

SOUTH AFRICAN PAVEMENT ENGINEERING MANUAL

Chapter 8

Material Sources



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

Date of Issue: October 2014

Second Edition

South African Pavement Engineering Manual
Chapter 8: Material Sources

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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

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QUALITY MANAGEMENT

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SCOPE

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

SAPEM consists of 14 chapters covering all aspects of pavement engineering. A brief description of each chapter is given below to provide the context for this chapter, Chapter 8.

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 investigations into fills, cuts, structures and tunnels, and includes discussion on geophysical methods, drilling and probing, and stability assessments. Guidelines for the reporting of the investigations are provided.

Chapter 8: Material Sources provides information for sourcing materials from project quarries and borrow pits, commercial materials sources and alternative sources. For project quarries and borrow pits, the full process for sourcing materials is described, from prospecting and material investigations, to land acquisition and authorisation, mining planning and operations, and finally, to closure and reporting and monitoring. For commercial material sources, the resources for producers are provided, quarrying processes are described, as are the quality assurance and quality control required. The legal and environmental requirements for sourcing materials are given. The suitability of rocks for particular applications is given, as well as the typical products available from commercial quarries. For alternative sources, the procedures for evaluating a new material are given, including methods of classifying and using waste products. The types of alternative sources discussed are recycled pavement materials, construction and demolition waste, slag, fly ash and mine waste.

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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 precoat 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.

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

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

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

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

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

FEEDBACK

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

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

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1. INTRODUCTION

Political, legal, economic, environmental and technical level interventions are making the upgrading and maintenance of the road network increasingly more challenging. A primary concern is the difficulty surrounding the identification and exploitation of road construction materials. The enactment of the Minerals and Petroleum Resources Development Act (No 28 of 2002) (Department of Minerals and Energy (DME), now Department of Mineral Resources (DMR), 2002), which includes the mining of construction materials, sets more onerous standards for compliance and is having a major effect on how road authorities (and their agents) manage quarries and borrow pits to ensure legal compliance. Other limiting issues include the dearth of suitable materials in many areas of South Africa, high costs of material processing, landowner reluctance and apathy, increased environmental and legal awareness, and budget constraints.

This chapter covers the sourcing of granular materials and aggregates used in road construction and maintenance projects from other than within the road prism. The most desirable option, however, remains to source the material from within the road prism. The three main options for the supply of road construction materials are considered to be:

- **Project borrow pits and quarries:** sources developed and operated to supply materials for a specific project.
- **Commercial sources:** quarries with permanent infrastructure established to service a viable market.
- **Alternative sources:** recycled materials sourced either from the existing road prism, or other local supply.

The sourcing of materials plays a critical role in most road construction and maintenance projects. The principal factors that influence the selection of materials sources are:

- **Availability**
- **Quality** requirements
- **Technical feasibility**
- **Environmental** considerations
- **Commercial viability**

Ideally, the required quantities of good quality materials are locally available and the route and road alignments are selected for optimal material use. Furthermore, these sources should be exploited with no adverse environmental impacts and supplied at commercially attractive rates. However, projects are not ideal and can be very challenging if the selection of suitable material sources is to meet the technical, environmental and commercial objectives. Some of the more common problems typically experienced with materials supply include:

- Material sources may be located far from the site, leading to **excessive haulage distances**, and consequently, high costs.
- Opportunities to **develop project quarries or borrow pits** are severely restricted due to
 - Environmental constraints.
 - Long lead in time required for environmental authorization.
- Commercial sources available close to the site supply at **high cost**.
- Opportunities for recycling materials exist, but due to **clients' reluctance to consider "new technology"**, these opportunities are not exploited.

Considering these challenges, it is crucial to explore all possible options for supplying the needed construction materials at the earliest onset of a project.

The objective of this chapter is to provide an overview of the various options available for materials supply as well as provide guidance on key aspects. The following three sections of the chapter each cover a primary type of material source, i.e.:

- **Section 2:** Project Borrow Pits and Quarries
- **Section 3:** Commercial Quarries
- **Section 4:** Alternative Sources

Section 2 provides an overview of the process required to develop a project borrow pit or quarry and covers the following topics:



Upgrading and Maintenance of Road Network

Political, legal, economic, environmental and technical level interventions are making the upgrading and maintenance of the road network increasingly more challenging.



Investigations Phases

The various phases for road prism investigations and associated geotechnical investigations, of which the sourcing of materials is an important component, are covered in Chapter 6: 5 (Table 2) and Chapter 7: 3 (Table 2).

- Prospecting
- Materials investigations
- Developing mine plans
- Environmental authorization
- Securing land rights
- Operational procedures
- Closure of quarries and pits

The development process is not only demanding from technical and environmental perspectives but also requires fulfilling legal requirements. The information contained in this section is considered essential knowledge for those involved with identifying, planning, operating and closing quarries and borrow pits.

Section 3 looks at **commercial aggregate suppliers** and in particular provides an overview of:

- South African aggregate market
- Typical quarrying processes
- Raw materials and commercial aggregate products
- Specification issues relating to the supply of commercial aggregate products

In **Section 4**, the emphasis is on the **use of alternative materials** in place of traditional materials. The use of alternative materials as a viable option stems from the depletion of natural resources, the need to conserve power, as well as a heightened awareness of environmental issues and the regulatory consent requirements for developing quarries and borrow pits. Wherever feasible, the utilization of recycled construction and industrial by-products should be considered.

The use of waste products for construction materials in South Africa is limited and more emphasis needs to be placed on the potential use of such products by the industry. Much of the information provided in this section relates to overseas experience, however, where possible South African references have been included.

Available alternative materials, their classification and the advantages and disadvantages of their use as road construction materials are discussed in the section. Alternative materials that are readily available in South Africa are discussed in detail and include:

- Recycled road pavement materials
- Construction and demolition waste
- Slags
- Fly ash
- Other mine waste



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.



Definitions

Contaminated water: water contaminated as a result of the mining activities, e.g., runoff from refuelling areas and sediment laden storm water.

Current mining area: assuming a phased approach, the area that is being mined at any one point in time and which would be the subject of the Mining Plan.

Closure Plan: typically the document that accompanies the application for closure and forms part of the Environmental Management Programme or Environmental Management Plan. This plan includes the description of the closure objectives as well as rehabilitation provisions and details of any long-term management and maintenance expected. Where no mining plan has been developed for a particular borrow pit, a closure plan may be developed as a proactive step for closure of the site.

Environment: the surroundings within which humans exist and that are made up of:

- The land, water and atmosphere of the earth.
- Micro-organisms, plant and animal life.
- Any part or combination of the above and the inter-relationships among and between them.
- Physical, chemical, aesthetic, cultural properties and conditions influencing human health and well-being.

Environmental Management Plan (EMP): plan to manage and rehabilitate the environmental impact as a result of prospecting, reconnaissance, exploration or mining operations conducted under the authority of a reconnaissance permission, prospecting right, reconnaissance permit, exploration right or mining permit.

Environmental Management Programme (EMProg): a plan to manage and rehabilitate the environmental impact as a result of prospecting, reconnaissance, exploration or mining operations conducted under the authority of a mining right.

Environmental Risk Report: a report detailing the risks, as identified in a risk assessment, and management measures, that accompanies an application for closure.

Expropriation: the act of expropriating; the surrender of a claim to exclusive property; the act of taking of ownership or proprietary rights.

Feasibility Report: a report based on a desk study and/or very limited field investigations ranging from a single site visit to minimal trial pitting and/or limited bore holes (in the case of a hard rock quarry), to determine the basic economic and feasibility of a source.

Mine: any operation or activity for the purposes of winning any mineral on, in or under the earth, water or any residue deposit, whether by underground or open working or otherwise and includes any operation or activity incidental thereto.

Mining operation: any operation relating to the act of mining and matters directly related.

Mining plan: a plan detailing the approach to the development, operation and decommission phase of a borrow pit operation.

Overburden: the layer of soil immediately beneath the topsoil but above the mineral that is the target of the mining activities.

Pollution: any change in the environment caused by substances; noise, odours or dust, emitted from any activity, including the storage or treatment of waste or substances, construction and the provision of services, where that change has an adverse effect on human health or well-being or on the composition, resilience and productivity of natural or managed ecosystems, or on materials useful to people, or will have such an effect in the future.

Reconnaissance: investigation, scouting, inspection or surveying of aspects or sites.

Solid waste: all solid waste, including construction debris, chemical waste, excess cement or concrete, wrapping materials, timber, tins and cans, drums, wire, nails, food and domestic waste, e.g., plastic packets and wrappers.

Spoil: excavated material which is unsuitable for use as material in the Works or is material which is surplus to the requirements of the works.

State land: land which vests in the national or a provincial government, and includes land below the high water mark and the Admiralty Reserve (land above and adjoining the high water mark, but which is a Navy/Defence force reserve) but excludes land belonging to a local authority.

Sustainable development: the integration of social, economic and environmental factors into planning, implementation and decision making so as to ensure that mineral and petroleum resources development serves present and future generations.

Topsoil: means a varying depth (usually up to 300 mm in depth) of the soil profile irrespective of the fertility appearance, structure, composition or agricultural potential of the soil.

Watercourse: any river, stream and natural drainage channel, whether carrying water or not.

2. PROJECT QUARRIES AND BORROW PITS

The purpose of this section is to provide an overview of the entire process of exploiting a material source for the production of road construction materials. This process proceeds from the identification of a suitable material source (feasibility), through to the planning and operational stages, to finally achieving successful closure. Failure to effectively manage this process can have serious negative impacts on road quality, project programme and costs, as well as to the environment. Fulfilling the legal requirements is an essential part of the process. Quarries and borrow pits cannot be operated without prior authorisation from the relevant government departments.

The typical borrow pit or quarry project cycle consists of the following 5 stages:

- Feasibility
- Planning
- Operation
- Closure
- Monitoring and reporting

The timeframe required to complete the feasibility and planning stages of the process typically extends up to one year, but may take significantly longer for hard rock quarries. Therefore, it is critical that the process be managed effectively and commences as far in advance of the works as practically feasible.

In the context of this manual, the following definitions apply:

- **Borrow pit** (Figure 1) describes an area where material, usually soil, gravel, sand, or weathered rock, has been dug for use as a natural granular material for use in road construction. The types of materials normally obtained from a borrow pit are:
 - Natural soil or gravel (G4 to G10)
 - Natural soil and gravel for the production of gravel wearing course
- **Quarry** describes an open excavation from where rock is obtained, usually by drilling and blasting, to produce rock aggregate for use in road construction. Road construction materials obtained from quarries include:
 - Graded, crushed stone for bases (G1 to G4)
 - Crushed stone for subbase production (G5), where natural gravels are not available
 - Graded, crushed stone for the production of surfacing stone
 - Graded, crushed aggregates for the production of asphalt
 - Graded, crushed concrete aggregates (coarse and fine)
 - Blasted rock for dump-rock, rip-rap, gabions and stone pitching



G Classifications for Granular Materials

See Chapter 4, Section 2.4, 2.5, 2.6 and 3.5.1, and the Chapter 4 Appendix for a description of the classification of granular materials into the G classes.



Operations Manual for Borrow Pits

A comprehensive manual produced by the Western Cape Provincial Administration, "*Operations Manual for the Development, Operation and Closure of Borrow Pits*" provides detailed guidance on all aspects of borrow pit operations (WCPA, 2008). The manual is available on the web at http://rnis.pgwc.gov.za/rnis/rnis_web_reports.main.



Figure 1. Borrow Pit

The required steps in the identification, proving, authorising, operation and closure of material sources are shown in Figure 2 (from WCPA, 2006).

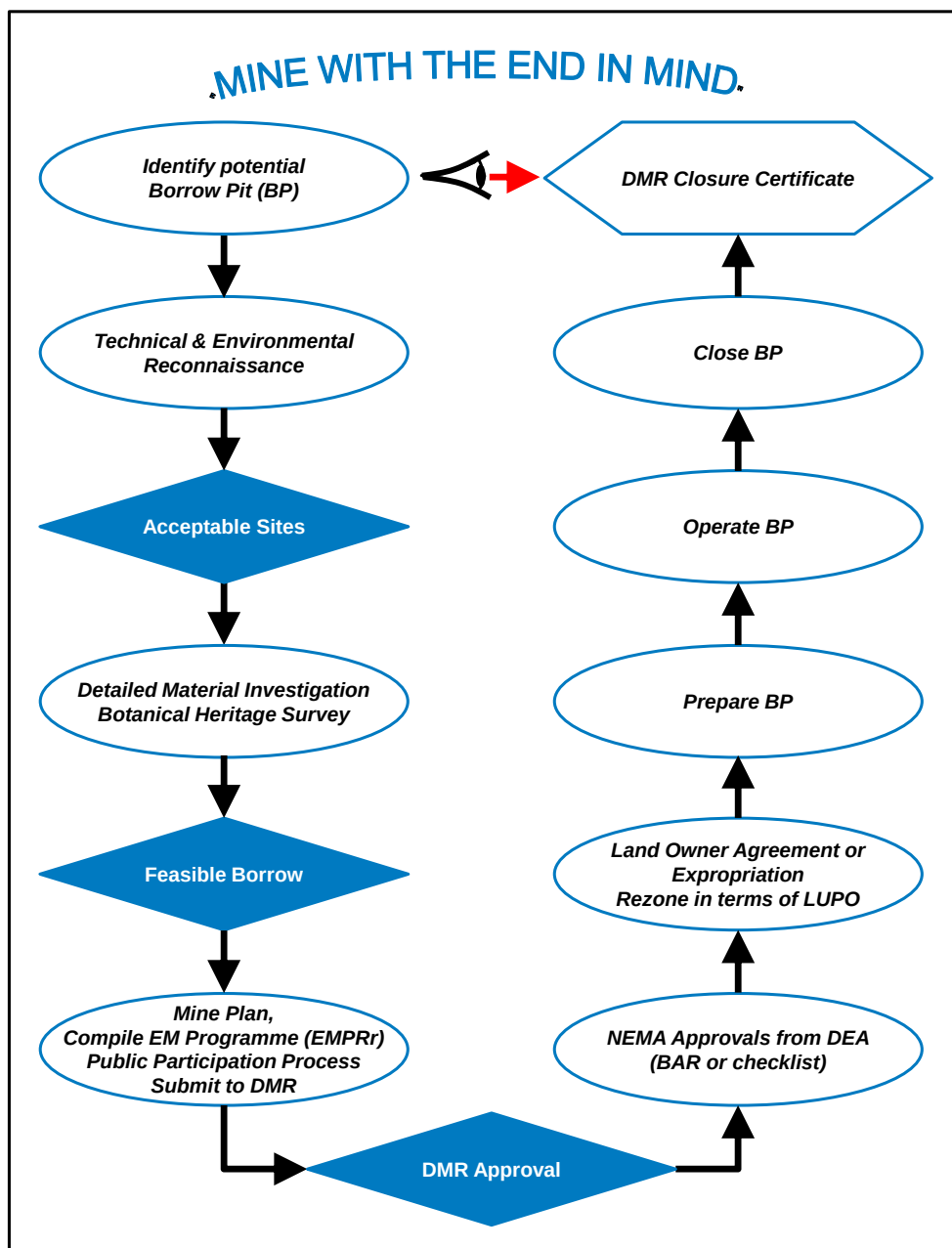


Figure 2. Required Steps in the Identification, Proving, Authorising, Operation and Closure of Material Sources

The five stages of a project cycle are shown in Table 1. Personnel managing and supervising the various disciplines required in the process should be professionally registered and preferably also be member affiliated as indicated in Table 2, or have similar foreign registrations or affiliations.

Table 1. Quarries and Borrow Pits Project Cycle

Stage	Activity	Section in this Chapter
Stage 1	Feasibility	Prospecting and Material Location Materials Investigation Environmental Screening for Acceptability
Stage 2	Planning	Planning of Mining Authorisation Process Land Acquisition Process
Stage 3	Operation	Operations
Stage 4	Closure	Closure
Stage 5	Monitoring and Reporting	Reporting and Monitoring

Table 2. Registration and Affiliations Requirements

Discipline	Registration Authority RSA	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
Materials or Pavement Engineer	ECSA	SAICE Transportation Division
Environmentalist	EAPSA ⁶	IAIA ⁷

Note

1. ECSA is the Engineering Council of South Africa
2. SACNASP is the South African Council for Natural 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 Geophysical Association
6. EAPSA is the Environmental Assessment Practitioners of South Africa
7. IAIA is the International Association of Impact Assessment

2.1 Prospecting

The purpose of this section is to give guidance for the various steps taken when prospecting for a new material source. The objectives of the prospecting stage are:

- **Identify** prospective exploitable sources of materials (desk study).
- Carry out **site reconnaissance** to determine if prospective sites are technically and environmentally feasible.
- **Select** sites for further investigation.

Prospecting for materials sources is a skilled activity that should be carried out by a professionally registered engineering geologist, or professionally registered civil engineer or civil engineering technologist, with appropriate experience.

The following factors are critical determinants in the identification and selection of a suitable material source:

- Material quality and quantity
- Haul distance
- Environmental sensitivity and impact



Identification of Potential Sites

During the desk study, it is important to identify as many potential sites as feasible. These sites are assessed during the site reconnaissance phase. Using information gathered during the reconnaissance, the sites are screened to determine their technical and environmental feasibility. Feasible sites can then be selected for further investigation.



Selecting a Site for Investigation

In selecting a site for investigation, all of the applicable factors should be taken into account. The aim should be to select a site that **optimises the interaction between these variables**. However, this is often not achievable and a balance needs to be found to maximize the overall benefit to the road users, landowners, roads authority and the environment.

- Land-use sensitivity and expropriation value
- Overburden ratio, i.e., the ratio of unuseable overburden that needs to be removed, compared to useable underlying material

In selecting a site for investigation, all of the above factors should be considered. The aim is to select a site that optimises the interaction between these variables. However, this is often not achievable and a balance needs to be found to maximize the overall benefit to the road users, landowners, roads authority and the environment.

The various steps in the process of prospecting for a new material source are shown in Table 3.

Table 3. Prospecting for Quarries and Borrow Pits

Step	Activity
Step 1	Obtain available relevant plans, geological maps, aerial photographs and reports
Step 2	Identify prospective sites for reconnaissance (desk study)
Step 3	Obtain relevant landowner information & permission from landowner(s) to access the site
Step 4	Carry out site reconnaissance
Step 5	Screen sites (technical feasibility and environmental sensitivity)
Step 6	Drilling targets and geophysical fieldwork
Step 7	Select site(s) for further field investigations

Key sources of information for identifying prospective sites are:

- **Topographical** maps
- **Geological** maps
- **Land-use** and vegetation maps
- **Aerial** photographs
- **Google earth** imagery
- **Historical, geological, geotechnical** and **materials** reports
- **Local knowledge**, i.e., communications with relevant parties

Many of these are discussed in Chapter 7: 3.

Utilising the above sources of information, sites can be identified based on favourable conditions for location, access, geology, land-use and topography, as shown in Table 4.

Prior to commencing with site reconnaissance, the prospective sites should be marked up on appropriate plans or maps, and permission to access the site obtained from the landowner.

The initial field reconnaissance for a site should include both a technical and environmental assessment. Important information to gather and record during the initial reconnaissance of a site includes:



Landowners Permission

Before commencing any fieldworks, permission should be sought, from relevant landowners, to access their land to carry out prospecting.

Table 4. Considerations for Identifying Sites

Aspect	Consideration
Location	- Locate sources so as to achieve minimum feasible haul distances. - Borrow pits for fill should be optimally located, as required by the preliminary long sections for the road and/or mass-haul diagrams (See Chapter 9: 3.2.5). - Borrow pits for layer works should be located at suitably spaced distances along the entire route.
Access	- Avoid sites that require the construction of significant lengths of access roads. - Avoid sites where steep access roads are required.
Geology	- Select sites where geological conditions are likely to provide materials of the required quality. - Select alignment for optimal material utilisation, to avoid faults and other major linear features. - Select materials where the overburden is minimised.
Land-use	- Avoid nature conservation areas. - Avoid sites in close proximity to human habitation. - Avoid sites of cultural significance, e.g., graves, fossils, archaeological artefacts. - Consider cost of compensation to secure land (expropriation). - Consider costs for relocation of services, e.g., electricity and telecoms. - Avoid sites in close proximity to water bodies, e.g., (rivers and wetlands)
Topography	- Select sites that can be mined and rehabilitated effectively. - Avoid sites that would create negative visual impact.

Table 5. Information to Gather during Initial Reconnaissance

Aspect	Details
General	- Site access conditions and potential traffic safety hazards. - Occurrence of services, e.g., power cables and telephone lines.
Technical	Geological conditions such as description of soil profile if exposed in cuttings or excavations, description of rock outcrops, i.e., rock type, weathering and discontinuity data. Evaluation of how a pit could be developed on the site. - Requirements for a materials investigation to evaluate the quality and quantity of materials occurring at the site.
Environmental	- Potential visual impact of quarry or borrow pit. Topography and soils: The lay of the land and erosion potential Land capability and land-use of site and surrounds and potential to reinstate status quo Heritage Assessment, including input from specialist archaeologists and palaeontologists Vegetation: - Quality of vegetation - Sensitive habitats - Ecosystems - Conservation areas Animal life: Types of animals and movements. Surface water: Location of drainage lines and waterways. Groundwater: - Ground water abstraction in vicinity - Potential for contamination Air quality: Ambient air quality and dust. Noise: - Ambient noise levels - Proximity to noise generating activities that could serve to "muffle" noise Archaeological and cultural interest: - Burial sites - Sites of interest - Sites of importance to locals Sensitive landscapes from a visual perspective, or a tourist route. Interested and affected parties: - Landowners - Land-users - Adjacent communities

The information gathered during the site reconnaissance should be used to determine the technical and environmental feasibility of the sites, i.e., a site screening exercise. If sites exhibit specific features that make them unacceptable from either a technical or environmental perspective, i.e., fatal flaws, the sites should be excluded from further consideration.

Information gathered during the initial site reconnaissance should be recorded. A typical summary sheet recording information gathered during a preliminary assessment is shown in Figure 3. In addition to the assessment record, a locality plan is required for each site, as well as supporting photographs to show important features of the sites.

It is recommended that a competent, suitably qualified environmental practitioner carry out the environmental screening exercise. It is crucial to exclude environmentally flawed sites at this early stage of the process, rather than risk the later rejection of a mining application, on environmental grounds. Feasible sites should be considered on their relative advantages and disadvantages, and favoured sites selected for further investigation.



Damage from Prospecting

Any damage to property to gain access to land for prospecting, such as cut fences, shall be properly reinstated to the satisfaction of the landowner.

Borrow pit number and farm name		BP/Q12.5 QUAGGASKIRK
Description	Property name	Quaggaskirk Sahara 5255
	General	The new quarry site is located on the south side of a dolerite dyke, east of the N11/3. It is also located fairly close to an abattoir.
Ownership	Owner	L C S Meintjies
	Contact Person	L C S Meintjies
	Tel/Cell numbers	083 284 7986
	Address	P O Box 1343, Dundee, 3000
Locality		The quarry site is located 840 m east of the N11 at km 7.8 in a dolerite dyke running south east.
Access		Access is east at km 12.5 through a farm gate for 750m then sharp north for 200m and then east for 180m to the proposed site.
Existing Condition		Virgin land covered with boulders.
Topsoil		Unknown depth of dark brown red soil.
Vegetation		Medium length dense grass coverage with several indigenous shrubs.
Constraints:		Abattoir to the north east 250m Overhead power lines 100m west Farm residence 680m south
Deleterious material		No deleterious material was observed
Assessment of suitability		The material is assessed to be possibly suitable for G1 and G4/G5 crushed material.
Available quantities and possible development of borrow pit.		More than 100 000 m ³ estimated.
Recommendation		Normal procedure followed for quarry investigation is proposed.

Figure 3. Typical Preliminary Site Assessment Sheet

2.2 Material Location

Material location should follow a logical process entailing:

- Developing a basic understanding of the **local geology** and geomorphology
- Developing an understanding of **gravel indicators**
- A desktop study of **maps and aerial photographs**

- A **reconnaissance** survey
- A detailed **field survey**
- **Reporting**

2.2.1 Local Geology and Geomorphology

The general geology of the area can be determined from geological maps. An understanding of the geology should embrace a number of characteristics:

- **Material type:** The mineralogical components of the rock dictate how the rock weathers, what the end-products are and how they will perform in the road. Only acid and basic crystalline, e.g., granite and basalt, respectively, materials are considered to decompose. The remaining material groups essentially disintegrate, depending on climatic influences. Decomposing rocks are likely to yield materials that are more plastic, while disintegrating materials give better gravels.
- **Topography:** The topography has a major influence on ground water profiles and gravitational movement of materials, which in turn affect the weathering process.
- **Depth of weathering:** The depth of weathering is highly variable and is a function of the material type and structure, the main erosion cycles that have affected the material, availability of water and topography. The depth of weathering varies from a few centimetres where only a thin layer of gravel is found at the surface to very deep soils where, for example, granites beneath the African erosion surface (often underlying a laterite/ferricrete layer) can be weathered to a depth of 20 metres or more. In general, the soil profile consists of an organic top soil (A horizon), overlying weathered in situ material (B horizon) grading into the C horizon of weathered rock which overlies the R horizon or in situ mostly unweathered rock.

Natural gravel materials suitable for road construction are typically obtained from the B (residual material without relict structure) and C horizon (residual material with original rock structure or saprolite) and thus various depths of material need to be sampled and tested. In general, the plasticity of the material decreases with depth towards the unweathered rock, whilst the material coarseness and gravel component increase.

2.2.2 Understanding and Selecting Gravel Indicators

Three types of gravel indicators are typically used for material location. These are the landform, botanical indicators (specialised plants) and animal indicators (traces left by animal activity)

2.2.2.1 Landform

Landform refers to the configuration of the ground surface in a distinctive shape. It is important in gravel location, as different types of gravel are associated with particular landforms. This association is due to:

- The **presence of material near the surface** giving rise directly to a particular type of landform. For example, a band of harder rock gives rise to a bump on a slope or a flat hill top, depending upon the rock's position and orientation.
- The **development of a particular type of gravel** in relation to a geomorphological feature. For example, a river terrace is typically made up of alluvial gravel.

(i) Landforms of Rock Regions

Rock regions have the typical range of gravel landforms illustrated in Table 6. This table is the key to the landform names given in Table 7.

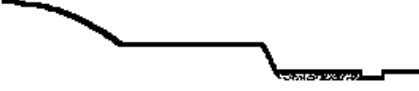


Materials Testing, Soil and Rock Profiling and Reporting

The following chapters in this manual provide additional information on materials testing, soil and rock profiling, and test data and reporting:

- Chapter 6, **Road Prism and Pavement Investigation**
- Chapter 7, **Geotechnical Investigations and Design Considerations**

Table 6. Landforms of Rock Regions Associated with Gravel Deposits

Landform	Description	Cross-sectional Diagram
Flat hill top	Flat, level hill top (plateau) with sharp edges at margins.	
Sloping hill top	Inclined, flat hill top with sharp edge between steep sharp slope and more gentle dip slope.	
Conical hill	Hill with pointed top, more or less circular in plan. Sides may be irregular or smooth.	
Mound	Rounded hill top with convex slopes, or convex 'bump' on a plateau or hill top.	
Ridge	Long, straight, narrow ridge running across country. Usually formed by an igneous intrusion (dyke or sill) or a quartz vein.	
Trench	Long, straight, narrow depression running across country. Like the Ridge landform, usually formed by an igneous intrusion. However, in this case, the surrounding rocks are more resistant to weathering than the intrusion. Sometimes the trench is formed by a pair of closely-spaced parallel ridges, formed by the surrounding rock being 'baked' hard by the heat of the intrusion.	
Footslope	Gentle slope at the foot of a steeper slope, formed (in this case) by the accumulation of pedogenic gravel, usually ferricrete, in the soil profile.	
Terrace	Raised platform situated at the edge of a valley, deposited by a river.	
Floodplain	Broad, flat valley floor with winding river. Sand and gravel accumulate on the inside of river bends.	

(ii) Landforms of Sand Regions

Landforms found in sand regions are given in Table 8, and the gravels associated with them are given in Table 9. If gravel particles are present in the soil, the processes of weathering and erosion tend to bring some of these to the surface. The accumulation of a layer of stones and gravel on the surface can give the false impression that the soil is composed of gravel, or that a gravel layer lies at depth. Before considering the area as a potential source of gravel, it is important to check that a gravel layer is actually present, by finding an exposed profile.



Finding Gravel Layers

The accumulation of a layer of stones and gravel on the surface can give the false impression that the soil is composed of gravel, or that a gravel layer lies at depth. Before considering the area as a potential source of gravel, it is important to check that a gravel layer is actually present, by finding an exposed profile.

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Chapter 8: Material Sources

Table 7. Types of Gravel Associated with Rock Regions

Gravel Type	Parent Material	Landform	Possible Engineering Problems
Residual Gravels			
Weathered rock	Lava	Flat hill top, sloping hill top	Lava of basic composition may contain weatherable minerals.
	Igneous dyke	Ridge or trench	Lavas of basic composition may contain weatherable minerals.
	Igneous sill	Ridge on side of hill	Lavas of basic composition may contain weatherable minerals. Sill may be difficult to exploit, owing to position on side of hill (overburden).
	Granite, gneiss	Mound, none	Gneiss may contain weatherable minerals.
	Quartzite	Ridge, sloping hill top, flat hill top, mound	Poor mechanical interlock of particles.
	Sandstone	Mound, flat hill top, none	Particles may be rather soft.
	Conglomerate, breccia	Flat hill top, sloping hill top, mound, none	Conglomerate particles are rounded. Properties of the coarse particles may be different from those of the matrix.
Vein quartz	Limestone, marble, dolomite	Flat hill top, sloping hill top, mound, none	
	Granite, gneisses of all types	Ridge	Poor mechanical interlock of particles.
Transported Gravels			
Quartz stone line		Footslope, none	Poor mechanical interlock of particles. May tend to contain too many fines.
Colluvium		Footslope	May contain too many fines.
Alluvium		Terrace, floodplain	Rounded particles, often sandy and lacking in fines.

Note: Some of these rock types are illustrated in Figure 18.

Table 8. Landforms of Sand Regions, Associated with Gravel Deposits

Landform		Diagram (cross-section)
Pan with 'platform'	Flat-floored pan with no or minimal vegetation. 'Platform' is a low bench situated on the edge of the pan but usually not extending all the way round. May be more than 500 m across, or less.	 Note: Platform is not usually as distinctive or obvious as shown here.
Pan without 'platform'	Flat-floored pan with no development of a low bench around the edge. May be more than 500 m across, or less. May be without vegetation, or contain grasses.	
Depression	Concave hollow in the sand surface, containing grasses. The grass communities are often arranged in concentric zones around the depression.	
Inter-dune hollow	Very long, straight concave channel in sand surface. One of many, forming parallel linear rises with hollows between. Calcretes are developed at intervals along the line of the hollow.	
Valley (old river channel)	A dry river valley, filled in with sand. Takes the form of a broad, gentle elongated depression that extends for many kilometres. In places, easily visible on the ground but in others, so wide and shallow as to be hardly detectable.	
Grey sand	No topographic relief, only grey sand contrasting with surrounding reddish or brown sands.	

Table 9. Gravel Types Associated with Sand Regions

Landform	Material	Characteristics and Comments
Pan with platform Around rim	Calcrete, possibly hardpan or nodular Silcrete	The best quality calcrete is found in the pan platform.
Pan without platform Around rim	Calcrete Silcrete	Good calcrete may occur, but is not usual. Quality is not predictable. Large pans may contain hard or boulder calcrete.
Depression	Calcrete can be nodular. Often no occurrence, or calcareous sand.	Usually poor quality calcrete. May occur on the side slopes.
Inter-dune hollow	Calcrete and silcrete hardpan or honeycomb or nodular.	Locally, good quality materials but generally none over most of the hollow's length
Valley (old river channel)	Calcrete, possibly hardpan or nodular.	Locally, good quality materials but generally none over most of the valley's length. Some valleys contain extensive calcified sands.
No landform - grey sand only, contrasting with surrounding red sand.	Calcareous sand. Possibly some calcrete.	Usually poor quality calcrete, but may be better if sand is non-plastic. Blackish sands usually yield better quality material.

2.2.2.2 Botanical Indicators

The presence of certain plant species and sometimes the nature of their growth can depend upon the mineralogical and physical properties of the soil in which they are growing. Botanical indicators can thus be a useful aid to materials location. However, plants are adaptable and the absence of an indicator species does not necessarily mean that the material is absent; whilst the presence of the indicator species does not always signify that the underlying material is suitable for engineering purposes.

The correct identification of plants is often difficult without botanical training. However, identification is generally not necessary. Instead, distinct changes in the species type, a dense thicket of a particular species or a change in the form (e.g., multi-stemmed instead of single stemmed, stunted, etc.) of the plants are easily observed and are useful ways of identifying a potential source. Plant indicators are particularly useful for locating pedocretes, i.e., ferricrete and calcrete, and dykes and intrusions that are not easily visible on the surface.

2.2.2.3 Animal Indicators

The activity of certain animals results in gravel particles, soil or stones being brought to the surface. Examples are termites, porcupines, suricates and squirrels. Examination of the material in termite mounds and anthills, and material excavated from burrows should be carried out.

2.3 Materials Investigations

This section gives guidance to the various steps taken to conduct a materials investigation, i.e., an investigation to prove the quality and quantity of material occurring in a prospective material source. The steps for a new material source are shown in Table 10.

Table 10. Materials Investigations for Quarries and Borrow Pits

Step	Activity
Step 1	Plan the investigation
Step 2	Carry out the exploratory works
Step 3	Evaluate the material source (quality of materials and estimated reserves)
Step 4	Report investigation

Planning and supervising materials investigations are skilled activities that should be carried out by a professionally registered engineering geologist, geophysicist or materials engineer, with the appropriate experience.

The **technical objectives** of a materials investigation are to:

- Evaluate **geological conditions**
 - Soil or rock profile to the required depth
 - Variations in the profile over the lateral extent of the source area
 - Soil or rock mass characteristics

- Prove the **quality of material** available.
- Estimate the **quantity** of compliant material available.

Materials investigations should be planned with regard to:

- Achieving the required **technical objectives**.
- Meeting **specific requirements** that may be set by individual roads authorities, or other organisations.
- Obtaining the **necessary permits** and permissions to carry out the investigation.

The planning of a materials investigation should cover:

- Investigation **methods** to be employed
- **Scope** of the investigation
- Material **sampling** requirements
- **Testing** requirements
- **Permits** and permissions

Various investigation methods are available to perform materials investigations, which include test pitting and rotary core drilling and, possibly, geophysics.

- **Test pitting** (illustrated in Figure 4)
 - Typically used for investigation of borrow areas.
 - Depth of investigation limited.
 - Entering test pits is a potentially hazardous activity and must only be carried out under the supervision of a competent person and in strict compliance with Operational Health and Safety (OHS) requirements. For guidance on OHS issues, refer to SAICE (2003).
 - Useful guidelines for sampling procedures can be found in TMH5 (Sampling Methods MA2 and MA3) and in the Western Cape Provincial Government, Department of Transport Materials Manual, Chapter 5 “Materials Investigations and Reporting” available at http://rnis.pgwc.gov.za/rnis/rnis_web_reports.main.
 - Harder materials are difficult to excavate in test pits.
- **Rotary core drilling** (illustrated in Figure 5)
 - Typically used for the investigation of hard rock quarries.
 - No depth limitation.
 - Usually higher cost than test pitting.
- **Other investigation methods**
 - Other investigation methods that are readily available can provide important data, depending on the specific requirements of the investigation. These include: large and small diameter auger holes; geophysical surveys such as seismic refraction; ground penetrating radar; and, resistivity and trial blasts. Auger and geophysical methods are typically used in determining overburden thicknesses.



Methods for Materials Investigations

Various methods for materials investigations are covered in:

- Chapter 6, **Road Prism and Pavement Investigations**
- Chapter 7, **Geotechnical Investigations and Design Considerations**



Entering Test Pits

Entering test pits is a potentially hazardous activity and must only be carried out under the supervision of a competent person and in strict compliance with OHS requirements. (SAICE, 2003)



Figure 4. Test Pit



Core Drilling Rig



Recovered Core

Figure 5. Core Drilling

The scope of the materials investigation should be adequate to prove the quality and quantity of material available. In scoping an investigation, the aspects given in Table 11 should be addressed:

Table 11. Scoping a Materials Investigation

Aspect	Details
Technical	- Investigation methods to be employed Technical specifications for the investigation methods to be employed: - Depth of boreholes - Drilling methods Location of investigation points Sampling requirements, such as the sampling methods and the sampling frequencies to be adopted Testing requirements - Test methods to be employed - Testing regimes - Testing frequencies
Environmental	- Details of any environmental constraints influencing the investigation, e.g., no-go areas - Details of permits or permissions required

Specific information on subsurface conditions, required from a materials investigation for a **hard rock quarry** includes:

- **Soil and rock profile** across the site to the depth of investigation
- **Extent** of source
- **Depth** to sound rock
- Degree and depth of rock **weathering**
- **Boundaries** of rock types
- Rock **strength** and hardness characteristics
- Rock **durability** characteristics
- Location of **fault or fracture zones**
- Orientation, attitude (how strata are lying), spacing and infill of **joints and bedding planes**
- Position of **water table**

Care should be taken to drill sufficient boreholes to determine the information. Angle-boreholes should be used to obtain data on sub-vertical jointing and other geological features.

Specific information on subsurface conditions required from a materials investigation for a **borrow pit** include:

- **Soil and rock profile** across the site to the depth of investigation
- **Boundaries** between soil types (variations vertically and horizontally)
- **Overburden** description and depth
- Occurrence of **hard or oversize materials** or contaminants
- Material **excavation** characteristics
- Depth of **water table**

Sufficient test pitting should be carried out to determine the required information to an acceptable accuracy. Sampling and testing of materials should be carried out with sampling plans, indicating the appropriate sampling methods, sampling frequencies and testing requirements. The sampling plans discussed in the next two sections are recommended.

2.3.1 Borrow Pits for Fill or Gravel Wearing Course

Trial pits should be evenly spaced over the borrow area with a maximum distance of 100 metres between any two pits. In cases where the material is very uniform, the spacing may be increased, depending on client requirements.

Samples are required from each trial pit for an indicator test on each layer of material 300 mm or thicker, excluding overburden, which should be saved and used for eventual rehabilitation purposes. Layers of less than 300 mm thickness that appear suitable may be sampled and tested together with one of the adjacent layers.

A CBR test should be carried out on material from each trial pit in a potential borrow pit, including overburden. The minimum number of CBR tests recommended for borrow pits intended to provide fill material is given in Table 12.

Table 12. Number of CBR tests from Borrow Pits for Fill or Gravel Wearing Course

Size of Borrow Pit	Number of CBR Tests
Smaller than 40 000 m ³	4
40 000 m ³ to 80 000 m ³	5
Larger than 80 000 m ³	6

2.3.2 Borrow Pits for Pavement Layers

Trial pits should be uniformly spaced over the borrow area; with a maximum spacing of 100 metres between any two pits for large borrow areas, and 30 metres for small areas. In cases where the material is very uniform, the spacing may be increased, depending on client requirements. Excavation of a trial pit in a borrow pit is shown in Figure 6.



Figure 6. Trial Pit in Borrow Pit

Samples for indicator tests should be taken as described for fill materials. However, should any layers of material, in any of the trial pits appear unsuitable, only a few representative samples need to be obtained.

Sufficient CBR tests should be carried out to obtain representative test results of the range of materials encountered in the borrow pit. The recommended minimum number of CBR tests required for borrow pits for pavement layers is given in Table 13. For stabilized subbases, additional material must be sampled for UCS, ITS and wet-dry durability tests.

Table 13. Number of CBR tests from Borrow Pits for Pavement Layers

Size of Borrow Pit	Number of CBR Tests
Smaller than 20 000 m ³	5
20 000 m ³ to 40 000 m ³	6
40 000 m ³ to 80 000 m ³	8
Larger than 80 000 m ³	10

The following stabilization tests are recommended for borrow pits supplying subbases and gravel bases. Where a selected subgrade is to be stabilized, the same requirements apply.

- Firstly, at least one sample per borrow pit, or 2 in the case of borrow pits larger than 40 000 m³, should be tested with various stabilizing agents to determine **which stabilizer reacts best with the material**. On this sample, the wet-dry durability test should also be done. Should unsatisfactory results be obtained with the amount of stabilizing agent used, a higher percentage of the most suitable agent should also be tested. The purpose of this testing is



Trial Pit Spacing

Trial pits should be evenly spaced, a maximum of 100 metres apart. If the borrow area is small and will be used for pavement layers, the spacing should be reduced to 30 metres.

to establish the most suitable type, and quantity, of stabilizing agent.

- Secondly, once the most suitable **type and percentage of stabilizing agent** has been established, the remaining samples should be tested with the particular type and percentage of stabilizing agent for UCS, ITS and wet-dry durability. (see Chapter 3: 5.3)

2.3.3 Quarries for Aggregates

Hard rock sources for the production of crushed aggregates should be investigated by drilling boreholes. The depth and spacing of boreholes will be dependent on the nature of the rock source being investigated. However, it is recommended that boreholes should be spaced no greater than 30 metres apart and be drilled to depths at least 5 metres below the proposed bottom of the quarry.

Before the investigation of a potential quarry site can proceed, it is essential to:

- **Scope** the drilling investigation
- Prepare a drilling **specification** and other necessary contractual documentation
- Establish the drilling **programme**
- Determine the **budget** to carry out the investigation
- Identify potential **service providers**
- Discuss aspects of the investigation with the **client** and obtain **approval** to proceed

During the execution of the exploratory works the following data should be collected:

- **Location** where test pits and/or boreholes were sited (coordinates from a hand held GPS suffice)
- Representative **photographs** of the source area
- **Test pit profiles** and/or borehole logs
- Representative **photographs** of test pits and/or cores
- **Sample details**, i.e., location, depth, soil layer or rock type, sample type, sample description
- Position of **water table** in test pits and/or boreholes

The necessary tests for evaluating the potential sources of crushed aggregate are carried out on core samples. These testing requirements are listed in Table 14. The tests listed are described in Chapter 3: 3.2.



Borehole Spacing

Boreholes should be spaced no greater than 30 metres apart and be drilled to depths at least 5 metres below the proposed bottom of the quarry.



Material Tests

Indicator (grading and Atterberg limit tests), CBR tests, and many other materials tests, are described in Chapter 3, **Materials Testing: Section 2.**

Table 14. Testing Required to Prove Quality of Road Construction Materials

Material Type	Testing Required
Natural soil or gravel G4 to G10	- Grading - Atterberg limits - Compaction characteristics (MDD) - CBR - Durability tests on rocks that may have potential to rapidly deteriorate with exposure to the elements, e.g., mudstones
Natural gravel for the production of gravel wearing course	- Grading - Atterberg limits - Compaction characteristics (MDD) - CBR - Venter durability
Graded, crushed stone base G1 to G4	- Petrographic analyses for all basic igneous and metamorphic rocks - Grading - Atterberg limits - Water absorption (%) for various fractions and degree of saturation - Bulk and apparent relative density - Wet and dry ACV & 10% FACT 10% FACT Ethyl Glycol (especially on dolerite and basalt) - Chemical testing as per the Standard Specifications - Durability tests, e.g., modified ethylene glycol test, on basic crystalline rocks that may have potential to rapidly deteriorate with exposure to the elements
Stabilized layers C1 to C4	- Grading - Atterberg limits - Compaction characteristics (MDD) - Initial consumption of stabilizer (ICS) - UCS and ITS - Wet and dry durability
Surfacing stone and asphalt aggregate	- Grading - Fines and dust content - Average least dimension (ALD) - Appropriate tests for bitumen adhesion properties - ACV & 10% FACT - Flakiness index (FI) - Polished Stone value (PSV)
Concrete aggregate (coarse and fine)	- Grading - Water absorption - Fineness modulus - Flakiness index - Organic impurities - Relative and bulk densities - ACV & 10% FACT - Alkali reactivity

2.3.4 Personnel Requirements for Materials Investigations

It is crucial that experienced personnel adequately supervise materials investigations. Without adequate supervision, substandard information will almost certainly be the result. Competent professionals should be responsible for profiling and core logging as described in Table 15.

Table 15. Profiling and Logging Responsibility

Activity	Responsible Person	Methodology
Profiling of test pits	Engineering geologist or materials engineer	Profiling should be carried out in accordance with the "Revised Guide to Soil Profiling for Civil Engineering Purposes in Southern Africa" (Jennings et al, 1973), or other appropriate standard (Brink and Bruin, 1990).
Logging of boreholes	Engineering geologist	Profiling should be carried out in accordance with "A Guide to Core Logging for Rock Engineering" (AEG, 1976), or other appropriate standard (Brink and Bruin).

Site investigations are potentially hazardous activities. Exploratory works should be carried out in accordance with the requirements of the:

- Occupational Health and Safety Act No. 85 of 1993
- Construction Regulations, 2001
- Client's specific OHS requirements

2.3.5 Reporting of Materials Investigations

Evaluation of the information gathered during the materials investigation should be collated, reviewed and analysed to fully assess the potential of the source. The evaluation process includes:

- **Assessment of material quality**
 - Evaluate if materials meet the required specifications. Compare test results with relevant specified acceptance limits.
 - Assess material quality variation.
- **Estimation of material reserves**
 - Calculate material reserves.
 - Calculate overburden quantity.
 - Consider how the source could be extended to optimally provide additional materials.

The various road authorities have standard formats for the compilation of materials reports. Where relevant, such standard report formats should be adhered to. In general, reporting of materials investigations should at least include the following information:

- **Material source data**
 - Proposed material usage
 - Haul distances to point of construction
- **Site description**
 - Location
 - Access
 - Topography
 - Geomorphology
 - Vegetation
 - Limitations or restrictions
 - Land-use
 - Presence of services
- **Description of the geological and geotechnical conditions**
 - Soil and rock profile
 - Description of soil and/or rock types
 - Soil and/or rock characteristics and properties
 - Excavation characteristics of soil and/or rock
 - Geohydrological information
- **Material quality and quantity**
 - Evaluation of material quality in relation to relevant material specifications
 - Estimation of material reserves
 - Particular technical concerns relating to the material source
- **Supporting information**
 - A locality plan showing the location of the site, as shown in Figure 7
 - Site plans showing the location of test pits and/or boreholes. The plan should provide GPS coordinates of the test pits and/or boreholes as well as all other pertinent information such as the presence of services, extent of borrow or quarry area, kilometre reference to nearest road access, north arrow, and geological features. An example is given in Figure 9.
 - Test pit profiles and/or borehole logs
 - Photographs of test pits, cores and typical materials (Figure 8)
 - Test results



Site Investigations

Site investigations are potentially hazardous activities. All appropriate OHS requirements must be followed.

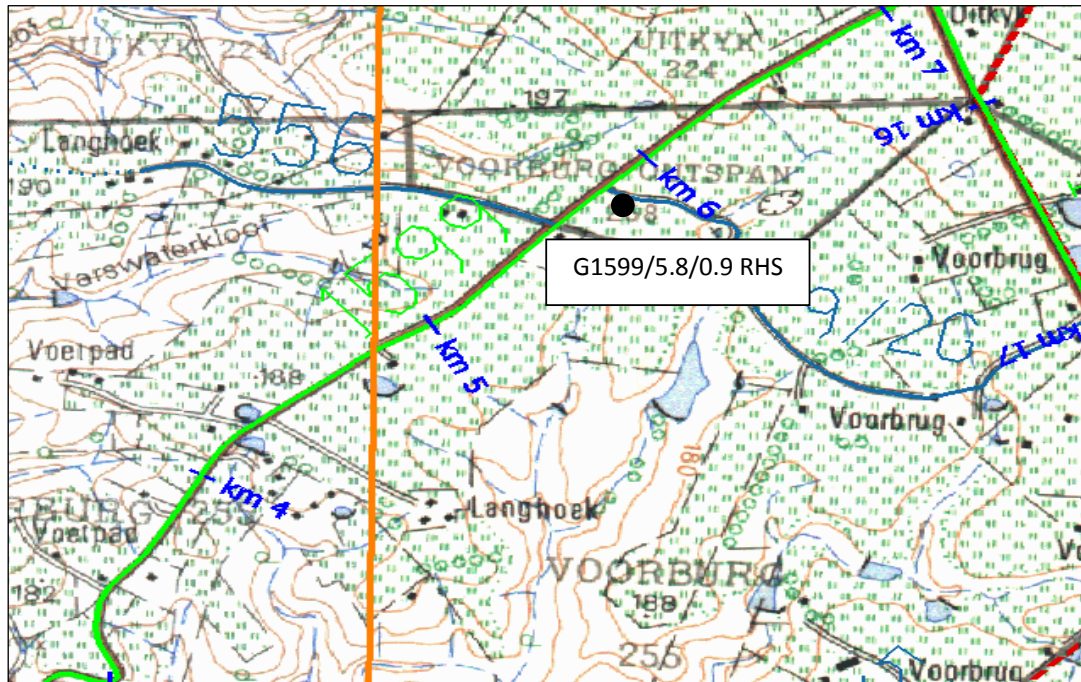


Figure 7. Locality Plan



Figure 8. Typical Materials

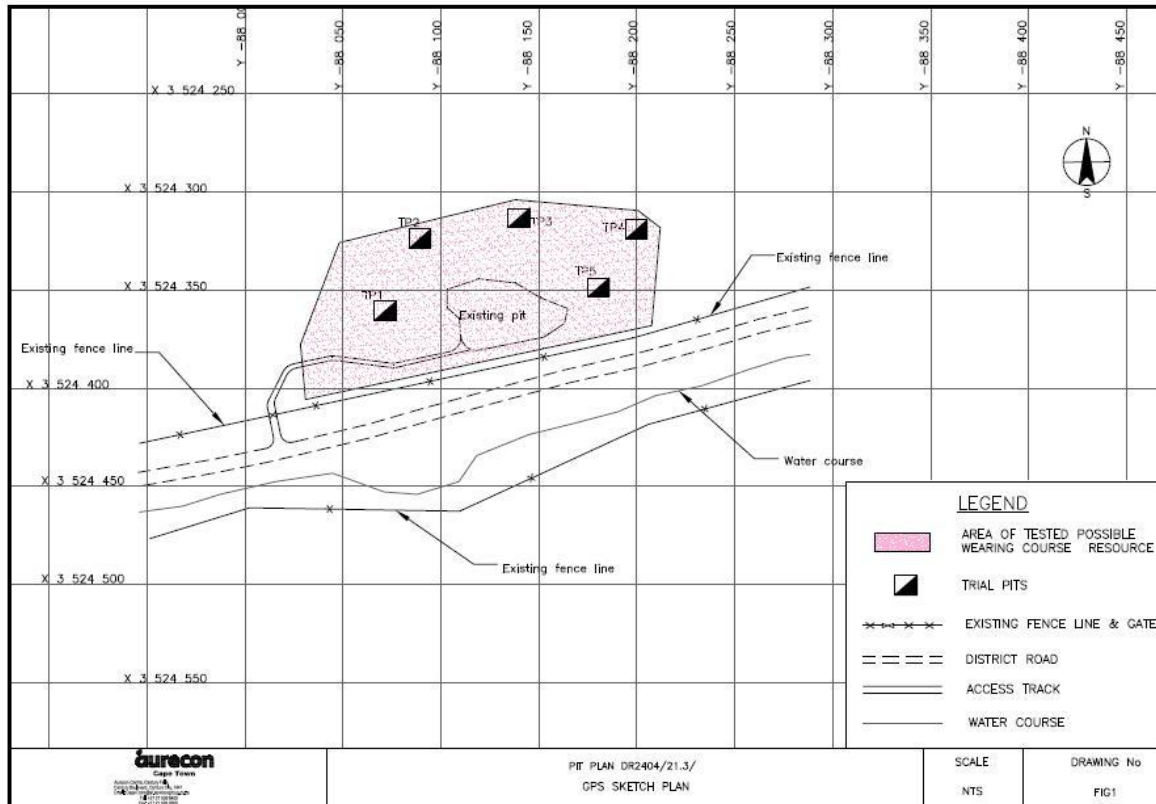


Figure 9. Site Plan Showing Locations of Test Pits

2.3.6 Good Environmental Practice for Prospecting/Reconnaissance

Before conducting reconnaissance or prospecting for possible borrow pits or quarries, it is important to take the following into account:

- **Contact the landowner** and obtain approval, before entry onto the land
- **Existing access roads** should be used, if possible, and only after consultation with landowner
- Any **fences** that are removed, or damaged, need to be replaced
- No **gates** should be left open during, or after, the visit to the farm
- No **fire wood** should be collected
- No **wild animals** should be disturbed
- No **littering or pollution**, e.g., oil spills
- Reinstatement of, or compensation for **damaged areas and crops**
- No **lighting of fires** for any reason whatsoever
- No unapproved **camping** or staying overnight
- No **water withdrawal from rivers**, without required approvals

2.4 Mining Plan

Developing an appropriate and adequate Mining Plan is a fundamental part of the planning operation. A mine plan should cover the commissioning, operation, decommissioning and closure of a material source. A sound mining plan is essential to achieve optimal and sustainable resource development and utilisation. Sustainable mining requires an approach that balances the curbing of environmental degradation with the optimising of materials extraction and the minimisation of cost.



Mining Plan

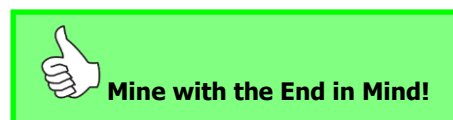
This is a detailed plan of the methods to be employed to mine a gravel source or hard rock quarry over the intended life span.

This section outlines how to effectively develop and implement a mining plan. The various steps in the development of a mine plan are shown in Table 16.

Table 16. Developing a Mine Plan

Step	Task
1	Set the mining and closure objectives
2	Carry out a risk assessment
3	Design pit or quarry
4	Develop the mine plan
5	Document the design

2.4.1 Set the Mining and Closure Objectives



The mining and closure objectives provide the framework for the basic approach to the establishment, operation and closure of a particular site. Overall mining objectives include:

- **Optimising yield** and economic viability
- Enhancing **technical efficiency** of extraction
- Optimising **operational efficiency**
- Minimizing adverse **environmental impacts**
- Promoting **health and safety**
- Maintaining **legal and technical compliance** at the highest level
- Mitigating **risks** to all stakeholders, including landowners
- Meeting **budget**
- Meeting affected parties and local and provincial authorities **constraints**
- Honouring **conditions** of agreement with landowners
- Assuring that land is **restored** to beneficial use thereafter, if practical

The aim of closure should be to reclaim the site methodically and progressively. Rehabilitation practices should ensure the physical stabilization of the soils to achieve a sustainable land-use so the land may be returned to a productive state as soon as practically possible after mining activities have ceased. Rehabilitation must be recognized as an integral part of the extraction process, and must therefore be included in mine planning.

2.4.2 Risk Assessment

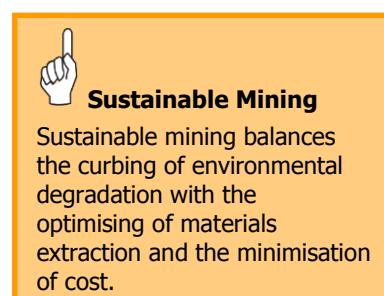
The critical step in formulating a Mining Plan is to undertake a risk assessment. The key question is “*What are the risks associated with exploiting a particular material source and how can these risks be mitigated?*” Risk can be managed in the following ways:

- **Avoiding risk** by not doing particular things or not working in particular areas.
- **Minimizing risk** by doing things in a particular way, e.g., minimizing the area of active extraction, progressive rehabilitation, regular inspection and contingency planning.
- **Controlling risk** through the utilization of specific control measures, e.g., sediment traps.
- **Transferring risk**, e.g., by obtaining the requisite permits (commissioning and closure), reallocating the risk to the landowner or establishing dual-operator agreements.

The measures to be implemented to manage the risks associated with exploiting a particular source must be incorporated into the Mining Plan.

2.4.3 Pit Design

The characteristics of borrow pits and quarries developed for the sourcing of road construction materials vary extensively with respect to the extent of the material reserves, natural environment, topography, geology and intended life span. Some pits may be of limited extent and mined in a single operation for a particular project. Others may be larger and mined in multiple phases to provide materials over extended time duration. Accordingly, the design solutions applied to develop successful mining operations also vary extensively



and depend on the particular conditions encountered at each pit location, as well as the intended use of the pit. The level of design required is dependent on the size and nature of the pit, as well as its intended use. The design of open pit mines is a specialised field and it is recommended that for larger pits, mined in multiple phases to provide materials over extended time durations, specialist professional input from a mining engineer be sought. Drill and blast design for pits is also a specialised field, and should be carried out by a specialist blasting engineer. An example of a typical quarry is shown in Figure 10.



Figure 10. Typical Quarry

2.4.4 Develop Mine Plan

Basic information needed to develop a mine plan includes:

- **Topography** of the area to be mined from a topographic survey
- **Environmental conditions** surrounding the pit
- **Extent** (hectares) and **depth** (metres) of the proposed pit from the geotechnical or materials report
- Extent of the **overburden** (waste material)
- Approximate quantity of material to be **excavated** (m^3)
- Characteristics of the **materials** to be mined from the geotechnical or materials report
- **Excavatability** of material, i.e., if it requires blasting or if it can be mechanically excavated
- Information regarding any **additional processing** that may be required for the material to meet the specifications
- **Stockpiling** requirements
- **Mining equipment** requirements
- **Time-frames** for mining
- **Legal** requirements, particularly as they relate to the Mine Health and Safety Act and the obligations attached to the EMPro
- Relevant **closure** objectives
- **Risk** assessment
- Special requirements of **interested and affected parties**

2.4.5 Document the Design

The pit or quarry design forms the technical guideline for the future operation and therefore needs to be documented clearly and with sufficient detail to allow the design to be put into practice. The pit design needs to be developed in a drawing, or series of drawings (plans and cross-sections) that indicate how the pit is to be mined and rehabilitated.

The drawings are used by the technical staff responsible for mining and should provide a clear picture of what they are required to achieve. The design should also include a schedule of tonnes (or cubic metres) of material reserves to be mined during each mining stage, such as topsoil, borrow material and waste material.

The mine plan should indicate:

- **Areas to be mined**, clearly indicating no-go areas
- **Cut slope** angles
- Different **phases of operation**
- **Security** requirements, e.g., location of fencing and gates
- **Access roads** to and from the pit
- **Stockpile locations** for topsoil, temporary or waste stockpiles
- **Drainage** structures around the pit
- **Temporary areas** for the contractor's camp or workshop areas and explosive storage magazines, if necessary
- Planned finish for **slope face, i.e., stepped, vertical or sloping**
- **Fencing** of the borrow pit or quarry after completion
- **Ablution** facilities

In addition the mine plan should provide guidance on:

- Emergency procedure
- Securing the site
- Traffic management
- Topsoil management
- Hydrocarbon (petrol, diesel, engine oils) management
- Waste management
- Stormwater management and erosion
- Fire management
- Dust and noise control
- Protection of flora and fauna
- Protection of archaeological and palaeontological remains
- Protection of natural features
- Material processing requirements
- Rehabilitation of the pit

The documented mine plan should form a key component of the EMP or EMProg submission to DMR.

2.5 Authorisation Process

All prospecting, material investigations and mining must be conducted within the legal requirements of the various Acts, Ordinances, Regulations and Bylaws. The purpose of this section is to provide an overview of the legal requirements and focuses on the specific requirement of the mining legislation, the Mineral and Petroleum Resources Development Act (No 28 of 2002). The understanding detailed in this section is based on current (2008) legislation, but the law, and its interpretation, are subject to constant change.

The extraction of materials for use in road works constitutes a mining activity, and any proposed material sources (borrow pits or quarries) require approval from the relevant Department of Minerals Resources (DMR), in terms of the requirements outlined in the Mineral and Petroleum Resources



Authorisation for Borrow Pits and Quarries

DMR has indicated that permission only needs to be sought for mining and not for the reconnaissance and prospecting phases for borrow pits or quarries for road construction or maintenance purposes.

Development Act. For borrow pits and quarries for road construction or maintenance purposes, DMR has indicated that permission only needs to be sought for mining and not for the reconnaissance and prospecting phases.

The Act distinguishes between mining permits and mining rights as follows:

- **Mining Permit:** Required where the activity will last less than two years and affects an area of less than 1.5 hectares in extent. The permit is valid for 3 years. In terms of the Act, a mining permit requires the submission of an Environmental Management Plan (EMP) to DMR for approval prior to the onset of activities.
- **Mining Right:** Required for larger mining operations. It is renewable and valid for 30 years. In terms of the Act, a mining right requires the submission of an Environmental Management Programme (EMProg) to DMR for approval prior to the onset of activities.

In light of their limited spatio-temporal extent, borrow pit and quarry operations would typically require a mining permit.

In June 2004, the Minister of Minerals and Energy exempted various organs of state, including SANRAL and Provincial Governments, from the provisions of Sections 16, 20, 22 and 27 of the Mineral and Petroleum Resources Development Act. In terms of this exemption, where an organ of state is undertaking the construction or maintenance of roads under its control, no application would need to be submitted for a mining right or permit. However, according to the provisions of Section 106(2) of the Act, prior to the extraction of any material from a proposed borrow pit or quarry, it would still be required to prepare and submit an EMP or EMProg to DMR for their approval.

2.5.1 Application Process

There is currently, an everchanging and broad range of legislation, which has bearing on the selection, investigation, and removal of materials. The most pertinent requirements have been highlighted, but relevant legislation, listed below, is not comprehensive. This guideline should be used by professionals for projects of different scales, types and within particular environments. These factors influence the applicability of the laws detailed below and hence requirements differ among projects. It is for this reason that the section does not attempt to guide the reader through a simplified checklist with respect to the legal requirements.

It is the responsibility of the proponent to ensure that all requirements are fulfilled, and it is therefore advisable that the requirements are confirmed with the relevant authorities prior to undertaking an investigation or activity.

The following legislation needs consideration and is described in this section:

- **Mineral and Petroleum Resources Development Act (MPRDA)** (No. 28 of 2002) as amended
- **National Water Act** (No. 36 of 1998) as amended
- **Water Services Act** (No. 108 of 1997) as amended
- **National Environmental Management Act** (No. 107 of 1998) as amended
- **Conservation of Agricultural Resources Act** (No. 43 of 1983) as amended
- **National Heritage Resources Act** (No. 25 of 1999)
- National Environmental Management: **Air Quality Act** (No. 39 of 2004) as amended which replaces the Atmospheric Pollution Prevention Act (No. 45 of 1965)
- **Mine Health and Safety Act** (No. 29 of 1996) as amended
- **Explosives Act** (No. 15 of 2003)
- **Road Ordinance** (No. 19 of 1976) as amended
- **Land Use Planning Ordinance** (No. 15 of 1985) as amended

Many of the laws listed have an environmental focus. Environmental processes do not have to be costly but they have a long time line and ***it is strongly recommended that this be allowed for in the project programme. Late consideration of environmental aspects is likely to cause costly delays to projects. Furthermore, non-compliance with legislation can lead to considerable delays, costs, penalties and criminal proceedings***



Adherence to Environmental Processes

Many of the laws listed have an environmental focus. Environmental processes do not have to be costly but they have a long time line and ***it is strongly recommended that this be allowed for in the project programme. Late consideration of environmental aspects is likely to cause costly delays to projects. Furthermore, non-compliance with legislation can lead to considerable delays, costs, penalties and criminal proceedings***

The MPRDA application process, as applied to exempted organs of state, is illustrated in Figure 11. The Act attaches specific timeframes to various stages of the application process, and an attempt has been made to indicate these timeframes where relevant, but can take from 12 to 18 months.

The following critical issues must be taken into consideration:

- **Authorisation** is an essential requirement and without it, mining activities are illegal.
- The **timeframe** to complete the authorisation process is extensive, requiring a minimum period of six months but could be far longer.

The preparing of mining applications and EMPs or EMProgs are specialised activities.

Approvals are required from the Department of Environmental Affairs (DEA), or, in some Provinces Department of Environmental Affairs and Development Planning (DEA&DP), with respect to National Environmental Management Act (NEMA). This in turn requires approvals in terms of the National Water Act, Conservation of Agricultural Resources



National Environmental Management Act, No. 107 of 1988 **[Assented to 19 November 1998, Date of Commencement to be Proclaimed]**

ACT

To provide for cooperative environmental governance by establishing principles for decision making on matters affecting the environment, institutions that will promote cooperative governance and procedures for coordinating environmental functions exercised by organs of state; and to provide for matters connected therewith.

PREAMBLE

- WHEREAS many inhabitants of South Africa live in an environment that is harmful to their health and wellbeing;
- Everyone has the right to an environment that is not harmful to his or her health or wellbeing;
- The State must respect, protect, promote and fulfil the social, economic and environmental rights of everyone and strive to meet the basic needs of previously disadvantaged communities;
- Inequality in the distribution of wealth and resources, and the resultant poverty, are among the important causes as well as the results of environmentally harmful practices;
- Sustainable development requires the integration of social, economic and environmental factors in the planning, implementation and evaluation of decisions to ensure that development serves present and future generations;
- Everyone has the right to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that prevent pollution and ecological degradation;
- Promote conservation; and
- Secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development;
- The environment is a functional area of concurrent national and provincial legislative competence, and all spheres of government and all organs of state must cooperate with, consult and support one another;
- AND WHEREAS it is desirable:
 - That the law develops a framework for integrating good environmental management into all development activities;
 - That the law should promote certainty with regard to decision making by organs of state on matters affecting the environment;
 - That the law should establish principles guiding the exercise of functions affecting the environment;
 - That the law should ensure that organs of state maintain the principles guiding the exercise of functions affecting the environment;
 - That the law should establish procedures and institutions to facilitate and promote cooperative government and intergovernmental relations;
 - That the law should establish procedures and institutions to facilitate and promote public participation in environmental governance;
 - That the law should be enforced by the State and that the law should facilitate the enforcement of environmental laws by civil society.

Act, National Heritage Resources Act, et al, and may require specialist reports from botanists, archaeologists and palaeontologists. To get NEMA approval, either a full Basic Assessment (approximately six months) or a "check list" to get verification that a full Basic Assessment (BAR) is not required (approximately two months), must be submitted for approval.



Authorisation

The authorisation process must be carried out by a suitably qualified and experienced environmental assessment practitioner (EAP). It is recommended that the authorisation process commence at least one year ahead of the planned requirement.

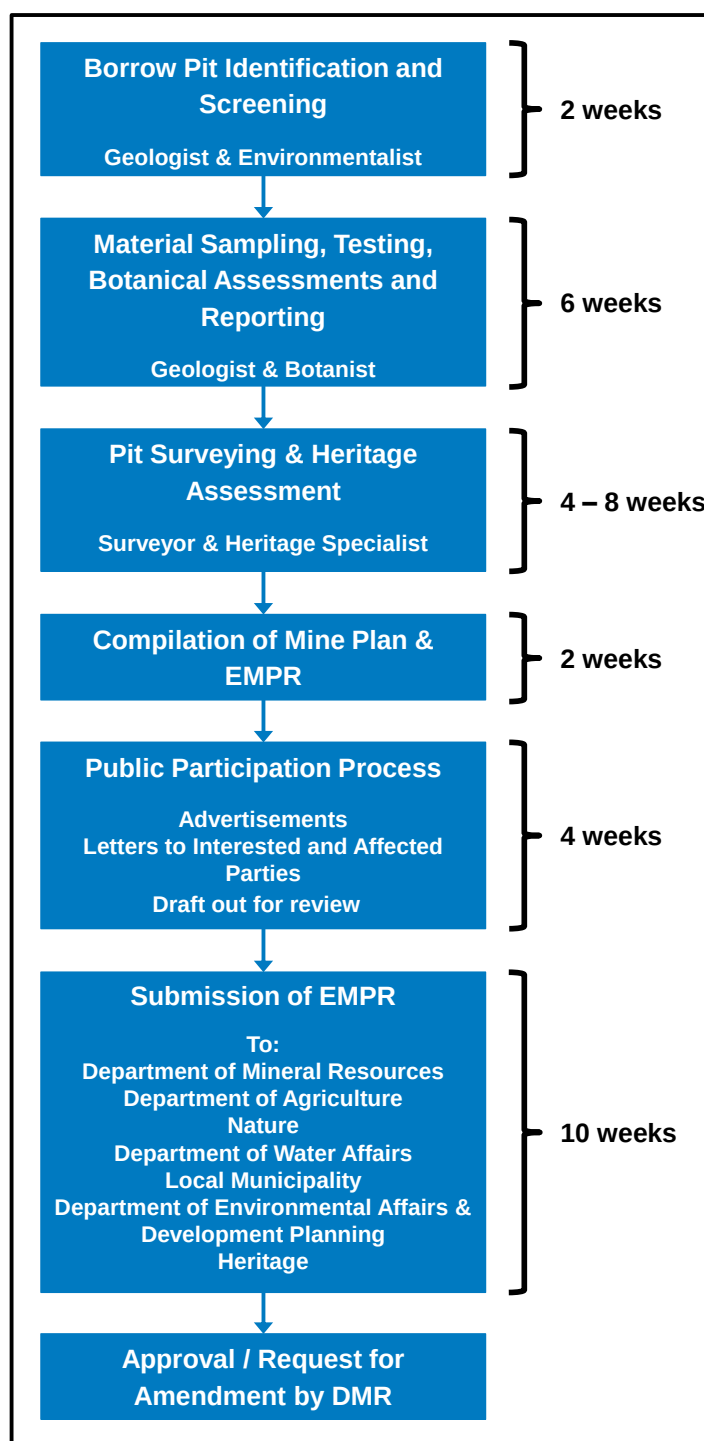


Figure 11. Authorisation Process for Mineral and Petroleum Resources Act

2.5.2 Closure

It is important to recognise that the mining right or permit holder's liability continues until such time as a Closure Certificate has been issued by DMR.

Pursuant to the successful implementation of the rehabilitation plan contained in the EMProg, an Application for Closure needs to be prepared and submitted within 180 days of cessation of the mining operation. The Application for Closure includes:

- Closure Plan
- Environmental Risk Report
- Financial Performance Assessment Report

The need to ensure continuity and integration between the EMProg, Mining Plan, mining operations and Closure Application is obvious as the EMProg specifies the closure objectives and approach to environmental management and is a critical informant of the Application for Closure.

DMR may not issue a Closure Certificate unless it has been confirmed that the provisions pertaining to health, safety and management of potential pollution to water resources have been addressed.

2.6 Land Acquisition

After the quality and quantity of material occurring in a prospective material source has been satisfactorily proved, the planning stage to develop a borrow pit or quarry can proceed. This planning stage covers land acquisition, authorisation and planning of mining. These aspects of the planning process are discussed in this and the following two sections, namely, Authorisation Process (Section 2.5) and Planning of Mining (Section 2.4).

The purpose of this section is to give guidance on the various steps required to secure the rights to operate a borrow pit or quarry on private or state land. Ownership and access are key planning considerations. As early as possible, it is important to establish:

- **Legal requirements** for utilising a particular source.
- **Restrictions or prohibitions** that may be in place on an affected property.
- Landowner's **attitude** towards the possible acquisition.
- Preferred options to **secure the right to occupy land** include:
 - Expropriation
 - Landowner agreements and leases

Whether land rights should be obtained through expropriation, agreement or lease must be carefully considered. The optimum approach to achieve the project objectives, as well as meeting client and landowner needs, must be chosen. Certain of the provincial road authorities favour the expropriation route. SANRAL, however, prefers land owner agreements of fixed duration. The basic elements of the land acquisition process are shown in Table 17.

Table 17. Land Acquisition Process

Step	Process
1	Consideration of ownership
2	Consideration of access
3	Consultation with landowner
4	Expropriation or agreement and Leases
5	Planning and/or rezoning

2.6.1 Consideration of Ownership

It is important to obtain up to date and accurate information regarding the landownership status of land earmarked for mining. Details required for different land ownership scenarios are given in Table 18.

Table 18. Landownership Scenarios

Land Type	Information to be Recorded
Farm land outside of the “urban edge”	• Farm name • Erf number/farm number and portion number • Extent • Owner • Contact person
Land within the “urban edge”	• Erf number and portion number • Extent • Owner • Contact person
State land	• Erf number and portion number • Extent • Department with which ownership rests or has been ceded • Contact details

2.6.2 Consideration of Access

Access is a key consideration when planning mining. Access issues include:

- Obtaining **permission to access** the property to undertake prospecting and mining.
- Identifying registered **access servitudes** that may limit the access to or use the site.
- Clarifying the **access rights of others** over the land.

2.6.3 Consultation with Landowner

Once a site has been identified and ownership confirmed, the landowners should be consulted to discuss the proposed use of the site. Consultation with landowners includes:

- Proposed use of the site
- Access to the site
- Security issues
- Water rights
- Post mining rehabilitation and closure
- Compensation
- Landowner’s materials requirements
- Expropriation and landowner agreement
- Any concerns the landowner may have



Compiling the Site Investigation Design Report

Landowner inputs are a key consideration in the compilation of the Environmental Management Programme.

Many of these aspects are important to provide input into the expropriation process, or the compilation of a formal landowner agreement.

2.6.4 Expropriation

In terms of the Constitution of the Republic of South Africa (No 108 of 1996), organs of state are empowered to expropriate land subject to various provisions. Expropriation by road authorities is generally undertaken in terms of the Expropriation Act (No 63 of 1975, or as subsequently amended), read in concert with the powers provided for in the Road Ordinance (No 19 of 1976). Section 1 of the road ordinance specifically provides that a road authority may “*take the right temporarily to use property and to raise and remove materials ... from a property.*” for road construction purposes.

The Act distinguishes between temporary and permanent expropriation:

- **Temporary Expropriation:** Taking the right to use the land temporarily. The duration of use would be stipulated in the notice of expropriation. Ownership of the land is not transferred to the organ of state and the land reverts to the landowner following its use.
- **Permanent Expropriation:** Ownership of the land is transferred to the organ of state.

The following activities are required to commence the expropriation process:

- Landowner **consultation**
- **Survey** of the exact extent of land to be expropriated
- **Serve a notice** to the landowners in accordance with Section 7(2) of the Expropriation Act and Section 29 of the Roads Ordinance

2.6.5 Land Owner Agreements and Leases

If the landowner permits the use of his/her land for use as a borrow pit or quarry, a formal agreement can be entered into. Such agreement should at least cover:

- **Duration** of use of land
- **Extent** of land to be utilised
- **Special requirements** of the landowner or client
- Provision for **financial compensation**
- **Responsibilities** of the road authorities and landowner

2.6.5.1 Compensation

In terms of the Minerals and Petroleum Resources Development Act (DME, 2002), all of South Africa's mineral resources have been placed in the custodianship of the State. It is important to recognise that during the expropriation process, gravel or water resources are not expropriated, but rather the right to remove the materials is granted. Nevertheless, the market value of the gravel is still relevant in calculating compensation since it can be deemed that the landowner has suffered a financial loss due to the removal of the material (under Section 12(1)(b) of Expropriation Act 63 of 1975). Accordingly, compensation is payable for both aspects of the expropriated right, the right of use of land by the landowner and the gravel removed. Determining the compensation is based on:

- Term of usage
- Recovery period
- Market value of land
- Surface area

2.6.5.2 Rezoning

Any change in land-use needs to be authorised in terms of the Land-Use Planning Ordinance (LUPO) 15 of 1985. Planning approval may be required if the site falls within an urban area or is included in the zoning scheme for a town, and its zoning does not provide for mining use. In general, most areas outside of the urban edge can be mined, as this use is in line with its "rural" zoning.

Some municipalities may require a formal planning process to be undertaken for a site where the envisaged change in land-use (to allow for mining) is not accommodated in the zoning scheme. One of two processes could apply, i.e., a rezoning or a departure. A departure is formal permission from the controlling authority to deviate from an official requirement.

In order to apply to the relevant local municipality for approval in terms of LUPO, approvals from both DMR and NEMA are a prerequisite.

2.7 Operations

The operation of a borrow pit or quarry should be in accordance with the requirements of the: Mine Health and Safety Act (No 29 of 1996); mine plan; EMP/EMProg; and any other relevant legislation pertaining to a particular site. Prior to commissioning and operating a pit, it is crucial that the operational staff are familiar with these requirements and that they clearly understand the mining and closure objectives.

2.7.1 Mine Health and Safety Act

The Mine Health and Safety Act (No 29 of 1996) deals with the prevention of occupational accidents and injuries in mines and quarries. The objectives of this Act are to:

- Protect the **health and safety** of persons at mines.
- Ensure that employers and employees identify hazards and eliminate,



Mine Health and Safety Act (No 29 of 1996)

This act deals with the prevention of occupational accidents and injuries in mines and quarries.

control and minimise the risks relating to health and safety at mines.

- Give effect to the national and international **legal obligations** for health and safety at mines.
- Provide for **employee participation** in matters of health and safety.
- Provide for **enforcement** of health and safety measures at mines.
- Provide for **effective monitoring** of health and safety conditions at mines.
- Provide for investigations and inquiries to **improve health and safety** at mines.
- **Promote:**
 - A culture of health and safety in the mining industry.
 - Training in health and safety in the mining industry.
 - Co-operation and consultation on health and safety between the State, employers, employees and their representatives.



Health and Safety Responsibilities until Mine Closure

The Act is clear that the ongoing responsibility for the management of the health and safety of a mine vests with the mine owner or manager. This responsibility only ceases once a closure certificate has been issued by DMR. This emphasises the importance of applying for the closure of exhausted or unsuitable materials sources.

The Act establishes the employers' responsibility to ensure, as far as reasonably practical, that the mine, pit or quarry, is commissioned, operated, maintained and decommissioned in such a way that employees can perform their work without endangering their health and safety. The Act requires:

- Appointment of a **mine manager**.
- Maintenance of a **healthy and safe** mine environment.
- Providing **adequate health and safety equipment and facilities**, including providing adequate ablutions.
- **Staffing** of the mine with due regard to health and safety considerations.
- Establishing and implementing a **health and safety policy**.
- Developing and implementing **codes of practice** to guide health and safety strategies.
- Providing health and safety **training** for the employees for both routine operations and emergency situations.
- Assessing, managing or mitigating **risk**, whether by physical means or staff awareness.

In terms of the provisions of the Act, employees also have the right to leave any working place where circumstances arise which may reasonably pose a danger to their health and/or safety. Moreover, employees may not be charged for the health and safety equipment and facilities, which must be provided to them in terms of the Act.

It should be noted that the Act is clear that the on-going responsibility for the management of the health and safety of a mine vests with the mine owner or manager. This responsibility only ceases once a closure certificate has been issued by DMR. This emphasises the importance of applying for the closure of exhausted or unsuitable materials sources.

2.7.2 Explosives Act

This Act and its regulations control the use of explosives. It also specifies the actions required to ensure the protection of surrounding property during blasting. A blasting permit, is necessary for all blasting operations and is obtained from SAPS. Note that proper processes must be applied for the transport and storage of explosives.

This Act and its regulations control the use of explosives. It also specifies the actions required to ensure the protection of surrounding property during blasting. A permit (explosive registration certificate) is required from SAPS, and includes transporting and storing explosives.

Where blasting is carried out within 500 metres of a building or other structure, the Regulations of the Explosive Act (No.26 of 1956) under Sections 10.17.1 and 10.17.2, as well as the Mines and Works Act (No.27 of 1956) under Sections 9.33.5 and 9.33.7, stipulate certain requirements that a manager, which in this case means the contractor, should adhere to. A recommendation is also included that the structures are examined in the presence of the owner for cracks or other existing damage. A record, including photographs, should be made of the observations and a copy



Explosives Act

This Act and its regulations control the use of explosives. It also specifies the actions required to ensure the protection of surrounding property during blasting. A permit is required from the SAPS to both transport and store explosives.

provided to the owner. The engineer, or the authorised representative, and the site agent should carry out an inspection with the owner before blasting commences. It is recommended that seismic measurement should be taken and recorded during each blast.

Regulation 10.21 requires that *"surface soil and loose overburden be cleared back from the working face (requiring blasting) for a distance of at least 3 metres, to prevent any portion of face from being undercut, in weathered, loose or friable rock or ground not to have a face in excess of 3 m in vertical height, but to carry such faces in terraces of 3 m or at an angle of not greater than 60° from the horizontal"*.

Regulation 10.22 states that *"When blasting materials are used in the making of excavations the manager and blaster shall arrange for various forms of protective measures"*.

In addition, when blasting all residents, businesses and farmers should be timeously informed to ensure enough time to make appropriate arrangements. In particular, owners of domestic animals must be given sufficient warning so as to make proper arrangements to ensure the safety of their animals.

Blasting should only be carried out during normal working hours in areas in close proximity to communities and/or residences. Should noise generating activities have to occur at night, e.g., drilling of blast holes, communities and/or landowners in the vicinity of the drilling should be warned about the noise well in advance, and the activities should be kept to a minimum. Compliance with the appropriate legislation for noise is mandatory.

2.7.3 Pit Management

The following aspects of pit management are important to ensure a pit is worked in a sustainable and sensitive manner, that is, environmental impacts are minimised, material extraction is optimised and costs are curtailed.

- **Training of staff.** Ensure site staff are familiar with:
 - Mining and closure objectives
 - Mine plan requirements
 - Mine Health and Safety Act
 - EMP or EMProg
- **Securing perimeter.** Fence the pit and erect signage to:
 - Clearly indicate the mining area to the public
 - Keep mining activities within the designated area
 - Restrict access in and out of the pit to ensure adequate security and public safety
- **Demarcate areas.** Set out and demarcate:
 - Location and extent of areas to be mined to limit the extent of any environmental impacts and minimise unnecessary remediation
 - No-go areas
 - Stockpile areas
 - Access roads
 - Infrastructure
- **Access and haul roads.** Set out and establish access and haul roads in accordance with the Mining Plan. Maintain these roads.
- **Traffic management.** Establish and maintain the necessary traffic management measures, such as signage and flag persons, to ensure safety of site staff and road users.
- **Topsoil management.** Remove vegetation and topsoil, including roots and seeds, separately and stockpile alongside pit for reuse during the rehabilitation. Topsoil must be handled and stored correctly to ensure it is not contaminated, dispersed or degraded. The stockpiles should be of limited height to avoid deterioration of potential seeds and rhizomes necessary to encourage later vegetation.
- **Stockpiling of materials.** Maintain separate stockpiles for topsoil, waste material and products. Establish and maintain procedures for preventing contamination, dispersion or degradation of materials in stockpiles.



Blasting of Borrow Pits

If the borrow material requires blasting, this places a restriction on the location of the borrow pit with respect to existing settlements and infrastructure, contractors camp, etc. Generally, blasting must not take place within 500 metres of any permanent or temporary infrastructure. If this is seen to be unachievable, special blasting permits can be applied for, provided that certain precautions are taken during blasting (covered blasting, restriction of access/traffic, temporary vacation of premises, etc.). Similar restrictions apply to the location of explosive magazines, transport of explosives, etc.



Notification of Blasting

All interested and affected parties must be timeously notified of any blasting.

Unsuitable material can be used during rehabilitation for reshaping and smoothing prior to replacement of the topsoil.

- **Construction Plant.** Maintain plant in good operating order and operated by licensed, qualified personnel. Utilise plant only for the tasks it is designed to perform.
- **Ablution facilities.** Establish and maintain adequate on-site ablution facilities.
- **Fuel management.** Establish and maintain procedures to manage the risk of fuel leaks and spills and the associated risk of pollution.
- **Waste management.** Establish and maintain the necessary procedures to minimise waste generation and dispose of waste to prevent pollution of the environment.
- **Stormwater management and erosion.** Take the necessary measures to limit erosion and prevent polluted runoff entering watercourses or water bodies.
- **Water resources.** Minimise the use of water and take measures to limit wastage to an absolute minimum. Construction water must be legally sourced and natural water resources protected.
- **Fire management.** Take reasonable and proactive steps to minimise the risk of fire and manage the risk to the public and environment. Basic fire-fighting equipment should always be available on-site and site staff should be trained on its use.
- **Dust and noise control.** Take the necessary measures to minimise the generation of dust and noise associated with mining activities. Dust and noise are a nuisance and health hazards, which must be managed effectively.
- **Protection of flora and fauna.** Follow the requirements provided in the EMP or EMProg and Mining Plan.
- **Protection of archaeological and palaeontological remains.** Follow the requirements provided in the EMP/EMProg and Mining Plan. Should any remains be unearthed, immediately protect such remains, cordon off and report to the relevant authorities.
- **Clean up and rehabilitation.** On completion of the mining operation:
 - Clean up the site
 - Remove all infrastructure
 - Create final slope profiles
 - Prepare slopes for rehabilitation
 - Install permanent drainage, ideally the pit should be free-draining
 - Follow mining plan specifications for topsoiling, rehabilitation and revegetation
- **Emergency procedures.** Ensure emergency procedures are documented, communicated to all staff and a copy of the emergency procedures is kept on-site.
- **Interested and affected parties.** Establish and foster good relationships with affected parties. Inform affected parties of the onset of mining. Establish mechanisms for dealing with complaints.

The Western Cape Provincial Administration, Department of Transport and Public Works, Road Infrastructure Branch, has developed a series of "Operator Instruction Sheets" designed to provide guidance to personnel operating borrow pits. There are 24 sheets in the series and each sheet deals with a specific borrow pit management activity. For each activity the what, why, when and where to do it is discussed as well as the "do's and don'ts" associated with the activity. The sheets are a useful reference and are available in English, Afrikaans and isiXhosa. The sheets are available on the web at http://tdr.wcape.gov.za/tdr/doc.user_manual_web.main.

2.8 Closure

Once a material source has been exhausted, or for some reason is no longer suitable for use, it is essential to undertake a closure process whereby, once operations have ceased, the site must be rehabilitated and returned to a safe and stable state. An example of a well rehabilitated borrow pit is shown in Figure 12.

Historically, rehabilitation was typically limited to the removal of equipment following the cessation of activities. This practice is not only lax, but is unacceptable from both community safety and environmental sustainability perspectives. Moreover, as outlined previously, in terms of the Minerals and Petroleum Resources Development Act (2002), the holder of a mining right or permit remains liable for any pollution or ecological degradation, and the management thereof, until DMR has issued a closure certificate for the subject site. The operator retains liability for the borrow pit or quarry, until a Closure Certificate has been issued for each site by DMR.

Accordingly, following the implementation of the rehabilitation measures, an Application for Closure, supported by the requisite Closure Plan, Environmental Risk Report and Financial Performance Assessment Report, should be prepared for submission to DMR. The Act requires that the Application for Closure be submitted within 180 days of cessation of the mining operation at the subject borrow pit). The financial provision takes place in accordance with signed Memorandum of Understanding secured between SANRAL and DMR.

In terms of the requirements of the Mineral and Petroleum Resources Development Act, financial provision must be made for the closure or sudden cessation of work, and for any rehabilitation and revegetation work.

Closure should ensure that:

- Operations are ended **efficiently and cost effectively**.
- The site is **rehabilitated** and returned to a safe and stable state.
- The **final land use** conforms to the concept of sustainable development.
- **Legal liability** is transferred from the operator.

Required measures for site clean-up include:

- **Demolish and remove infrastructure** that was erected at the site.
- **Remove all equipment**, plant, concrete footings, fencing (except where permanently required), etc. from site
- Remove all **foreign materials** from site.
- Not disposing **domestic or other waste** in the pit. Waste must be disposed of off-site at an approved landfill.
- Not disposing **soil contaminated** with oil, grease, fuel or other hydrocarbon in the excavation.

Each borrow pit should be rehabilitated, in such a way that:

- It **blends in with the surrounding area** and appears as a natural extension to the adjacent, undisturbed ground profiles.
- Sharp **angles or corners** are avoided.
- **Smooth and flowing curves** are created that blend with the surrounding landscape.
- **Even contours** are created.
- The borrow pit is, wherever possible, **free-draining**. Alternatively, precautions, such as fencing, must be implemented to avoid liability issues.
- Where feasible, **no slopes steeper than 1:3** are created.
- The site is stabilized by **revegetation**.

Where the need for revegetation has been identified, specialist guidance should be sought to determine the exact requirements of a specific borrow pit. The mix of vegetation types, i.e., indigenous, naturalised or alien species, and approach to revegetation, such as seeds, cultivated plants or search and rescue from adjacent areas, should be tailored to the environment and meet the specific closure objectives. Where quick cover is required, reliance on natural regeneration is inappropriate, and a revegetation programme needs to be implemented. Unless an elaborate and extensive approach to the rehabilitation of the borrow pit is envisaged, the re-vegetation programme should focus on using species which:

- **Establish rapidly** on disturbed land.
- **Rapidly bind and cover soil**, thereby affording effective protection against erosion.
- Are resilient to the prevailing **environmental conditions**.
- Will **not invade** the surrounding habitat.
- Are **endemic and indigenous** to the area.
- Will **not prevent indigenous species colonising** the rehabilitated areas from the surrounding areas.



Before



During



After

Figure 12. Opening, Using and Rehabilitating a Borrow Pit

2.9 Reporting and Monitoring

The preceding sections give considerable guidance on the planning, commissioning, operation and decommissioning of borrow pits. However, to ensure that the required management measures are effectively and timeously implemented, regular compliance monitoring and auditing of all borrow pits is essential. Ultimately, compliance monitoring and auditing is an essential quality management tool that assists in achieving the effective management of risk and sustainable utilisation of gravel material sources.

To adequately assess the progress of the rehabilitation measures, and rectify any problems that may arise, sequential and regular photographs of the site from fixed points should be taken from the onset of the mining operations.

Factors to monitor and audit for each quarry or borrow pit include:

- **Status of the mining process**, particularly as it relates to the phased mining and rehabilitation process.
- **Compliance** with
 - Mining or Closure Plan.
 - Mining and Closure Objectives.
 - Commitments in terms of any environmental authorisations, expropriations or landowner agreements.
- Adequacy of **safety and security** aspects.
- **Environmental impacts**, in particular any concerns regarding negative environmental impacts.
- **Material usage**, including the status (percentage completion) and quantity and quality of material used.
- Status of progressive **rehabilitation efforts**.
- Status of **budget** compared to actual spending.



DMR Approved Borrow Pits and Quarries

Material sources (borrow pits or quarries) require approval from the Department of Mineral Resources (DMR), in terms of the requirements outlined in the Mineral and Petroleum Resources Development Act. Quarries operating without the required legal authorizations should not be considered for use.



Compliance Monitoring and Auditing

To ensure that the required management measures are effectively and timeously implemented, regular compliance monitoring and auditing of all borrow pits is essential.

3. COMMERCIAL MATERIAL SOURCES

A commercial quarry is defined as “a quarry with permanent infrastructure established to service a viable market.” Because aggregates are a “low value, high volume” commodity, commercial quarries are usually located as close as possible to urban growth nodes. “Non-commercial quarries”, also referred to as temporary quarries, typically include borrow pits and project quarries. Non-commercial material sources are discussed in detail in Section 2 of this Chapter.

Project quarries generally supply aggregate for a specific project, for example, a road resurfacing contract, or construction of a bridge. In most cases, project quarries are opened in remote areas, generally where haul distances from commercial quarries are too far. Commercial quarries tend to be larger, satisfy more sustainable development criteria, create stable employment and offer more benefits to the community than non-commercial project quarries. A comparison of commercial and non-commercial quarrying is presented in Table 19 (ASPASA, 2005).

The aggregate industry comprises both the formal and informal sectors. The formal aggregate and sand producers are legally required to declare production volumes to the Department of Mineral Resources (DMR). The informal sector consists of three distinct groups, namely:

- **Mobile operators** producing from licensed borrow pits
- **Small scale miners**
- **Illegal miners**, i.e., operators without the required legal authorizations to operate

Table 19. Commercial Quarries vs Non-Commercial Quarries

Aspect	Commercial	Non-Commercial
Optimal resource recovery	Yes	No
Closeness to market (transport optimization)	Yes, urban	Yes, project
Quality of product for general construction	Yes, buildings, road, rail and brick	Usually project specific
Product range	Usually wide, community needs	Usually project specific
Mining charter	Yes	?
Environment – Dust control	Yes	Sometimes
Environment – Noise control	Yes	No
Environment – Blast vibration control	Yes	No
Environment – Sustainable end-use	Usually	Minimal rehabilitation
Employment opportunity	Permanent	Temporary
Health and safety	High standards	?
Employee training	High standards	?
Social responsibility and community investment	High and long duration	Low and short duration
Long term servicing of community need	Yes	No

The South African aggregate and sand market was estimated at about 120 million tons in 2007. Road construction materials are estimated to account for around 26% of the total aggregate and sand market in South Africa, see Figure 13. Road construction materials that are typically sourced from commercial sources include crushed stone base and subbase, surfacing stone, and asphalt and concrete aggregates.

The decision whether to source materials from a commercial or project quarry depends on several factors:

- **Location** of commercial quarry sources in the project proximity.
- **Availability** of the required materials, in quality and quantity, from commercial sources.
- **Commercial viability** commercial aggregates compared with obtaining aggregates from a project quarry.
- **Feasibility** of opening project quarries in the project area. The potential to open a quarry could be severely constrained by legal, environmental and land-use issues.

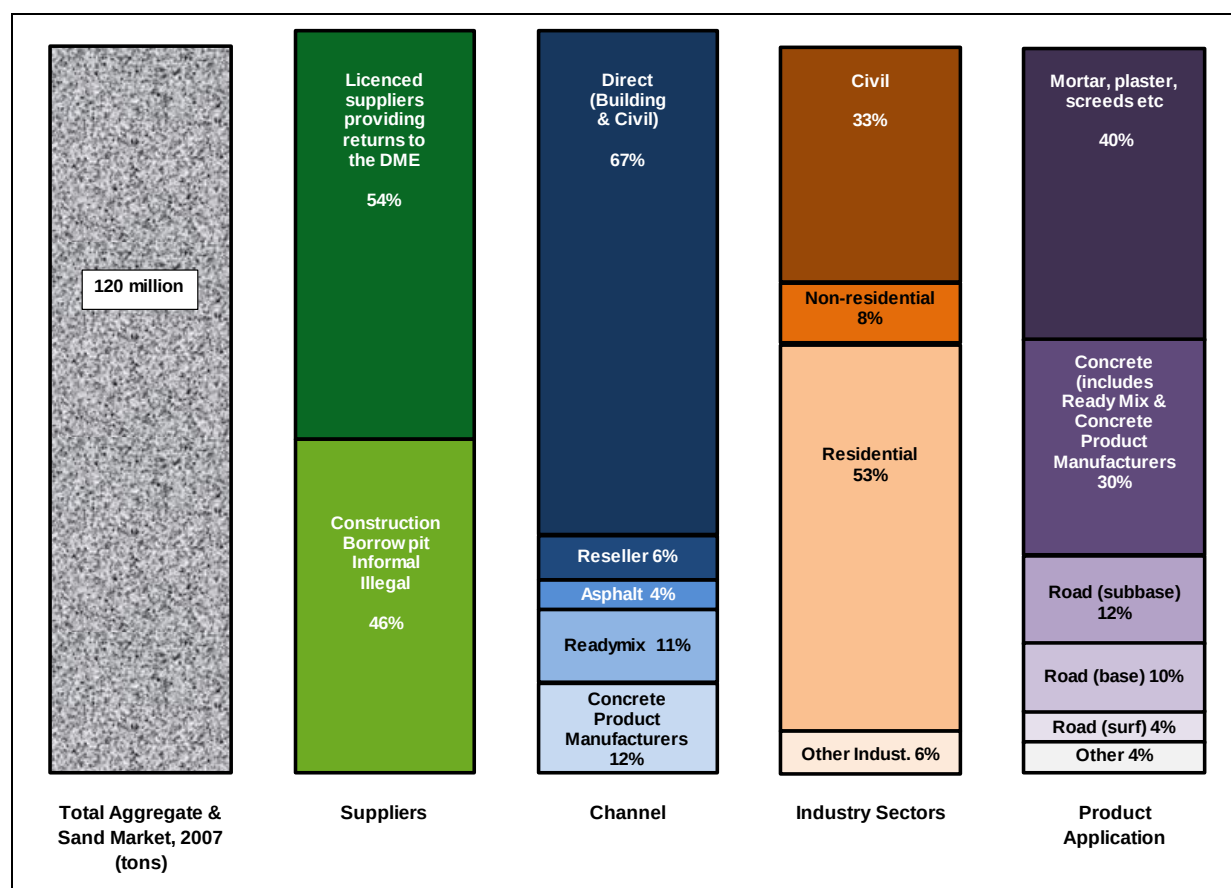


Figure 13. South African Aggregate Market Map

3.1 Resources for Quarrying, Sand and Aggregate Producers

Some useful resources relating to quarrying and sand and aggregate producers in South Africa are the Department of Minerals and Energy, Aggregate and Sand Producers Association of Southern Africa (ASPASA) and The Institute of Quarrying.

(i) Department of Minerals and Energy

The Minerals Economics Department of the Department of Mineral Resources (DMR) regularly produces directories of South Africa's various minerals industries. These directories are regularly updated and provide useful information. The "Producers of Sand and Aggregate in the Republic of South Africa" (DME, 2006) directory lists and provides contact details of sand and aggregate producers, and is comprehensive. Producers are listed according to province, alphabetically by magisterial district and then alphabetically by mine or quarry. The document can be downloaded from www.dmr.gov.za.

(ii) Aggregate and Sand Producers Association of Southern Africa (ASPASA)

This national body represents aggregate and sand companies, and is also responsible for promoting the aggregate and sand industry. ASPASA's objectives are to set standards and guidelines with regard to health, safety and environmental issues. To be a member of ASPASA, their stringent policies must be met and adhered to. In addition, members are regularly audited to ensure compliance with the standards. ASPASA's website is www.aspasa.co.za.

(iii) The Institute of Quarrying

The Institute of Quarrying (www.iqsa.co.za) is the international professional body for quarrying, surface mining and the related extractive, processing and construction industries. Membership is open to individuals, rather than companies. The stated objective of the institute to act as the forum representing the individual in the quarrying industry, which aims to:

- Provide value through an expanding **network of well-informed members**.

- Provide ongoing **professional development** through regional meetings, technical conferences and social events.
- Co-ordinate **education and training**.
- Promote the **image and professionalism** of the quarrying industry.

3.2 Quarrying Process

Quarrying is the multistage process by which rock is extracted from the ground and crushed to produce aggregate. This is then screened into the sizes required for immediate use, or for further processing, such as coating with bitumen to produce asphalt.

A stone quarry typically produces the following types of products:

- **Large size blocks** blasted from the quarry face, approximately 0.5 m^3 to 1.25 m^3 , are called **rip rap** or **rock armour**. They are used in coastal and river flood defence schemes to shore up sea fronts and river banks. Figure 14 shows their use in a dam wall.
- Material screened immediately prior to primary crushing is called **scalpings** or **grizzly**, which is often used for fill on construction sites.
- **Direct, unscreened output** from a crusher contains a complete mix of sizes from dust up to the maximum size that the crusher can pass, see Figure 15.
- Some screens have **multiple decks** and can screen out several grades. As with crusher run, screened fractions contain a mix of sizes, from the maximum size that the screen mesh can pass, down to dust. These go through further screening to extract the dust.
- **Screened, graded aggregate** for concrete production.



Figure 14. Large Size Blocks Used on Dam Wall



Figure 15. Mix of Rock Sizes from Crushing Operation

An example of a well-designed and laid out quarry operation is depicted in Figure 16.



Figure 16. A Well Designed and Laid Out Quarry Operation

3.2.1 Blasting

Rock is usually extracted from the ground in a drill and blast operation. This operation typically consists of the following sequence of activities:

- **Survey** the quarry face
- **Design** the blast

- **Drill** shotholes
- **Charge** shotholes with explosives
- **Detonate** the explosives

After the blast, the face and shotpile (sometimes called the muck-heap) are inspected to check that all the shot holes have fired correctly. The face shovel or loader then tidies up the shotpile and starts to load dumper trucks to take the rock to the crusher. Boulders that are too big to go through the crusher are set to one side for secondary breaking at a later date. Secondary breaking is typically done using a hydraulic excavator fitted with a hydraulic hammer, although drop-balls are also sometimes used.

3.2.2 Crushing

Crushing can be done in up to four stages, primary (first stage), secondary (second stage), tertiary (third stage) and, in some quarries, a quaternary (fourth stage). The primary crusher is fed via a hopper and vibrating feeder. The base of the feeder is made of steel "grizzly" bars. Fine material and dust produced by the blast, along with any remaining subsoil or weathered rock from the top of the quarry face, drops through the bars onto a separate conveyor belt and onto a stockpile. This screened material is called scalplings and is used as rock fill. The output from the primary crusher is conveyed onto the primary stockpile, from which the secondary crusher is fed. After passing through the secondary crusher, usually small size crushed stone and dust is screened out onto stockpiles.

The larger sized stone goes through the final crushing stages (tertiary and possibly quaternary) where it is fed through a series of crushers and screens. The output from the final crushers is conveyed to a screening plant where large multiple deck screens sort the crushed stone into the required aggregate sizes.

In general, particular crushers are used for the various stages of crushing, as given in Table 20. Primary crushing is usually by a jaw crusher. The size of the crushed stone which passes through the jaws is partly governed by the gap set at the bottom of the jaws, though larger size rocks can pass through if the rock is flaky or elongated in shape. Large scale gyratory crushers can also be used. Various types of crushers are illustrated in Figure 17.

Table 20. Types of Crushers

Crusher Stage	Type of Crusher
Primary	Single or double jaw crusher
Secondary	Gyratory crusher Standard head cone crusher Impactor Hammermill
Tertiary	Fine (short) head cone crusher Impactor Hammermill Vertical shaft impactor
Quaternary	Sand cone impactor Hammermill Vertical shaft impactor (VSI)

Secondary, tertiary and quaternary crushers are typically gyratory or cone crushers. These operate on the principle of a steel mantle mounted on an eccentric bearing and vertical shaft assembly. Rotation of the eccentric assembly makes the mantle gyrate within a static outer concave. Between the mantle and the concave there is a gap, which is tapered towards the base. As the mantle gyrates inside the concave, the gap between it and the concave narrows and widens on each gyration, producing the required crushing action. Stone is fed in at the top and crushed product falls out the bottom of the cone. The concave can be raised or lowered to a limited degree within the bowl, changing the gap, and consequently the size of the crushed product to be varied.

Vertical shaft impactor (VSI) crushers usually produce stone with very good shape, minimizing flat and elongated particles. A properly fed cone or gyratory crusher can also give good particle shape.

Crushers are also discussed in Chapter 12: 2.1.

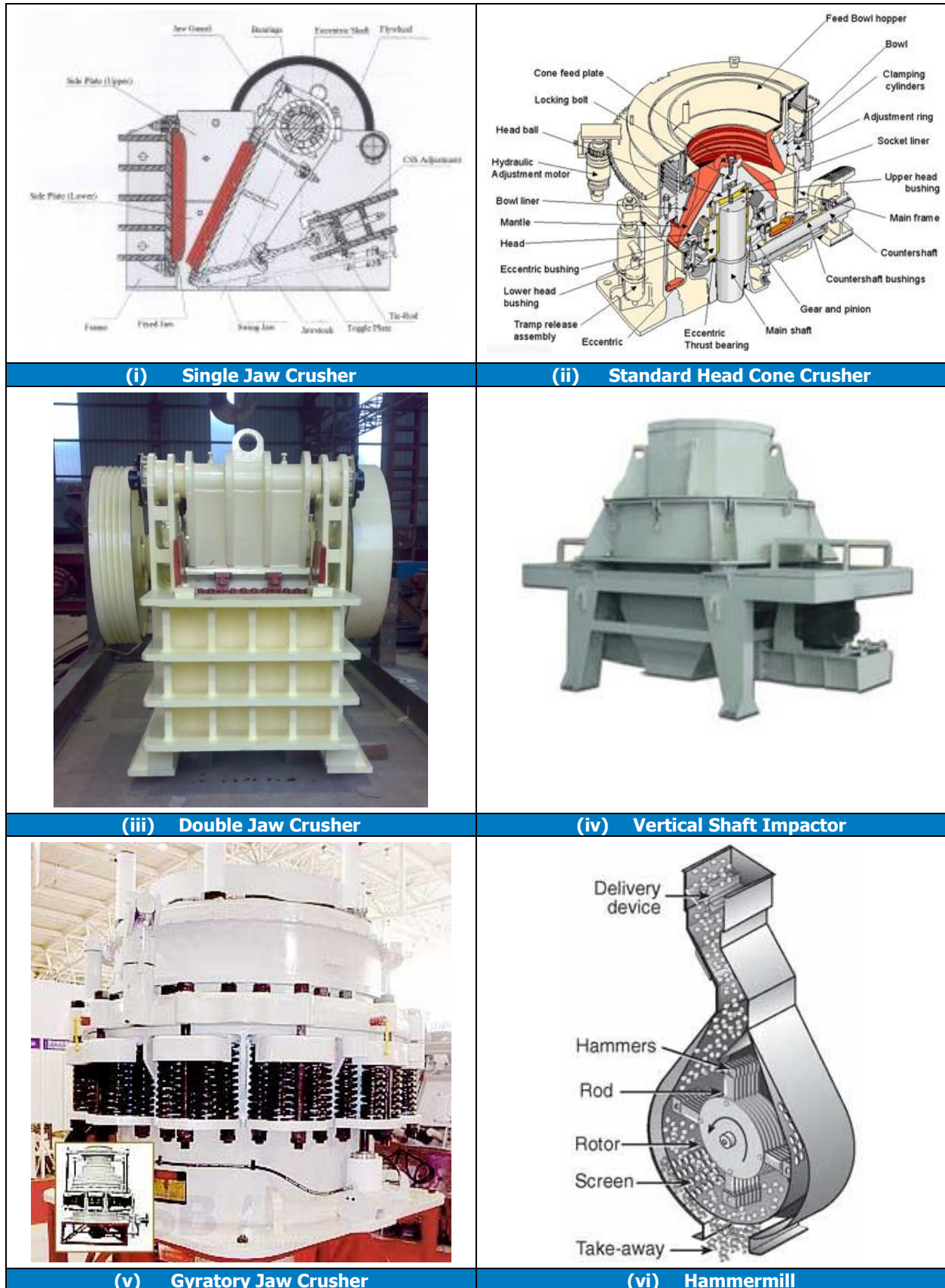


Figure 17. Crusher Types

3.3 Source Materials and Products

It is critically important that rock types utilized for the production of road construction materials are fit for the required purpose. Not all rock types are suitable for use in concrete or asphalt. In some cases, the mineral (chemical) composition of the rock may be incompatible with the cement resulting in a premature failure. In other cases, the physical characteristics of the rock may result in structural weakness in the concrete or slippery road surfaces when used in asphalt.

A wide range of road construction products is available from commercial quarrying operations. These products include concrete aggregates, sand, gravel and crushed stone for pavement layers and surfacing aggregates, as well as special products produced for specific uses. The standard products available are given in Table 21. Not all products are available from each quarry.

In South Africa, commercial quarries exploit a wide range of different rock types to produce aggregates. The natural road building materials used for road construction in southern Africa are listed in Table 22 (Weinert, 1980). The rocks more commonly quarried in the different regions of South Africa are given in Table 23. Figure 18 gives examples of some of the common rocks used in South Africa.

Table 21. Standard Products Available from Commercial Quarries

Product Type	Products
Concrete aggregate	53 mm
	37.5 mm
	28 mm
	20 mm
	14 mm
	10 mm
	7.1 mm
Crusher sand	Washed
	Unwashed
Base	G1
	G2
	G3
Subbase	G5
	G6
	G7
Surfacing aggregates	20 mm
	14 mm
	10 mm
	7.1 mm
Ballast	63 mm
	75 mm
Specials and non-standard products	Various



SANS Sieve Sizes

Note that the new SANS sieve sizes are used in this chapter. Most quarries and commercial laboratories are still using the old sieve sizes for their screens. With the move to the SANS sieve sizes (see Chapter 3: 1.2), they will slowly change over to the new sieve sizes.

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Table 22. Natural Road Building Materials Used for Road Construction in Southern Africa

Materials		Use		
Group	Rock	Surfacing Aggregate	Base	Subbase
Basic crystalline rocks	Amphibolite	✓	✓	
	Andesite	✓	✓	✓
	Anorthosite		✓	
	Basalt	✓	✓	✓
	Diabase	✓	✓	✓
	Diorite	✓		✓
	Dolerite	✓	✓	✓
	Gabbro	✓	✓	✓
	Greenschist	✓	✓	✓
	Norite		✓	✓
	Peridotite		✓	✓
	Phonolite	✓		
	Serpentinite	✓	✓	✓
Acid crystalline rocks	Felsite	✓	✓	✓
	Gneiss		✓	✓
	Granite	✓	✓	✓
	Pegmatite		✓	✓
	Rhyolite	✓		
	Syenite	✓	✓	
High-silica rocks	Chert		✓	✓
	Hornfels	✓	✓	
	Quartzite	✓	✓	✓
	Vein quartz	✓	✓	✓
Arenaceous rocks	Arkose	✓	✓	✓
	Conglomerate		✓	✓
	Gritstone		✓	✓
	Mica schist			✓
	Sandstone	✓	✓	✓
Argillaceous rocks	Sericite schist, phyllite		✓	✓
	Shale, slate, mudstone		✓	✓
Carbonate rocks	Dolomite	✓	✓	✓
	Limestone		✓	✓
	Marble	✓	✓	✓
Metalliferous rock	Iron stone		✓	✓
	Magnesite		✓	✓
	Magnetite		✓	✓
Pedocretes	Calcrete	✓	✓	✓
	Ferricrete		✓	✓
	Phoscrete		✓	
	Silcrete	✓	✓	✓
Diamictities	Tillite	✓	✓	✓
Transported soils	Local soils			✓
	River gravel		✓	✓
	Wind-blown sand		✓	✓

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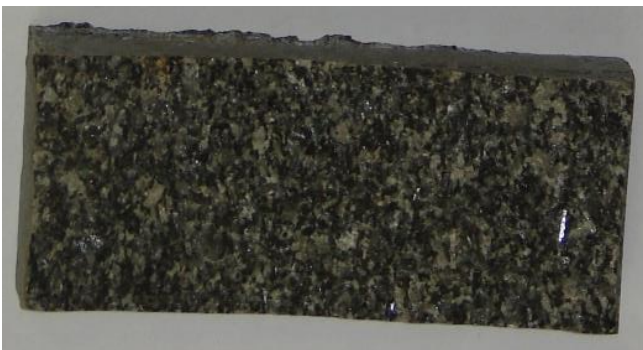
Dolerite	Norite
	
Basalt	Granite
	
Gneiss	Hornfels
	
Quartzite	Tillite
	

Figure 18. Common Rock Types

Table 23. Typical Rocks Found in South Africa

Rock Type	Province								
	Gauteng	Western Cape	Kwazulu-Natal	North West	Limpopo	Mpumalanga	Free State	Eastern Cape	Northern Cape
Andesite	✓			✓					
Chert	✓			✓					
Dolerite	✓		✓			✓	✓	✓	✓
Dolomite	✓			✓					
Gneiss					✓				
Granite	✓	✓	✓		✓	✓			
Meta Greywacke		✓							
Norite				✓	✓	✓			
Quartzite	✓	✓	✓	✓				✓	
Sandstone					✓	✓	✓	✓	✓
Shale	✓	✓	✓			✓	✓		✓
Tillite			✓						✓
Hornfels		✓							

3.4 Quality Assurance and Quality Control

Road construction materials sourced from commercial quarries need to meet project requirements, including that:

- They meet the required material **product specification**.
- They are produced from a **constant source of rock**.
- The properties of a material product supplied **do not vary significantly**, especially during the supply period for a project.
- The quality of the material products are not significantly **negatively affected due to transportation** to site and/or **poor on-site stockpiling** procedures.

To assure the quality of their products, quarrying operations should implement an ISO 9000 series based quality management system (QMS). As part of a QMS, procedures should be in place to control the processes that affect the quality of the products produced. Such procedures cover:

- Ensuring the **quality** of the source material.
- **Maintaining** the required performance of the production plant.

Quarrying operations should run a quality control testing programme that continually monitors if the products produced comply with relevant specifications and client requirements. Typically, such programmes consist of performing a suite of appropriate laboratory tests on a particular product based on a production rate. For example, Afrisam quarries perform gradings and flakiness index (FI) testing on concrete aggregates based on samples obtained every 500 tons produced. The sampling rate may be adjusted up or down, depending on the material produced and level of variability. Monthly testing is conducted on road materials that includes, but is not limited to, polishing stone value (PSV), CBR, MDD, aggregate crushing value (ACV) and Atterberg limits. These tests are all described in Chapter 3: 3. Annual testing is also done to determine any changes in the mineralogy of the rock in the quarry being mined.

The results of quality control testing provide:

- **Assurance** that products meet the relevant specifications and client requirements.
- Data of the **material properties**.
- Test data indicating the **historical quality** of products produced from the quarry.

Access to the above data is essential when evaluating whether to utilize a commercial source for the supply of road construction materials.



ASPASA COLTO Exclusion Clauses

ASPASA has issued COLTO exclusion clauses relating to the supply of various road construction products. It is important that the implications of these exclusion clauses are considered when considering utilizing commercial products from ASPASA members.

(i) Base Material

ASPASA members agree to supply G1 to G9 materials as defined in the following sections of the COLTO Standard Specification for Road and Bridge Works for State Road Authorities, Series 3000: Earthworks and Pavement Layers of Gravel or Crushed Stone (1998), specifically Section 3400: Pavement Layers of Gravel Material and Section 3600: Crushed Stone Base, subject to the following conditions.

- **Table 3402/1 Requirement for types G4 to G6 materials, Grading:** ASPASA members do not draw a distinction between crushed and uncrushed material as defined under G4 material. Unless agreed with the ASPASA members, all G4 material will therefore conform to the limits specified for uncrushed material.
- **Section 3602 (c) Grading requirements:** ASPASA members shall not comply with an after compaction grading specification since the members have no control over the manipulation of the material after it as been delivered to site. ASPASA members will endeavour to achieve only the limit as defined in Table 3602/1 – Crushed stone base and subbase: Material Requirements, Grading.
- **Section 3602(c)(i)(5) Grading requirements:** Since the coarse sand ratio (CSR) is a factor of the crushing property of the rock, and hence cannot be physically controlled without occasional addition of non-parent materials, ASPASA members shall not comply with the limits specified in this section.
- **Table 3602/1 Crushed stone base and subbase, Material Requirements, Compaction requirements:** Because ASPASA members are not responsible for the achieved in situ density, no reduced payment as defined in section 8208 (b) (2) Conditional acceptance: Notes, shall apply.
- **Table 3602/4 Tolerance on target grading:** Because ASPASA members are not responsible for the grading limits after compaction, the tolerance on target grading specified in this table shall not apply.
- **Section 3603 Trial section and other requirements before the crushed stone layer may be constructed:** ASPASA members will assist their customers in attempting to achieve a final layer that conforms to specification requirements. Full payment for material supplied for a trial section will however still be insisted upon even if the trial section is removed as excess/unsuitable material.

(ii) Surfacing Material

ASPASA members agree to supply surfacing material as defined in COLTO Standard Specification for Road and Bridge Works for State Road Authorities Series 4000: Asphalt Pavements and Seals, and Section 4200: Asphalt Base and Surfacing, subject to the following conditions.

- **Section 4202 (b) Aggregate:** ASPASA members shall not comply with the second sentence of clause 3602 (a), namely, *"It shall not contain any deleterious material such as weathered rock, clay, shale or mica"*, since the vast majority of commercial rock available contains some traces of these components.
- **Section 4202 (b) (iii) Polishing:** Due to the variability achieved with the Polished Stone Value (PSV) test in recent round robin test programmes, ASPASA members reserve the right to specify potential test houses for testing of materials. Historical tests should also be used as a guide to determine the acceptability of a material source for use under the conditions specified in this section.
- **Section 4202 (b) (viii) Grading:** Where all-in materials are supplied in accordance with limits specified in Tables 4202/6 to 4202/10, the average grading of material supplied by ASPASA members shall conform to the limits specified in these tables, and is not subject to the tolerance specified in sub-clause 4213 (c) and Table 4213/1.

(iii) General

Where there is a dispute regarding the quality or achieved grading of material supplied by ASPASA members, the members reserve the right to only accept test results from a SANAS accredited laboratory for the tests in question. Disputes related to quality or the achieved grading of material tested after compaction shall not be entertained.

3.5 Problem Aggregates

Certain aggregates have inherent problems that can affect their performance as crushed stone or natural gravels. The problems are usually related to the presence of particular deleterious minerals. Typical problems related to mineralogy are:

- Alkali-silica reaction
- Basic crystalline rock durability
- Sulphides
- Micas
- Nepheline

3.5.1 Alkali-Silica Reaction

Alkali-silica reaction primarily affects concrete and has led to severe failures of concrete roads and structures. An example of such a failure is given in Figure 19.



Figure 19. Concrete Failure due to Alkali-Silica Reaction

The problem is caused by a chemical reaction between fine grained meta-stable silica minerals in rocks and the alkalis in cement, typically cements with $> 0.6\%$ alkali in terms of the sodium oxide equivalent ($\% \text{Na}_2\text{O-eq}$). The reaction products are gels which expand and crack the material, or cause a loss of bond between the aggregate and the cement matrix.

Various tests are used to identify rocks with a potential for alkali silica reaction problems including ASTM C227 and C289. The same cement planned for use on the project should be used in the test.

No confirmed reports on this same reaction affecting cement stabilization have been documented. It is likely that the high voids content in compacted stabilized soils can tolerate any expansion caused by alkali silicate reaction in these road layers.

The problem is discussed in detail by Oberholster (2009).

3.5.2 Basic Crystalline Rock Durability

Many South African (and international) basic crystalline rocks, particularly dolerite and basalt, have undergone a chemical change during their formation resulting in alteration of their primary minerals (mainly olivine and pyroxene) to the highly expansive smectite clays. These rocks, when used as construction materials, specifically base courses, but also concrete and surfacing aggregate, can degrade rapidly, generating soft aggregate, high plasticities and leading to road failures on a large scale.

The presence of smectites in basic crystalline rocks is usually assessed using XRD analyses. It should be noted, however, that because of the fine and variable nature of smectite clays, the quantity of smectites is often overestimated in XRD analyses. Smectite clays, however, are particularly susceptible to swelling in ethylene glycol and various tests employing this liquid have been developed to accelerate the degradation of problem rocks as discussed in Chapter 3: 3 (Test Methods).

3.5.3 Sulphides

Many rocks contain sulphide minerals (usually in the form of pyrite, pyrrhotite, marcasite or chalcopyrite). These sulphides are prone to rapid oxidation under suitable environmental conditions (heat, moisture and oxygen often accelerated by certain bacteria) and break-down to form sulphuric acid and sulphate minerals (soluble salts). Rocks containing more than, say, 1% of these materials are not advisable for use as base, subbase or surfacing.

The low pH conditions formed by the sulphuric acid can have a severe negative impact on any cement or lime (alkaline) stabilization as well as any concrete structures in contact with the solution. The end result of the oxidation reaction in the road is often sulphates of magnesium or sodium, which can lead to soluble salt problems. As oxidation of the aggregate can occur in stockpiles and dumps, it thus becomes necessary to test aggregates that may potentially contain sulphides for the presence of both sulphides (acid soluble) and sulphates (water and/or acid soluble) according to the methods specified in the Standard Specifications. The recommended tests also include measurement of the pH and electrical conductivity (see Chapter 3: 3.2.6).

The effect of oxidation of sulphides is visible in many asphalt wearing courses in South Africa and internationally, where red/orange staining of the asphalt results, as illustrated in Figure 20.



Figure 20. Asphalt Staining from Oxidation of Sulphides

3.5.4 Micaceous

The mica minerals consist of extremely thin layers of aluminium silicates that are stacked on top of each other to form larger crystals. The layered structure causes the individual mica flakes to be very platy and highly elastic and springy when released into rock fines during crushing. Their effects obviously can only take effect if the flakes are released from the rock into the fines. For this reason, specifications often refer to free mica, ie, those flakes that can be seen in the fine crushed material.

Muscovite and biotite are the most common micas and biotite has only been reported to be a problem in one case. In this instance, the material was a partly weathered granite and visual appearance of the biotite was typical of the mineral. However, when compaction difficulties occurred, XRD analysis showed that the biotite flakes were actually badly decomposed and consisted of a high percentage of smectite clay. The high moisture contents held by the smectite caused the biotite flakes to be very resilient and they could not be compacted properly, "bouncing" back after being rolled.

Muscovite generally has larger crystals which act as "springs" during compaction. Typically any flakes larger than 0.5 mm are likely to cause compaction problems and the rule of thumb is that if the mica is obviously visible with the

naked eye, there is too much in the rock. It has also been proposed that if the muscovite content is less than 10% by volume, problems are unlikely to be encountered. However, as described above, only the muscovite released during crushing affects the material and it is better to carry out quantitative XRD analyses or point load counting of geological thin sections (on slides cut on three different axes).

Mica can also have a significant effect on the moisture retaining properties of aggregates and affect the PI and OMC. Compaction problems at the wrong moisture content can then be encountered. Cement stabilization of micaceous soils can often eliminate these problems.

3.5.5 Nepheline

Nepheline is a member of the feldspathoid group of minerals, a series of highly alkaline minerals. On exposure to fluctuating temperatures (particularly in a moist environment), nepheline is altered to the zeolite (analcime), accompanied by a large increase in volume. This exerts internal pressures on the rock significant enough to cause cracking and disintegration of the aggregate pieces. Fortunately, nepheline is not widespread in South Africa being restricted to a number of deposits of alkaline rocks, such as Pilanesberg and other minor igneous deposits. The so-called "Sunburn" test is used for its identification during which the aggregate is boiled for 36 hours in water. If nepheline is present, white powdery specks appear at the surface of the rock.

3.5.6 Soluble Salts

Near the coast and in dry parts of the country, particularly where Weinert N is more than 5 or Thornthwaite less than -20, soils and weathered rocks contain soluble salts, such as NaCl (halite). These salts tend to be drawn to the upper base and may react with the primed surface causing disintegration, destroying the bond between the base and the surfacing, blistering and crack the surfacing. If in doubt, suspected materials should be tested, as should the construction water.

3.5.7 Mine Waste

Mine waste may contain free sulphuric acid and soluble salts, which are detrimental to stabilization agents, such as Portland cement. These salts mainly comprise $\text{MgAl}_2(\text{SO}_4)_4 \cdot 22\text{H}_2\text{O}$ (pickeringite), $\text{MgSO}_4 \cdot 6\text{H}_2\text{O}$ (hexahydrate) and $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ (epsomite). As for soluble salts, these chemicals can lead to severe blistering and cracking of thin asphalt surfacings. Such materials, if no alternative can be found, are often treated with lime to precipitate out the salts as relatively insoluble gypsum and hydroxides.

3.5.8 Serpentine

Serpentine causes spalling and disruption of concrete. Ultrabasic rocks should, therefore, be checked for their Serpentine content if they are to be considered for use in bridges, culverts or similar structures.

4. ALTERNATIVE SOURCES

In the past, materials for the construction of road pavements have typically comprised of natural soils and gravels for fill, selected and subbase layers, and crushed aggregates for base layers, concrete pavements and surfacing. However, recently there has been an increased pressure, where feasible, to utilize alternative materials in place of the traditional materials. Some of the main issues promoting the use of alternative materials include:

- **Depletion** of natural resources.
- **Regulatory consent requirements** for developing quarries and borrow pits.
- Heightened awareness of **environmental issues** associated with quarrying and road construction in general.
- **Conservation of power.**

This has resulted in pressures to not only conserve existing aggregate resources, but also to recycle construction and industrial by-products wherever possible. The use of recycled materials has a win-win effect in that there is reduced demand for quarried aggregates and a reduced volume of material being dumped in landfills. The use of recycled materials could also have the benefit of reduced transportation costs if the recycled material is located at, or close to, the site where it is being re-used.

There are potential barriers to recycling of materials, including (Reid, 2000):

- Many **older specifications** do not permit the use of alternative materials.
- Lack of awareness of **methods available for recycling**, developments in specifications and successful projects.
- **Perception** that the use of alternative materials and recycling is a **high-risk activity**.
- Where cheap natural aggregates are available, alternative materials may not be **price competitive**.
- Concerns about **leaching of contaminants** from alternative materials.
- **Practical difficulties** with individual materials and methods, which are often site specific.

This section is intended only as an introduction and general overview to the use of alternative materials, and is limited to discussing the types of waste products that have potential to be recycled for road construction as well as their potential uses.

Considerations for whether or not to use an alternative material include:

- **Quality**
 - Classification or suitability for proposed usage
 - Standards and specifications
 - Test protocols
- **Supply**
 - Cost
 - Availability
 - Haul routes and distances
- **Environmental**
- **Health and safety**

There are possible disadvantages in the use of waste material, which should be carefully considered. Such disadvantages could relate to:

- **Haulage** costs
- **Greater variability** of waste materials
- **Long-term pollution** problems

The following sections discuss a procedure for evaluating a new material (Section 4.1), and the classification and use of waste products (Section 4.2). Sections 4.3 to 4.7 provide an overview of the classification and use of the more widespread alternative materials used for road construction including:

- Recycled pavement materials (Section 4.3)
- Construction and demolition waste, excluding recycled pavement materials (Section 4.4)
- Slags (Section 4.5)
- Fly ash (Section 4.6)
- Mining waste (Section 4.7)

4.1 Procedure for Evaluating a New Material

The decision to use alternative materials on a road construction project should be taken after a thorough evaluation. The procedure proposed for evaluating a new material is summarised in Table 24.

Table 24. Five-Stage Procedure for Evaluating a New Material

Stage	Objective	Details
1	Desk study	To assess and evaluate existing information on the material
2	Laboratory study	Tests of the mechanical properties of materials to allow theoretical predictions of performance.
3	Pilot-scale trials	Evaluate construction and performance of materials in small scale trials.
4	Full-scale trials	Trial to establish whether the previous assessments obtained from Stages 2 and 3 are realized.
5	Road authority specification trials	This stage is necessary to carry out further evaluation of the material and to test the specification under contract conditions.

A valuable source in the field of alternative materials is Philip Sherwood's book "Alternative Materials in Road Construction: A Guide to the Use of Recycled and Secondary Aggregates" (2001). This book provides practical guidance on the selection of substitute materials, including the economic and technical considerations of their use and advice on the benefits and pitfalls of each material. The book is divided into four parts that cover the following topics:

- **Part 1:**
 - Requirements for road making materials
 - Classification and sources
 - Specifications and standards for road making materials.
- **Part 2:**
 - Alternative materials available
 - Quantities, locations, general properties and potential uses
 - China clay wastes
 - Colliery spoil
 - Construction and demolition wastes
 - Glass waste
 - Municipal waste
 - Power station wastes (pulverized fuel ash and furnace bottom ash)
 - Rubber
 - Slags
 - Slate waste
 - Spent oil shale
- **Part 3:**
 - Environmental and economic considerations
 - Environmental effects of aggregate and waste production
 - Decision making
 - Traditional or alternative materials
 - Encouraging the use of alternative materials
 - Policy and controls on the supply and use of construction materials
 - Health and safety considerations
- **Part 4:**
 - References



Alternative Methods in Road Construction

Much of the information provided in these sections on alternative materials has been sourced from Sherwood's "Alternative Materials in Road Construction: A Guide to the Use of Recycled and Secondary Aggregates" (2001).

4.2 Classification and Use of Waste Products

Sherwood states that: "If alternative materials are to be used in road construction they have to be classified and meet specification requirements in the same way that classification systems and specification systems have been drawn up for road making materials already in use. In theory, the specifications for alternative materials need not necessarily be the same as those for traditional materials, but in current practice this is usually the case, although it is rapidly changing."

The potential uses of alternative materials in road construction are given in Table 25.

Table 25. Summary of Potential Uses of Alternative Materials in Road Construction

Material	Bulk fill	Unbound capping layer	Unbound subbase	Cement bound material	Concrete aggregate or additive	Bitumen bound material	Surface dressing aggregate
Crushed concrete	High ³	High	High	High	High	Some	None
Asphalt planings	High ³	High	High	Low	None	High	None
Demolition waste	High	Some	Some	Low	Low	Low	None
Blast-furnace slag	High ³	High	High	High	High	High	High
Steel slag	High	Low	Low	Low	Low	Some	High
Burnt colliery spoil	High	High	Some	High	Low	Low	None
Unburnt colliery spoil	High	Low	None	Some	None	None	None
Spent oil shale	High	High	Some	High	Low	Low	None
PFA ¹	High	Low	Low	High	High	None ⁴	None
FBA ²	High	Some	Some	High	Some	Low	None
China clay sand	High	High	Some	High	High	Some	Low
Slate waste	High	High	High	Some	Some	Low ⁴	None

Notes:

1. PFA = Pulverised Fuel Ash
2. FBA = Furnace Bottom Ash
3. Suitable but inappropriate (wasteful) use.
4. Fly ash and slate dust can be used as filler.

The results of a survey of the use of alternative materials in UK roads (Mallett et al, 1997) are summarized in Table 26. This survey indicates that the most widespread use of alternative materials relate to the production of secondary aggregates by reclamation of bituminous materials, in situ recycling of pavement layers, as well as processing of concrete waste, pulverized fuel ash and slag.

4.3 Recycled Road Pavement Materials

Waste from road reconstruction has a high potential for re-use in road construction. In South Africa, a growing emphasis is being placed on the use of recycled pavement materials for road projects. The different types of recycled pavement product are summarized in Table 27.

The benefits of the recycling of bituminous materials are (OECD, 1977):

- **Reduce transport costs** and fuel requirements.
- **Reduce aggregate requirements** and eliminate potential disposal problems.
- **Reduce bitumen content** by up to 75%.
- **Reduce energy** required for drying of aggregates.
- Generally **lower emissions** during construction.

Basic approaches for recycling pavements are given in Table 28.

In situ recycling and stabilizing with cement, lime, bitumen emulsion or foamed bitumen are well established technologies in South Africa. These are discussed in several other chapters of this guideline as well as in other industry guideline documents, such as TG2 for Bitumen Stabilized Materials and the Stabilization Manual (GDPTRW, 2004).

South African Pavement Engineering Manual

Chapter 8: Material Sources

Table 26. Survey of the Use of Alternative Materials in UK Road Schemes

Material	No. of schemes identified	Filter Drains	Road layer in which the material was frequently used				
			Surfacing	Base	Subbase	Capping	Earthworks
Reclaimed bituminous material	146		✓		✓	✓	✓
Shallow cold-mix in-situ	101		✓		✓		
Deep cold-mix in-situ	93		✓		✓		
Crushed concrete	55		✓			✓	
Pulverized fuel ash	50						✓
Steel slag	40		✓				
Blast-furnace slag	36		✓	✓	✓	✓	
Colliery spoil	23					✓	✓
Crushed demolition material	11				✓	✓	
Shallow hot mix in-situ	9		✓				
Hot mix off site	7		✓	✓			
Slate	7			✓	✓		
Phosphoric slag	7			✓	✓		
Tyres	7	✓					
China clay sand	6			✓			
Cold-mix off site	5		✓	✓	✓		
Crushed brick	4				✓	✓	✓
Rail ballast	2				✓		✓
Furnace bottom ash	1					✓	✓
Glass	1		✓				
Spent oil shale	1						✓

Table 27. Types of Recycled Pavement Products

Product	Description
Reclaimed Asphalt (RA)	Asphalt millings comprising aggregate ($\pm 95\%$) and bituminous binder. Milling and crushing yields a bitumen coated aggregate. If stockpiled for excessive periods (particularly in warm weather), particles may become bonded together but can be readily broken up.
Reclaimed Concrete Pavements	Crushed concrete is obtained from the demolition of concrete road pavements. See Section 4.4. The concrete has the potential to be contaminated by chloride ions (usually from de-icing salts in cold climates) or sulphates from contact with sulphate-rich soils.
Reclaimed Base and Subbase Materials	This is a broad range of materials suitable for the production of subbase and base layers. Recycling of these materials is potentially suitable for stabilized layers, granular subbase and fill.
Mixed materials	The above types of material may occur as uncontrolled mixtures. Due to the inherent variability of such materials, there is less scope for recycling.

Table 28. Recycling Methods

Method	Summary of Process
Hot In Situ Recycling (HIR)	Generally, total depth of treatment is about 50 mm. Process: • Heating of the surface layer • Scarifying • Reinforcing with thin asphalt overlay
Cold In Situ Recycling (CIR)	Total depth of treatment up to 300 mm. Process: • Milling in situ and reshaping of the existing road • Addition or removal of aggregate to achieve desired profile • Addition and mixing in of foamed bitumen, bitumen emulsion, cement or lime • Compaction • Apply surfacing

4.3.1 Reclaimed Asphalt (RA)

When considering the use of RA on road construction projects, the following aspects should be carefully considered:

- Recovery
- Classification
- Storage
- Design protocols and guidelines
- Manufacturing process

Examples of the process of reclaiming asphalt from a road are shown in Figure 21.

4.3.2 Recovery of RA

The mechanical properties of RA depend on the original asphalt pavement type, the methods utilized to recover the material, and the degree of processing necessary to prepare the RA for a particular application. Because RA may be obtained from any number of old pavement sources, its quality varies. The number of times the pavement has been resurfaced, the amount of patching and/or crack sealing, and the possible presence of prior seal coat applications will all influence the RA composition. The presence of geofabric patches significantly affects the usability of recycled asphalt.

4.3.3 Classification of RA

Milled or crushed RA can be used in a number of road construction applications. These include its use as an aggregate (and binder) supplement in recycled asphalt paving either with hot or cold mix, a granular base or subbase, or as a fill material. The use of RA as fill is, however, not encouraged as it is considered wasteful. However, it may be a practical alternative for RA that has been stockpiled for a considerable time, or is mingled from many different sources. The use of RA as fill material within the same carriageway could also be a suitable alternative to the disposal of excess asphalt that is generated on a project, where transport to an asphalt plant would be uneconomical.



Recycling Existing Pavements

The following chapters in this manual deal with in situ recycling of existing pavement layers and stabilizing with cementitious stabilizers (cement and lime) and bitumen stabilizers (bitumen emulsion and foamed bitumen).

- Chapter 3, **Materials Testing**
 - Section 4.2.4 (Reclaimed Asphalt)
 - Section 4.6 (BSM)
 - Section 5.3 (Cement Stabilized)
- Chapter 4, **Standards**
 - Section 4.6 (BSM)
 - Section 5.3 (Cement Stabilized)
- Chapter 9, **Materials Utilisation and Design**
 - Section 6 (Cement Stabilized)
 - Section 9 (BSM)
- Chapter 10, **Pavement Design**
 - Section 7, (both)
- Chapter 12, **Construction Equipment and Method Guidelines:**
 - Section 2 (both)
 - Section 3.4 (Cement Stabilized)
 - Section 3.5 (BSM)
- Chapter 13, **Quality Management**
 - Section 4 (Cement Stabilized)
 - Section 5 (BSM)



Figure 21. Reclaiming Asphalt

4.3.4 Storage of RA

Storage of RA requires particular attention to ensure a consistent and reliable RA product. RA stockpiles need careful handling to ensure that they remain useable. Stockpiles need to be kept below 2 metres high. Heavy vehicles must not be allowed to drive over the RA, to minimize consolidation of the material. The RA must be protected from the elements. Indications are that the moisture content increases while in storage, particularly if exposed to rain. During periods of extensive rainfall, the moisture content of some RA stockpiles may be as high as 7 to 8%. Lengthy stockpiling of RA should, therefore, be kept to a minimum.

4.3.5 Manufacturing Process

Typically asphalt batch plants in South Africa are capable of blending in up to 20% RA into their standard mixes. This is done via a RA feed into the hopper, at the end of the aggregate heating drum. The RA has therefore only got a short time to be heated by the other aggregates. The heat transfer rate is a constraint on the percentage of RA that can be incorporated into mixes. Higher (>20%) utilization of RA requires costly plant upgrades, to enable RA to feed directly into the drying drum.



RA Guidelines

TRH21, **Hot Recycled Asphalt** was updated in 2009, and provides a good guideline for the use of RA. This guideline is available for download from www.sabita.co.za.



Use of RA in Fill

The use of RA as fill is not encouraged as it is considered wasteful. However, it may be a practical alternative for RA that has been stockpiled for a considerable time, or is mingled from many different sources. The use of RA as fill material within the same carriageway could also be a suitable alternative to the disposal of excess asphalt that is generated on a project, where transport to an asphalt plant is uneconomical.

4.4 Construction and Demolition Waste

Construction and demolition waste, in this chapter, includes recycled pavement materials. Waste products are produced as a consequence of the demolition of roads, airfield runways, buildings include: concrete, masonry, bituminous road materials, aggregates and soils. These materials are potentially suitable for recycling and reuse in road construction.

Concrete and masonry waste reused for producing secondary aggregates are termed Recycled Aggregates (RCA). Various schemes for the classification of RCA have been suggested, based on the composition of the waste. Mulheron (1991) distinguished four main categories of construction and demolition waste (excluding asphalt road planings).

- **Clean crushed concrete:** Crushed and graded concrete containing less than 5% of brick or other stony material.
- **Clean crushed brick:** Crushed and graded brick containing less than 5% of other materials such as concrete or natural stone.
- **Clean demolition debris:** Crushed and graded concrete and brick.
- **Crushed demolition debris:** Mixed crushed concrete and brick that has been screened and sorted to remove excess contamination, but still contains a proportion of wood, glass or other impurities.

The BRE Digest (BRE, 1998) defines recycled aggregates as “crushed concrete and brick masonry” and gives three classes of RCA depending on the relative amounts of brick and concrete, as shown in Table 29.

Table 29. Classes of RCA

Class	Origin	Brick Content (%)
RCA I	Brickwork	Up to 100
RCA II	Concrete	0 – 10
RCA III	Concrete & brick	0 – 50

A Dutch classification for recycled granular base materials (Sweere, 1991) defines crushed concrete as shown in Table 30.

Table 30. Composition of Crushed Concrete

Component	Description
Main components	At least 80% by mass of crushed gravel or crushed aggregate concrete. At most 10% by mass of other broken stony material, the particles of which shall have a particle density of at least 2 100 kg/m ³ .
Additional elements	At most 10% by mass of all other materials, such as crushed stone or broken stony material. Asphalt shall not exceed 5% by mass.
Impurities	Maximum 1% non-stony material, i.e., plastic, plaster and rubber acceptable. Maximum 0.1% decomposable organic matter such as wood and vegetable remains.

Potential uses for different types of demolition waste, classified according to composition are summarized in Table 31.

Table 31. Potential Uses for Demolition Waste

Product	Potential Use
Crushed concrete	May be used as a substitute for natural aggregates for most purposes. Concrete derived from the demolition of buildings is likely to contain reinforcement, making it difficult to crush. It is also likely to be contaminated with other building waste materials.
Recycled crushed cement bound subbase and base	May be crushed or milled to produce granular materials meeting the requirements for a subbase. May also be restabilized with cement or bitumen to produce a stabilized material.
Crushed brick	Where bricks are available in quantity but are unsuitable for re-use, they may be crushed to produce granular materials meeting the requirements for a subbase. Contamination from gypsum plaster could result in crushed bricks having an unacceptably high sulphate content. Some brick types have soluble sulphate contents high enough to be deleterious.
Crushed demolition debris (other than concrete and masonry)	May be used as general fill. Rubble containing timber should be avoided because, when it rots, cavities remain in the fill.

4.5 Slags

Various types of metallurgical slag are produced as waste products of metallurgical processes. These include:

- Blast furnace slag
- Steel slag
- Non-ferrous slag

4.5.1 Blast Furnace Slag

Blast furnace slag is a by-product obtained in the manufacture of pig iron in the blast furnace. In the blast furnace, iron ore and limestone flux are combined and heated at high temperatures (between 1 300 °C and 1 600 °C) by the burning of coke. These materials react to produce molten iron, carbon dioxide and molten slag. The slag is then cooled, either by air or water producing:

- **Air-cooled slag** (Figure 22(ii)), a rock-like material with crystalline structure, which when crushed can produce an excellent substitute for natural aggregates.
- **Water-cooled slag** (Figure 22(i)), a granulated glassy material.



Blast Furnace Slag

This is a by-product obtained in the manufacture of pig iron in a blast furnace. Iron ore and limestone flux are combined and heated at very high temperatures by burning coke. These materials react to produce molten iron, carbon dioxide and molten slag. The slag is then cooled.

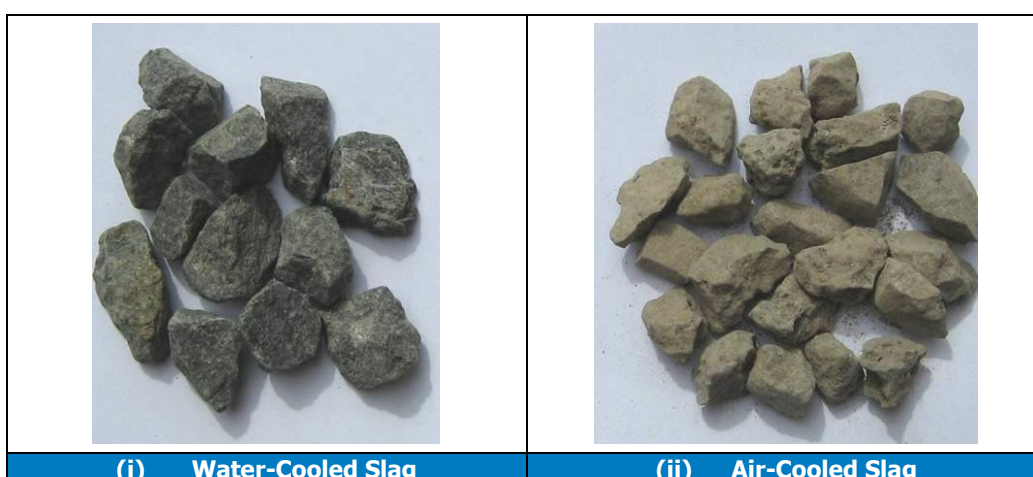


Figure 22. Water and Air-Cooled Slag

The chemical composition of slag is variable. The ranges in mineral composition reported by Lee (1974) are shown in Table 32.

Table 32. Mineral Composition of Slag

Component	Range (% by mass)
CaO	36 – 43
SiO ₂	28 – 36
Al ₂ O ₃	12 – 22
MgO	4 – 11
Total sulphur (as S)	1 – 2
Total iron (FeO+Fe ₂ O ₃)	0.3 – 2.7

For most purposes, blast furnace slag is generally regarded as being at least as good as natural aggregates. However, the physical and chemical properties differ from natural aggregates and hence specifications and testing methods for natural aggregates do not necessarily apply. Generally speaking, slag meeting the requirements of BS 1047 should prove suitable for aggregate for concrete and road construction.

When crushed and screened by normal quarrying procedures, blast furnace slag generally produces good quality aggregate with a cubic shape and a rough surface texture giving good frictional properties and good adhesion to bituminous and cementitious binders.

Ground granulated blast furnace slag (GGBS) is used as a cement extender in the production of concrete. The use of GGBS as a cement extender is discussed in more detail in Chapter 9: 6 and 12.

A potential problem related to the use of blast furnace slag in road construction is its instability, as it is not inert. Two forms of instability have been recognized; unsoundness and the potential to corrode steel. The instability is related to expansive reactions causing the slag to disintegrate. BS EN 11744-1 includes methods for detecting unsoundness. When used as a concrete aggregate, the possibility of corrosion of steel reinforcement due to sulphur in the slag has been alluded to, but there do not appear to be any recorded cases of slag concrete affecting the corrosion of reinforcing steel (Everett and Gutt, 1967).

The use of slag below water could give rise to problems with water pollution. There is a risk of corrosion if slag comes into contact with metals that corrode in an alkaline environment.

4.5.2 Steel Slag

Steel or Linz-Donawitz (LD) slag, is produced in the conversion of raw iron into steel using the Linz-Donawitz process. It is also referred to as Blast Oxygen Furnace Slag (BOF) slag. LD slag is produced in all the steel producing regions in South Africa, the most important of which are the Witwatersrand area, Newcastle in KwaZulu-Natal and the Saldhana region in the Western Cape. However, all the slag produced is suited to use as a road-building aggregate.

The chemical composition of steel slag depends on the method of production, but when cooled yields a product that resembles igneous rock, as illustrated in Figure 23. The suitability of all types of steel slag as an alternative to natural aggregates is viewed with caution. This is because, when freshly produced, they can contain both free calcium oxide (CaO) and free magnesium oxide (MgO) that originate from the limestone or dolomite used as flux in the smelting process. These oxides, in the presence of water, hydrate and swell leading to instability. Hydration times can be prolonged; it may take decades or even centuries for magnesium oxide and hard burnt lime to hydrate completely (Collins and Sherwood, 1995).



Steel Slag

Steel or Linz-Donawitz (LD) slag, is produced in the conversion of raw iron into steel using the Linz-Donawitz process. It is also referred to as Blast Oxygen Furnace Slag (BOF) slag.



Figure 23. Steel Slag as a Single Seal

Due to the presence of free lime and magnesium, with the consequent risk of expansion, the use of steel slags in road construction was viewed as being limited to situations where expansion is unlikely, e.g., where aggregate particles are coated with bitumen and water has difficulty penetrating the particle to cause hydration, and where any expansion that does occur is not likely to be a serious problem. Lieuw Kie Song and Emery (2001) reported that experience with LD slag in South Africa was not satisfactory. It was used as a base in roads in the Vanderbijlpark area, but the roads deteriorated quickly after construction and required reconstruction. The likely reasons given for the performance was swelling due to the presence of free lime which hydrated.

However, the process to remedy the expansive properties has improved and steel slag is now considered an alternative to natural aggregates in the road construction industry. To prevent expansion, the steel slag needs to be weathered prior to use. This is to hydrate the free calcium oxide, which if not done, results in water causing hydration and breaking down on the aggregate. In a steel slag mix, this is characterised by isolated white deposits from the formation of calcium carbonate, which pop out. Steel slag for road construction aggregate should be stockpiled for a minimum of 3 months and kept constantly wet by rain or water spraying. The storage or ageing is to allow potentially destructive hydration and the associated expansion to take place prior to using the material as an aggregate. There is wide variation in the amount of time required for adequate exposure to the elements. Up to 18 months may be required.



Using Steel Slag as an Aggregate in Asphalt or Crushed Stone Base

Before using steel slag as an aggregate in asphalt or in a crushed stone base, it is critically important that the material is pre-weathered to prevent expansion. It is not necessary to weather steel slag when used in seal work.

It is important to keep the stockpiles covered after weathering during rainy weather, and to open the covers during hot weather to facilitate drying. Because of the high permeability, the slag retains water, which makes drying during the mixing process more costly.

For seals, pre-weathering is not necessary because the stone is always exposed and minor fragmentation is not an issue. The smaller than 3 mm aggregate, when used in asphalt, is assumed to be coated completely by bitumen, and hence the pre-weathering is again not critical. Storage stockpiles of crushed fines for use in asphalt must be covered to ensure that they do not get wet. Moisture results in cementing and solidifying that requires additional breaking down.

It is not advisable to use steel slag as the fine aggregate in an untreated base as it is unlikely that the hydration and slaking process is complete. Hydration of the fines can result in cementing/solidifying the material, with the fines getting lumpy. This requires additional crushing. Crushing previously weathered aggregate for fines can mitigate the risk of unhydrated fines, and reduce the risk of expansion.

Since 2004, steel slag asphalt with an SBS polymer modified binder and penetration grade binder has been successfully used on the N3 Toll Concession roads. One of the steel slag sections is shown in Figure 24. See the side box for a case study. Work is currently underway to investigate ways to use steel slag as an aggregate for bases.



Figure 24. Steel Slag on N3TC Section

4.5.3 Non-Ferrous Slag

Non-ferrous slag is produced from the smelting of other metal ores. The use of these materials is not widespread, however ferro-chrome slag has been used fairly extensively on the N4 toll concession (TRAC). Potential problems with non-ferrous slags are that they may contain unstable components in the presence of water and/or that water leaching through them may contain harmful pollutants.



Non-Ferrous Slag

Non-ferrous slag is produced from the smelting of other metal ores.



South African Case Study: The Use of Steel Slag Asphalt on the N3 Toll Road

The N3 between Durban and Johannesburg is the most heavily trafficked route in South Africa. As a result of changes in traffic spectrum, steep gradients, variable moisture conditions and high road surface temperatures, it was necessary to find an alternative to conventional hot mix asphalt to improve durability, rut and skid resistance of the asphalt surfacing. In addition, the material needs to be workable and still show good fatigue properties. To overcome these challenges, steel slag aggregate was used. The information presented in this case study comes from Bouwmeester et al, "The Use of Steel Slag Aggregate in Hot-mix Asphalt in South Africa" (2008) and Mr Douglas Judd, Technical Manager of the N3TC.

Steel slag is a waste by-product of the steel making process. Utilising steel slag as an aggregate is a means to reduce the large waste stockpiles, as well as to preserve natural resources by not quarrying natural aggregates. The steel slag used on the N3 is from the ArcelorMittal works in Newcastle.

On the N3, steel slag was found to provide a high quality aggregate, with the following notable properties:

- The **particle density** of steel slag is denser and heavier, approximately 20% more than dolerite and quartzite. This impacts transport costs and less kilometres are covered for the same tonnage. However, depending on the location of the project, the higher haul cost can be compensated by the lower purchase price as the procurement cost of steel slag is significantly less than that of conventional aggregates.
- The **water absorption** (determined by standard test methods) is higher than dolerite and quartzite, because of the shape of some particles with cavities from the water cooling process, rather than the aggregate being porous. More binder is required to fill the cavities than with conventional aggregates. The use of a high softening point modified binder allows coating of the particles without filling all the cavities. Good practice procedures must be followed to manage and prevent segregation, which helps in managing the risk of interconnecting voids.
- The **pH** is between 8 and 11, and hence has a strong affinity to bitumen. This aids in retaining the binder coating, preventing stripping. This is important for long-term durability, especially in high moisture regions.
- Steel slag particles have a **cubical shape**, and therefore a dense packing. However, the **rough surface texture** makes compaction more difficult than with conventional aggregates. The binder content and binder filler ratio must be carefully controlled to ensure workability. Steel slag retains heat longer than conventional aggregate, aiding compaction.

The application of steel slag aggregates is only practical if the slag is stable with a low risk of expansion. Stability is indicated by the presence of free lime. Expansion, measured using the ASTM standard expansion test, must be below 7% for use in asphalt. The work on the N3 has indicated that the minimum weathering time in South Africa is 3 months at a moisture content exceeding 6%. The volumetric expansion should be tested.

For the N3 mix, a continuously graded coarse grading was used. Agricultural lime was used as a filler when the percentage fines were low, but generally the raw aggregate gradings can be managed to ensure a 100% steel slag mix. The binder was a Styrene Butadiene Styrene (SBS) polymer modifier, used because of its consistency and reduced temperature susceptibility, resilience and toughness, improved stability and cohesion, and improved binder aggregate adhesion. Even with the SBS binder, the mix is stiff and should only be placed on bases with relatively low deflections (< 400 μm). The binder copes with high daily and seasonal temperature fluctuations and meets the stability and flexibility requirements for high traffic. The binder also allows a sufficient film thickness coating of the steel slag particles, without filling all cavities of the hollow particles.

Various tests were done on the mix to assess the properties:

- **Marshall stability and flow** indicated the mix is stable and has some flexibility.
- **ITS test stiffness** was significantly higher than South African requirements, indicating the mix was ideally suited for rut resistance.
- **Gyratory testing** results exceeded the minimum South African standards. The mix would not be easily compacted under traffic.
- **Wheel tracking** results showed the mix had better deformation resistance than dolerite and some SMAs.

The first steel slag section was an approximately 150 mm thick asphalt inlay, constructed in 2004 on Van Reenen's Pass. In the first four years, the inlays carried approximately 18.5 MESA. The conventional mix used on Van Reenen prior to the steel slag asphalt typically started rutting within one year with a rut rate of up to 10 mm per year. At the time, a concrete inlay seemed to be the only solution. Annual performance measurements during the 6 years after construction show that the riding quality significantly improved, and remained below an IRI of 1.6 m/km, and rutting measurements remained below 2.5 mm. Some problems related to cracking were experienced, where the support was insufficient.

Subsequent to the use of steel slag asphalt on Van Reenen's Pass, it has been widely used on the N3 for inlays, overlays and new construction. At the end of 2011, approximately 400 lane km of the 1660 lane km N3TC network has steel slag asphalt. This equates to approximately 300 000 tons. In addition, there are approximately 420 lane km of single seals using steel slag aggregate.



South African Case Study: The Use of Ferro-chrome Slag in Construction on the N4 Toll Road

Since the initial construction phase of the N4 Toll Concession Contract, ferro-chrome slag has been identified and used as a versatile construction material. The information presented in this case study was provided by Mr Gawie Jordaan, Road Pavement and Materials Specialist, Trans African Concessions (Pty) Ltd (TRAC).

Three main sources of ferro-chrome slag waste material are found along the N4 toll road at: Witbank, from Samancor; Middelburg, from Ferralloys marketed by Enviro aggregates; and, Machadodorp, from Asmangchrome. The slag is usually crushed, either as part of the chrome extraction process at the works, or to specifically comply with various specifications. The pre-crushed slag is usually processed for road works by screening out required fractions for specific applications. Material processed in such a manner has been used for various purposes.

Potential negative aspects of using ferro-chrome slag include the possible presence of Chrome VI, which is considered toxic if leached out in the ground water, and blow holes in the slag that may lead to higher binder absorption in asphalt and seals.

On the N4, ferro-chrome slag has been used for drainage, layer works and asphalt. In excess of 175 000 tonnes of ferro-chrome slag asphalt have been used on the N4 by 2008. A paper on the use of the slag by Jooste, Verhaeghe and Jordaan was presented at the 1999 CAPSA.

(i) Drainage: The pre-crushed slag is screened to produce aggregate complying with the Standard Specification for drainage aggregate. Considerable quantities of the slag have been used for this purpose all along the N4. No problems have been experienced and the relatively coarse size particles of slag utilised for this application should only contain trace amounts of Chrome VI, and are therefore not considered a significant environmental hazard.

(ii) Layer Works: An attempt was made to use the crushed slag as a G1 or G2 base material. However, it required blending slag from various sources, as well as a small quantity of sand. A short, 300 metre, trial section was built for rehabilitation works between Belfast and Machadodorp on the N4/5X. It worked successfully after the correct grading was attained.

The ferro-chrome slag has been successfully used in mixtures with other natural soils and gravel layer materials to improve the properties of the material. By 2008, the following approximate quantities of slag have been used for this purpose:

- Rebuilding shoulders along the N4, mixed with in situ gravel: 5 500 m³ (10 000 t)
- Subbase construction on $\pm$ 30% of N4/5 (Wonderfontein to Belfast), mixed with borrow-pit material: 20 000 t

(iii) Asphalt: By far the most ferro-chrome slag used on the N4 has been for asphalt manufacture. At the asphalt plant, located in Witbank, the slag, mixed with pit sand, has been used for the production of asphalt for many years with great success. When the N4 was originally upgraded between 1999 and 2000, appreciable quantities of this type of asphalt was used for patching and mill and inlay work.

In 2004, the slow lanes of the first 14.8 km of the N4/3, west of Witbank, was inlaid with 40 mm of this particular ferro-chrome asphalt. Approximately 60 km of the N4/6N and N4/7N between Machadodorp and Montrose, through Watervalonder, was overlaid with 40 mm of ferro-chrome asphalt from Machadodorp. At that time, the ferro-chrome plant at Machadodorp had a significant quantity of crushed slag in stock with a grading that complied with the requirements of the continuous medium asphalt grading in the Standard Specifications. The crushed slag was used without further processing, but with small adjustments to the filler content. This was the first large scale use of ferro-chrome slag in asphalt. A complete series of design tests were conducted to ensure its suitability.

Other applications include an ultra-thin friction course (UTFC) overlay constructed on the N4/3 old concrete road in 2008. On the widened section between Wonderfontein and Belfast, a 35 mm asphalt surfacing was used.

Comments on the construction and performance of the asphalt:

- **Haul costs** increase by $\pm$ 20% compared to natural aggregates, due to the high relative density of the slag.
- **Water absorption** of the slag is relatively high due to blow holes in its structure. This may lead to a slightly higher binder content due to some binder being lost in these blow holes. However, there are no micro fissures in the slag as in some natural aggregates with high absorption, so that selective absorption of the bitumen is not considered to be a problem.
- Initially the **fatigue life** of the asphalt was doubted, but its performance exceeded expectations, even on pavements with relatively high deflections. After 11 years, the asphalt is still performing, although some sections have been sealed to improve skid resistance. The asphalt performs as well as, if not better, than conventional aggregates.

4.6 Fly Ash

Ash is produced as a by-product in a coal burning power station. Pulverized coal, in fine powder form, is burned in a furnace to produce electricity. As part of this process, a very fine, pulverized fuel ash (PFA) is produced and is carried out of the furnace with the flue gases. The coarser ash falls to the bottom of the furnace where it sinters and forms furnace bottom ash (FBA). Of the ash produced in a coal-fired power station, 75% to 85% of the ash is PFA. Various photos of fly ash are shown in Figure 25.

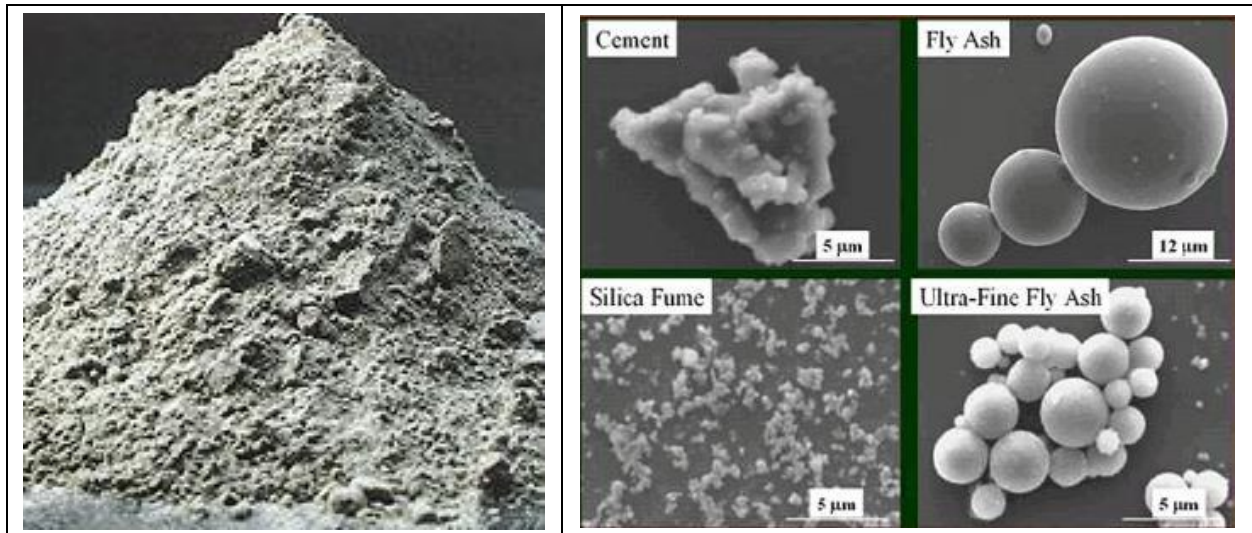


Figure 25. Fly Ash

PFA is removed from the flue gases by mechanical and electrostatic precipitators, collected, and usually, stockpiled. PFA is collected in hoppers in the dry form, or mixed with water and hydraulically transported, by pipeline, to waste stockpiles. Classified PFA is used as a cement extender in the production of concrete. PFA is a valuable bulk fill material for road construction. The following should be taken into consideration when using the material for this purpose:

- Grain shape and particle size make the upper layers of PFA **difficult to compact**.
- Freshly placed PFA behaves in a similar manner to silt and if not protected **may liquefy under wet conditions**.
- Capping and subbase layers tend to be **relatively permeable** and a layer of general fill over PFA is considered desirable to add some protection.
- PFA has a **relatively low density** compared to other natural fill materials.
- PFA is usually compacted to an **end-product specification**.
- PFA may possess **self-cementing properties** when compacted. Should hardening occur, settlement within the PFA fill will be less than with other materials.
- The **composition and properties** of PFA from different power stations may vary significantly.
- PFA is not suitable for **selected or subbase** layers.

FBA (clinker ash) is a coarse granular material ranging in particle size from fine sand to coarse gravel. The grading makes it suitable for selected and natural subbase. Because the particles have a porous structure, they tend to be relatively weak compared to most granular materials.

Work carried out by the CSIR, Transportek (Lea and Heath, 1999) showed that clinker and fly ash produced as a by-product of the coal gasification process at the Sasolburg plant in South Africa could be successfully utilized, when processed and blended in optimal proportions, as base for the construction of low volumes roads. Although the ash material did not perform as well as a 100 mm crushed stone base, it was equivalent to good quality natural gravel. The cost of construction of the base sections constructed using clinker ash was less than half of that of crushed stone, despite the fact that the test sections were located over 150 km from the Sasol plant.

Tohoku Electric Power (2008) report on their website on research being carried out to use coal ash as a substitute for filler for asphalt mixtures in road paving works. In this research project, the fillers made from coal ash were used at three road construction points on a national highway in Akita prefecture (Japan). Tohoku and the Tohoku

Regional Bureau of Ministry of Land, Infrastructure and Transport have jointly developed the technology to use coal ash (clinker ash) as banking materials for road construction. This technology has been adopted in the "Guideline for Utilization of Coal Ash for Road Banking and Displaced Soil at Construction" (2008).

4.7 Mine Waste

South Africa is home to a large mining industry that produces massive quantities of waste rock products. Typically, these waste materials are spoiled in mine dumps. These dumps are potentially good sources of sound rock for crushing to produce aggregates for construction. The use of this type of waste has significant positive environmental impacts. An example of an old mine dump in Stilfontein, which is being used as a source of crushed rock, is shown in Figure 26.



Figure 26. Crushed Rock from a Mine Dump

The old gold mine dumps at South Deep Gold Mine were excavated to produce gold-bearing fines. As a by-product, aggregate of various sizes for use in road works were produced. The final outcome of the project is that an unsightly mine dump will be removed in its entirety, creating rehabilitated open land which will become available for further development.

Another example of mine waste being recycled to produce road construction materials is from an old copper mine in Musina in Limpopo. This mine dump is producing commercial aggregates. The mine spoil consists of a mixture of rock types comprising quartzite, granite and slag. After processing, (crushed) spoil has been successfully used for:

- G1 base
- 13.2/6.7 mm surfacing aggregate
- Concrete aggregate

In all cases, processes mine waste should conform to the Standard Specifications, or other applicable specifications. The description for G1 material in the Standard Specifications allows for the use of mine waste: *"Parent material: Sound rock from an approved quarry, or clean, sound mine rock from mine dumps, or clean sound boulders."*

Prior to using aggregates derived from mine waste, an appropriately scoped testing programme should be carried out to confirm the quality of the material. Also, it must be confirmed that the material does not contain any toxic substances potentially considered an environmental hazard.

4.8 Other Alternative Materials

Alternative materials include many types and compositions as indicated in Table 25 and Table 26. Other than the usual, RA, slag and ashes, materials such as demolition waste, broken glass, used tyres, incinerator ash and many other types of waste product can be used in construction. It should be noted, however, that in many cases, the maximum benefit can be achieved by using a waste product for its primary purpose, i.e., glass should be recycled as glass before being considered for use in roads, and tyres should firstly be employed for their unique rubber properties before being used as a fill in roads.

Other than the more usual materials described earlier, many trial sections have been built around the world using unusual waste materials. The results, however, have either not been widely publicised, the roads have failed or

there has been resistance to wider use of the materials. Similarly, various other waste materials, e.g., neutralised manganese tailings, have been investigated and used in trial sections in South Africa, but have not been adequately followed up.

A good example of this locally has been work carried out on the use of phosphogypsum as a road base. Following extensive research in the United States, leading to the construction initially of trial sections and later full-scale roads, the material was investigated in South Africa in the 1990s. The basic properties of a material produced in Midrand were compared with those of the United States materials and found to be similar. A laboratory investigation using cement stabilization of the material was carried out and similar properties to those in the United States were obtained. A trial section of road was constructed and monitored and excellent results were obtained (Paige-Green and Gerber, 2000). The section is shown in Figure 27. However, during a site inspection by local engineers, despite the excellent road being inspected, after looking at the basic phosphogypsum material (a flour-like powder), it was decided that roads could not be built with such a fine material and no further interest in the product was shown. This product is available in large quantities at about 6 plants around South Africa.



Figure 27. Example of South African Road Built with Phosphogypsum

South African engineers are often quite conservative and although many sources of possible construction materials such as phosphogypsum are available, there has been little motivation or innovation towards using them or even carrying out the fundamental research necessary to prove or disprove their potential benefits in road construction.

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TRH Revisions

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