisaged. Rotary core drilling is often the most suitable method of investigation below water level (*or below high groundwater tables*), for recovery of *undisturbed samples* and for *coring* into hard materials. *This would include various in situ testing methods carried out in boreholes, auger holes or trial pits.*

For investigating the *conditions* in dolomitic areas, “down the hole hammer” percussion boreholes *are normally drilled*, as they have been found to be the most effective. Only operators experienced in dolomite should be used for this work. The chips collected must be logged by an experienced chip logger and any voids encountered during drilling must be diligently recorded. The recovery, sampling and labelling of samples is detailed in the Standard Specifications for Subsurface Investigations (2010).

B.1.5.4 (c) Sequence of Work

Generally hand or machine (backactor) excavated test pits would be used first, followed by large diameter auger holes (*if access is possible*), and finally small diameter cored holes *if necessary*. Planning should be flexible enough so that the work can be varied as necessary in the light of fresh information. To obtain the greatest benefit from the investigation, it is essential that there is adequate direction and supervision of the work by competent personnel who have appropriate knowledge and experience and the authority to decide on variations to the investigation when required.

B.1.5.4 (d) Safety and Personnel and the General Public

The safety requirements specified in *the new SAICE Code of Practise on the Safety of Men working in Small Diameter Shafts and Test Pits for Geotechnical Engineering Purposes (2008)* and in the *new Standard Specifications for Subsurface Investigations (2010)*, shall be complied with, as well as those in the *Occupational Health and Safety Act (Act 85 of 1993) including the new Regulations*.

B.1.5.4 (e) Spacing and Depth

The foundation investigation shall cover the full length and width of the structure including the approach embankments. Additional holes may be required beyond the extent of the structure to establish the locations of geological discontinuities

In general, for bridges the number of exploratory holes required depends on the lengths of the individual bases, information gained from investigations and the variability of the subsurface conditions.

The following is a rough guide for the initial selection of the number of exploratory holes at each base:

Length of bases	Recommended Number of Exploratory Holes at Each Base
Up to 5 m	1
Between 5 and 15 m	2
Between 15 and 30 m	3
Longer than 30 m	4

Where one hole per base is required, the holes shall be located at alternating ends of the individual bases. A minimum of two holes is required at each river bridge base, unless reliable information indicates uniform conditions.

For culverts and retaining walls, where exploratory holes are required, the initial pattern of holes should be staggered along the length of the structure. The holes shall be placed approximately 15 m apart.

For approach embankments, where exploratory holes are required, the initial layout of the holes should be a grid pattern with the holes about 30 m apart measured along the road centre line and at 20 m apart measured at right angles to the road centre line.

B.1.5.4 (f) Preparation of Records, Logging and Profiling

This work shall be in accordance with *the prescriptions given in the SAPEM Appendices and in the appropriate chapters in the new Standard Specifications for Subsurface Investigations (2010)*, including specified additional *Project Specifications (for the specific project in hand) in this regard*.

B.1.5.4 (g) Material of Archaeological Interest

If material is exposed which may be of archaeological or palaeontological interest, work at that location shall be stopped immediately. The area shall be fenced off and the engineer shall refer the matter to the *National Monuments Council for assessment* in order that further procedures may be planned.

B.1.6 Geotechnical Investigation Design Report

NB: This section must be read in conjunction with Section 2.2.3 in Chapter 7.

NOTE:

The Geotechnical Investigation and Design Report shall be signed by both the Compiler/Writer of the report and by the Geotechnical Engineer who planned/supervised the investigation, evaluated the results, prepared the geotechnical/foundation design parameters and recommended the most appropriate foundation type.

NB: *The Geotechnical Investigation Design Report shall always also serve the purpose of a Design Report w.r.t. the geotechnical components (such as bridge foundations or toll-building foundations) of a road project, i.e., the report shall contain geotechnical parameters for design and shall also provide clear guidance to the Structural/Bridge Design Engineers (guidance as prepared by the Geotechnical Engineer who carried out the geotechnical investigation) enabling the selection of the most appropriate solution and foundation type for each building or structure/bridge and its particular allowable differential settlements.*

[Or, the required details contained in the Report for example pertaining to high embankments/deep cuttings/lateral support measures, is normally aimed at the attention of the Road Engineer.]

The responsible Geotechnical Engineer shall also evaluate and elaborate in the Report on alternative foundation systems and/or solutions, if ground conditions or depth to a competent founding horizon suggest such a possibility. Settlement and load capacity analyses/calculations should be summarised in the report. Lateral support/slope stability analyses/calculations, as well as alternative solutions, shall be summarised as well. This Geotechnical Investigation Design Report shall thus not only contain all of the necessary soil/rock (and/or groundwater) parameters required for the design of the proposed high embankments and/or deep cuttings, but shall also give clear guidance with respect to the proposed foundation (or pile type) for each bridge/major culvert /minor culvert, including the respective approach embankments.

The reason for this requirement, over and above the fact that it is any case required from a Quality Assurance point of view, is that in some cases, depending on the type of tender documentation, or depending on the structuring or phasing of the project by individual Road Authorities, the detailed designs of foundations/piles/abutments or of lateral support systems are in many cases eventually the responsibility of another Geotechnical Engineer who was never involved in the original Geotechnical Investigation.

To include and to provide all the necessary interpreted geotechnical design parameters are therefore an essential and vital element in any geotechnical investigation design report.

The Report shall be compiled under the headings and in the sequence listed below:

- Introduction
- Description of the site(s) *
- *Geology, soil profile and water table**
- Investigations carried out *
- Test results/data
- *Geotechnical evaluation **
- *Evaluation of alternative foundation systems/types **
- Recommendations *
- References
- Annexures

Note: * The items marked * shall be dealt with under the heading of **each structure** for which investigations had been conducted.

[The Geotechnical Investigation *Design Report including appropriate Appendices thereof as directed by the Project Manager, needs to be bound into the Volume 6 section of the tender documents (see Section 14.2.5). The Volume 6 report, together with the inspection of the site, shall provide the contractor with sufficient information to reasonably anticipate any problems that may occur during execution of the works. This will enable the contractor to tender a realistic price for the construction of the work and to select the most appropriate equipment and techniques].*

The aspects covered under the above-mentioned headings shall include, but not be limited to, the following, as relevant:

B.1.6.1 Introduction

- Terms of reference and description of the project, with specific reference to the structures involved.
- Description of the stage, as described in Chapter 6, Section 1.3, and the purpose for which the investigation was conducted.

B.1.6.2 Description of the Site(s)

- Location of the site(s)
- Accessibility of the site(s)
- Trafficability of the site for construction equipment
- Listing of sources from which data is available or was obtained
- Description of regional geology, geomorphology, topography, vegetation, drainage and other general features of importance

B.1.6.3 Geology, Soil Profile and Water Table

- Formation(s) underlying site
- Typical soil profiles described

- Water table information
- Geological cross-section provided if applicable

B.1.6.4 Investigations Carried Out

- Name(s) of firm(s) responsible for the field work (consultant, contractor)
- Name(s) of person(s) responsible for the interpretation of the geophysical work and for the profiling *and/or core logging*.
- Date(s) on which the work was conducted
- Description of the types of field work undertaken *number of pits, auger holes or boreholes and probes*, and equipment used
- *Laboratory testing programme on soils/rock, (including groundwater quality testing w.r.t. possible effect on concrete)*

B.1.6.5 Test Results

- Summary of test results
- Discussion of results (factual)

B.1.6.6 Geotechnical Evaluation

- Discussion of "stability classes" (if on dolomite formation).
- Evaluation/interpretation of the soils encountered, identifying their stability or potential problems they may present, e.g., tendency to heave, collapse, settle.
- Evaluation/interpretation of hard rock geology (if encountered) identifying the type, quality, strength, degree of weathering, fracturing, excavatability classes. [Mention reference used to arrive at excavatability classes.]
- **Provide geotechnical/foundation design (or pile design) parameters**, etc.
- Potential for boulders and other obstructions to be encountered in deep seated foundations.
- Discussion/interpretation of problems experienced during investigation or to be expected during construction.
- Discussion/interpretation of groundwater table(s) and expected variations.
- Discussion/interpretation of field and laboratory testing (including chemical tests) carried out, i.e.,
 - *Evaluation of results obtained and comments on their reliability.*
 - *Evaluation of in situ testing results/geophysical investigations.*

B.1.6.7 Evaluation of Alternative Foundation Systems/Types

- Discuss and evaluate alternative foundation types, with pros and cons to be considered by bridge or structural engineers.
- Motivate preferred foundation (or pile) type

B.1.6.8 Recommendations

- Excavatability classes (i.r.o conventional foundations and caissons, or for piling).
- Maximum tolerable total settlement(s) and maximum tolerable differential settlement(s) applicable to the various bridge foundation components, as obtained from bridge design engineer.
- Type of foundation best suited.
- Founding options to be considered. Estimated safe bearing pressure and settlement for the respective materials/depths on which founding could be considered.
- Recommended founding depth and allowable bearing pressure at that depth.
- Precautionary protective measures against corrosion of concrete/ steel.
- Recommended pile type (if piling seems essential).
- Recommended design parameters e.g. friction values and rock socket parameters for the design of piles.
- Specified FOS to be designed for piling; applicable pile design code.
- Recommended supplementary geotechnical investigations to be conducted, or to allow for during construction phase (if any).
- Construction problems anticipated.

B.1.6.9 References

- *List reference for the classification of materials in respect of soil condition and rock hardness and excavatability classes.*
- *Others as applicable to the investigation, evaluation, or to the recommendations.*

B.1.6.10 Annexures

- Locality plan to appropriate scale
- Results of geophysical investigations *(if any)*
- Borehole, auger hole and test pit logs *(with coordinates and elevations)*
- Photographs of borehole cores recovered
- Laboratory test results/*In situ testing results*
- *Geological cross-section (s) drawings (if appropriate)*
- Drawings to scale, *for each bridge/ major culvert or other structure*, showing the location(s) including levels of all positions investigated, physical features of the site and setting out points *in relation to proposed bridge foundation layout(s)*.

SAPEM CHAPTER 7: APPENDIX B

**ANNEXURE 18.2 OF THE SANRAL CODE OF PROCEDURE:
GEOTECHNICAL INVESTIGATIONS**

Table 18.2.1: Geophysical Methods in Ground Investigation [Table 3, BS 5930 (1981)]

Problem		Example	Method And Remarks
Geological	Stratigraphical	Sediments over bedrock	Land
		(i) Sands & gravels over bedrock, water table deep in sands & gravels	Seismic refraction
		(ii) Sands & gravels overlying clay, water table high in sand & gravels	Resistivity
		(iii) Clay over bedrock	Resistivity or seismic refraction
		Sediments over bedrock generally	Marine Continuous seismic reflection profiling
	Erosional (for caverns; see shafts below)	Buried Channel	Seismic Refraction Resistivity for feature wider than depth of cover
		Buried karstic surface	Resistivity contouring
	Structural	Buried fault, dykes	Resistivity Contouring Seismic reflection or refraction Magnetic gravimetric (large faults)
Resources	Water	Location of aquifer Location of saline/potable interface	Resistivity and seismic refraction
	Sand and gravel	Sand, gravel over clay	Land: Resistivity
		Gravel banks	Marine: Continuous seismic profiling, side scan sonar, echo sounding
	Rock	Intrusive in sedimentary rocks	Magnetic (weathering may give low resistivity)
	Clay	Clay pockets	Resistivity
Engineering parameters	Modulus of elasticity, density and porosity	Dynamic deformation modulus	Seismic velocity at surface, or with single or multiple boreholes (cross hole transmission)
		Check on effects of ground treatment	Boreholes geophysics
	Rock rippability	Choice of excavation methods	Seismic (velocities at surface)
	Corrosivity of soils	Pipeline surveys	Surface resistivity, redox potential
Buried artifacts	Cables	Trenches on land	Magnetometer Electromagnetic field detectors
	Pipes	Submarine trenches	Echo sounding, side scan sonar
		Submarine pipelines	Side scan sonar, magnetic, continuous seismic profiling (especially if thought to be partially buried) with high frequency pinger
	Shafts, adits and caverns	Shaft, sink holes, mine workings	Resistivity Magnetometer contouring, infra-red air photography on clear areas Cross hole transmission Detailed gravity for large systems

SAPEM CHAPTER 7: APPENDIX B

**ANNEXURE 18.3 OF THE SANRAL CODE OF PROCEDURE:
GEOTECHNICAL INVESTIGATIONS**

Table 18.3.1 Some Laboratory Tests on Soils

Test	Material	Sample Type	Remarks	References
Gradings Analysis Sieving	Granular soils and gravels	D	Usually carried out in conjunction with Atterberg limit tests to give an indication of the soil behaviour and to classify the soil	SANS 3001 BS 1377 (1975)
Sedimentation	Cohesive and fine grained soils	D		
Atterberg Limits	Cohesive and fine grained soils	D	Plastic limit, liquid limit, plasticity index and linear shrinkage. Give indication of soil behaviour	SANS 3001
Moisture Content	Soil or rocks	D/U	Frequently carried out as part of other tests. Required for determination of degree of saturation Essential for expansive clay investigations	SANS 3001 BS 1377 (1975)
Specific Gravity	Soils or rocks	D	Used in conjunction with other tests such as density, moisture content and sedimentation	SANS 3001 BS 1377 (1975)
Bulk Density	Soils	D/U	May be carried out on undisturbed samples in the lab Cohesionless soils must be tested in situ Used with above two tests to determine degree of saturation and void ratio	SANS 3001 BS 1377 (1975)
Triaxial Compression Undrained unconsolidated	Saturated, normally consolidated clays	U	Undrained shear strength ($\Phi=0$) Short term stability In fissured clays, sample size has a significant effect	Bishop & Henkel (1962) Marsland (1971)
Consolidated undrained with p.w.p. measurements	Saturated normally consolidated clays Partially saturated clays (soaked)	U	Effective strength parameters (c', Φ')	Bishop & Henkel (1962) Akroyd (1957)
Consolidated drained	Clayey sands, sandy, clays, silts	U	Effective strength parameters (c', Φ')	Bishop & Henkel (1962) Akroyd (1957)
	Partially saturated clays (soaked)	U	Long term stability	
Direct Shear Box Immediate (b) Drained	Saturated clayey sands, silts and clays	U	Undrained shear strength. Triaxial tests generally preferred	Akroyd (1957)
	Clayey sands, sandy clays & silts Dry or saturated sands	U R	Effective strength parameters (c', Φ') Angle of shearing resistance ($c'=0$)	Akroyd (1957) Akroyd (1957) Bishop (1948)
Unconfined Compressive Strength	Saturated intact clays	U	Simple and rapid substitute for undrained triaxial test	Akroyd (1957)
One Dimensional Consolidation	Cohesive and fine grained soils	U	Gives measure of compressibility, pre-consolidation pressure and coefficient of consolidation.	Akroyd (1957)
Triaxial Consolidation	Cohesive and fine grained soils Recompacted sands	U R	Triaxial consolidation gives measure of elastic modulus	Akroyd (1957) Bishop & Henkel (1962)
Rowe Cell Consolidation	Cohesive and fine grained soils	U/R	Rowe cell uses larger samples and confining pressure may be varied	Rowe & Barden (1966)

D = Disturbed

I = In situ

R = Remoulded

U = Undisturbed

Table 18.3.2. Some Laboratory Tests on Rock

Test	Material	Sample Type	Remarks	References
Moisture Content, Bulk Density, Porosity	All rocks	C/L	Gives indication of strength, modulus of elasticity and degree of weathering	Int Soc Rock Mech (1979)
Swelling Test	Mainly argillaceous rocks	C/L	Indicates moisture sensitivity of rock and possible volume changes	Duncan et al (1968)
Point Load Test	Isotropic rocks	C/L	Quick and cheap indicator of rock strength Useful aid to core logging	
Uniaxial Compression Test	Most rocks which can be cored	C	Strength of intact rock Upper limit for jointed rock mass strength Widely used for predicting bearing capacity and skin friction Gives elastic properties of "intact" rock core if strain is measured This will over-estimate modulus of jointed rock	Hoek (1977) Hawkes & Mellor (1970) Clark (1966)
Triaxial Compression Test	Very soft/soft rock "intact" weathered rock	C	As above Only weak rocks may be tested with commonly available equipment	Hoek (1977)
Direct Shear Box Test	Usually applied to rock discontinuities or intact rock	L/I	Gives shear strength along discontinuities or of intact soft rocks	Hoek (1977)

C = Core Sample
I = In situ
L = Lump Sample

Table 18.3.3. Some In Situ Field Tests

Test	Material	Remarks	References
Standard Penetration Test (SPT)	Mainly sands and weak rocks Also used on other soils	Refer Standard Specifications for Subsurface Investigations (201) Performed generally at 1.5 m intervals in boreholes Gives indication of consistency/relative density of soil Results correlated with many soil properties and empirical design methods	Webb (1976) SAICE & NITRR (1978) Sanglerat (1972) Ervin (1983) OSOPT-1 (1988)
Dynamic Cone Test or Dynamic Spoon Test	Most soils	Performed by driving cone or spoon with no intermediate drilling or reaming of hole Not as widely accepted as SPT test but cheaper to perform Disturbed sample obtain from spoon test Results correlated with SPT results	Webb (1976) SAICE & NITRR (1978) Sanglerat (1972) Ervin (1983) OSOPT-1 (1988)
Cone Penetration Test (CPT) or Dutch Probe)	Loose granular soils and soft to firm clays	Gives point resistance (cone) and total resistance (cone and friction sleeve) Results correlated with bearing capacity and compressibility	TMG6 (1984) Webb (1976) SAICE & NITRR (1978) Sanglerat (1972) Ervin (1983) OSOPT-1 (1988)
Piezocone (CPTU)	Saturated, loose, granular soils and soft to firm clays	Tip resistance, sleeve resistance and dynamic pore pressure are measured while continuously driving the probe into the ground	Clemence (ED) (1986) OSOPT-1 (1988)
Pressuremeter	Soils and weak rocks	Pressuremeters may either be inserted into boreholes, be driven into the ground in a slotted casing or be self boring Results give indication of elastic modulus and soil strength	SAICE & NITRR (1978) Menard (1965) Windle & Wroth (1977) Ervin (1983)
Goodman Jack	Soft to hard rocks	Jack inserted into NX sized borehole Rock loaded by curved plates and deformations measured May be installed in horizontally drilled holes and rotated to determine degree of anisotropy Results give indication of elastic modulus of in situ rock mass	Goodman et al (1968)
Piezometer	All soils and rocks	Used to determine groundwater pressure at various depths in the ground In permeable ground, standpipe piezometers are used; but in impermeable conditions or where rapid response is required, hydraulic, pneumatic or electric piezometers are used	SAICE & NITRR (1978) BS 5930 (1981) Penman (1960)
Vane Shear Test	Saturated cohesive soils	Normally restricted to saturated clays with an undrained shear strength of less than 100 kPa This method can give peak and residual undrained shear strengths	SAICE & NITRR (1978) BS 5930 (1981) Ervin (1983) ASTM D2573
Plate Bearing Test	Moist soils and soft rocks Generally above water table	Test performed in trench or auger hole by jacking circular plates against the soil/rock May be carried out horizontally (across width of hole) or vertically (jacking against a kentledge) Size of plate depends on the zone of influence and hole size and stiffness of material generally 75 – 300 mm for horizontal tests and 200 – 1000 mm for vertical test	Ervin (1983) Wrench (1984)

ISOPT = International Symposium on Penetration Testing