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MINISTRY OF ROADS AND TRANSPORT

RDM 3.1

Road Design Manual

Volume 3: Materials and Pavement Design for New Roads

Part 1: Ground Investigations and Materials Prospecting

2025

Chief Engineer (Materials)
Materials Testing & Research Division
State Department for Roads
Ministry of Roads and Transport
Machakos Road, Industrial Area
P.O. Box 11873 - 00400
NAIROBI

Principal Secretary
State Department for Roads
Ministry of Roads and Transport
Works Building
Ngong Road
P.O. Box 30260 – 00100
NAIROBI

Foreword

This manual was developed by the Ministry pursuant to The Fourth Schedule of the Constitution which assigns to the National Government the functions and powers of setting standards for the construction and maintenance of all public roads including those under the County Governments.

It is part of a series of manuals that replace the first generation of road manuals developed in the first and second decades after independence. This second generation of the road manuals were developed to cover the entire road project cycle covering planning, appraisal, design, contracts, construction, maintenance, operations and monitoring. The series incorporates best practices, climate change considerations, and recent technologies to enable the provision of road infrastructure that is safe, secure, and efficient.

Under the Kenya Vision 2030 long term plan, infrastructure expansion and modernisation are some of the foundations for the realisation of economic, social and political transformation of Kenya into a rapidly industrialising middle-income country. The plan envisages an integrated, safe and efficient transport and communication infrastructure network consisting of roads, railways, ports, airports, waterways, and telecommunications infrastructure.

The strategies to be pursued under the Vision 2030 plan to improve infrastructure services and to maximise the economic and social impacts of infrastructure development and management include: Strengthening of the institutional framework for infrastructure development and maintenance; Raising efficiency and quality of infrastructure projects; Enhancing local content of identified infrastructure projects to minimise import content; Benchmarking infrastructure facilities and services provision with globally acceptable performance standards; and, Implementing infrastructure projects that will stimulate demand in hitherto marginalised areas.

The first three 5-year Medium Term Plans (MTP) under the Vision 2030 from 2008 to 2022 targeted construction of 1,950 km, 5,500 km and 10,000 km of new paved roads under MTP I, II and III, respectively, totalling 17,450 km. This was a massive infrastructure development program intended to double the paved road network in 10 years compared to 8,600 km developed from independence in 1963 to 2008.

Implementation of MTP I to III resulted in the construction of 14,000 km of paved roads, which extended the paved road coverage to Arid and Semi-Arid regions, that had been previously neglected. However, some key milestones of the Vision 2030 goals have not been realised. This has been due to internal and external challenges. External challenges included: climate change – prolonged droughts; the emergence of COVID-19 pandemic; global supply chain disruptions; exchange rate volatility; and rising interest rates in the leading economies.

The internal challenges included: inadequate road maintenance equipment; pavement overloading by heavy goods vehicles; huge maintenance backlog of the road network; low contracting and supervision capacity particularly in the Counties; poor quality control and assurance of works; congestion in urban areas; encroachment on road reserves; high costs and delays in payments of land acquisition; lack of harmonisation of cross-border transport regulation and operational procedures; rapid urbanisation; increased traffic volume with exponential growth of motorcycle traffic; high cost/delays in relocation of utilities and services along and across road reserves; inadequate funding of projects and programs; and, delay or default in payments for goods, services and works.

The implementation of MTP III came to an end on 30th June 2023, ushering in the implementation of the Fourth Medium Term Plan (MTP IV), which has been aligned to the aspirations of the Kenya Vision 2030 and the Kenya Kwanza Government’s Bottom-Up Economic Transformation Agenda (BETA) planning approach and its key priorities.

BETA is the Government's transformation agenda geared towards economic turnaround through a value chain approach. BETA has targeted sectors with the highest impact to drive economic recovery and growth. This will be achieved through bringing down the cost of living; eradicating hunger; creating jobs; expanding the tax base; improving foreign exchange balances; and inclusive growth. BETA ensures rational resource allocation by eliminating wastage of resources occasioned by duplication, overlaps, fragmentation and ineffective coordination in the implementation of programmes and projects.

The Fourth Medium Term Plan key priorities are clustered under five key sectors, namely: Finance and Production; Infrastructure; Social; Environment and Natural Resources; and Governance and Public Administration. The infrastructure sector seeks to: enhance transport connectivity by constructing 6,000 km of new roads, maintaining rural and urban roads, rail, air and seaport facilities and services; expand communication and broadcasting systems; and promote the development of energy generation and distribution by increasing investments in green energy (geothermal, wind, solar and hydro). The infrastructure gap is expected to be bridged by promoting economic participation of the private sector through public private partnerships in the financing, construction, development, operation, and maintenance of infrastructure.

The plan entails a shift of focus to fundamentals in project planning and implementation which include: respect for technical input, regulations and standard practices; adherence to project life cycle i.e., planning, feasibility studies and design before procurement of works; public and stakeholder consultation; procurement within budgetary ceilings; shifting focus during project implementation from the finished product ‘black top’ to the construction of the foundation; building local capacity particularly MSMEs by ensuring prompt payments; and capacity building at all levels to enable internalisation of policies and processes.

The first generation of the road manuals were used for 35 to 45 years. It is my sincere hope that the second generation of the road standards which have been developed in alignment with the Government’s strategy will provide guidance in solving most of the above challenges and those expected to emerge in the next 50 years. Implementation of the manuals will enable achievement of the Government aspirations which include inclusive growth; creation of sustainable employment; building of MSMEs; climate change adaptation and realisation of the UN SDGs; enhanced efficiency in management of infrastructure and transport system; and, laying the foundation for the next national long-term plan at the end of the Vision 2030.

On behalf of the Government of Kenya, I would wish to thank the European Union for financing the development of the first drafts of the manuals in 2009 and the African Development Bank for the financial support in the review and updating of the manuals. I would also like to thank the members of the National Steering Committee and the Technical Task Force for their input. The Technical Administrators, and the Kenya National Highways Authority (KeNHA) for the procurement and able administration of the consultancy Contract. I also thank the Consultant, TRL Limited for their role in providing technical expertise that was essential for the success of the manuals updating exercise. I also wish to express my deepest appreciation to our stakeholders and all those who have contributed to this process and the staff of the Ministry for their continued input.

Hon. Davis K. Chirchir, E.G.H
Cabinet Secretary, Ministry of Roads and Transport

Preface

This Part of Volume 3 provides the standard best practice for use in field investigations of road alignments. Health, safety and environmental concerns during conducting of materials investigations are addressed within this Part. In addition, the personnel required to conduct field investigations are specified.

The procedures for planning and conducting field investigations at both the preliminary and detailed design stage are covered. The interval for conducting alignment field tests such as dynamic cone penetration tests, test pit excavation, field density tests, among others is included. Field tests for determining the design properties of cut slopes, embankments, structures and problematic soils are described. The criteria to guide in the applicability of the different field tests to use for determining particular material properties is also included.

The materials sampling and testing programmes applicable to the feasibility and preliminary design stage as well as the detailed design stage have been specified. In addition to the different types of field investigations, the procedures and tests required for prospecting of alignment material sources such as gravel, hard stone, natural sand and water have also been described.

The findings from the field investigation shall be recorded in a factual materials report for road alignment investigations or geotechnical report for geotechnical investigations. This shall be complimented by an interpretative report detailing the analysis and providing information required for design. Typical layouts for these reports have been included in this Part.

By following the steps set out in this Part, Design Engineers should be able to conduct ground investigations and obtain reliable information. The information obtained shall be used to produce an economic and safe design that meets tender and construction requirements.

Eng. Joseph M. Mbugua, CBS
Principal Secretary, State Department for Roads

Document Management

Document Status

This document has the status of a Manual. Users shall apply the contents there-in to fully satisfy the requirements set out. The content of the manual is based on current practice in Kenya and latest practices in the road sector, both regionally and internationally.

Sources of the Document

Copies of the document can be obtained from:
The Principal Secretary, State Department for Roads, Ministry of Roads and Transport, Works Building, Ngong Road, P.O. Box 30260 - 00100, NAIROBI Email: ps@road.go.ke

A secured PDF copy may be downloaded from: www.roads.go.ke/downloads

Notification of Errors and Requests for Amendments

While all care and consideration has been applied in the compilation of this document, the Ministry accepts no responsibility for failure in any way related to the application of this manual or any reference documents cited in it.

Requests for edits and corrections can be freely sent to the following address:
The Principal Secretary, State Department for Roads, Ministry of Roads and Transport, Works Building, Ngong Road, P.O. Box 30260 - 00100, NAIROBI Email: ps@road.go.ke

Amendments Request Form Format

Request No.	Name	Organisation	Chapter	Page	Section/ Clause	Ref. to: Figure/ Table/	Type of Request	Request

Type of request: General – G; Editorial – E; Technical - T

Amendments to Date

Amendment No.	Details of Amendments	Amendment Effective Date	Amendment Approved by

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The technical work was undertaken under the guidance of a Technical Task Force, chaired by Eng. David Maganda, with the following gazetted members: Francis Gichaga (Prof.) (Eng.), Andrew Gitonga (Eng.), Timothy Nyomboi (Dr.) (Eng.), Rosemary Kungu (Eng.), Charles Obuon (Eng.), Sylvester Abuodha (Prof.) (Eng.), Samuel Kathindai (Eng.), Nicholas Musuni (Eng.), Charles Muriuki (Eng.), Tom Opiyo (Eng.), John Maina (Eng.), Fidelis Sakwa (Eng.), Daniel Cherono (Eng.), Maurice Ndeda (Eng.), Theo Uwamba (Eng.).

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Abbreviations

ACV	Aggregate Crushing Value
ALD	Average Least Dimension
API	Aerial Photograph Interpretation
AS	Auger Sampler
ASTM	American Society For Testing and Materials
bF	Smaller Side Length of the Foundation
BS	British Standard
CBR	California Bearing Ratio
CPT	Cone Penetration Test
CPTM	Mechanical Cone Penetration Test
CR	Crushing Ratio
DCP	Dynamic Cone Penetrometer
CS	Core Sampler
DP	Dynamic Probing
EN	European Norme
ERT	Electrical Resistivity Tomography
ESCS	European Soil Classification System
ESP	Exchange Sodium Percentage
FDP	Full Displacement
FI	Flakiness Index
FVT	Field Vane Shear Test
GCS	Graded Crushed Stone
GPR	Ground Penetrating Radar
GPS	Global Positioning System
HF	Hubbard - Field
ISO	International Standard Organisation
LAA	Los Angeles Abrasion
LL	Liquid Limit
MC	Moisture Content
MDD	Maximum Dry Density
MTRD	Materials Testing and Research Directorate
MWD	Measuring While Drilling
NGDC	National Geodata Centre
OCR	Over Consolidation Ratio
OMC	Optimum Moisture Content
OS	Open Sampler
pH	Power of Hydrogen
PI	Plasticity Index
PIL	Pile Load Test
PL	Plastic Limit
PLT	Plate Load Test
PM	Plasticity Modulus (Product of PI and % Passing 0.425 mm Sieve).
PMT	Pressuremeter Test
PS	Piston Sampler
RDM	Road Design Manual
RQD	Rock Quality Designation
SG	Specific Gravity
SPT	Standard Penetration Test
SSS	Sodium Sulphate Soundness
TP	Test Pit Sampling
TSS	Total Soluble Salts
UCS	Unconfined Compressive Strength
VH	Vibrating Hammer

Symbols

C_u	Uniformity coefficient $C_u = D_{60}/D_{10}$ Where D_{60} and D_{10} are the sieves which 60% and 10% pass,
C_c	Curvature Coefficient $C_c = (D_{30})^2/ (D_{10} \times D_{60})$ Where D_{60}, D_{30} and D_{10} are the sieves which 60% 30% and 10% pass, respectively.
C_l	Clay
G_r	Gravel
S_a	Sand
S_i	Silt
z_a	Depth below the lowest point of the foundation of the structure.

Glossary of Terms

Authority	The term is applicable to a road authority in Kenya having the control and jurisdiction over a specific road.
Borrow Area	A site from which natural material, other than solid stone, is obtained for pavement construction works. (The term borrow pit is also used.)
Collapsible Soil	Soil which is susceptible to sudden reduction in volume upon wetting.
Dispersive Soils	Soils which by their mineralogy and pore water chemistry, are susceptible to separation in water of individual clay particles.
Expansive Clay	Clay soil that is prone to large volume changes (swelling and shrinking) that are directly related to changes in water content.
Formation	The surface of the ground, in its final shape, upon which the pavement structure, consisting of subbase, base and surfacing is constructed.
Graded Crushed Stone	A base or subbase material, conforming to the grading, strength, shape, and soundness criteria given in Vol. 3, Part 4.
Gravel	This is one or a combination of the following materials: lateritic gravel, quartzitic gravel, calcareous gravel, some forms of partly decomposed rock, soft stone, coral rag, clayey sands, and crushed rock.
Gravel Wearing Course	The top surfacing course made from gravel and applied to a road formation where no pavement or bituminous surfacing is to be placed.
Hard Rock	The term is applicable to rock with a Mohs hardness greater than or equal to 5 (UCS > 7.5 Mpa).
Improved Subgrade	A layer of selected fill material, the top of which is at formation level, placed where the natural in-situ or fill material is unsuita-ble for the direct support of the pavement.
Improved/Modified Materials	These are naturally occurring gravels and clayey sands which are deficient in desirable properties and may be 'improved' by the addition of either lime or Portland cement. Engineering proper-ties such as strength and plasticity are improved but the material remains flexible. Improved materials may be suitable for either subbase or base.
May	This indicates that a statement is optional.
Quarry	An open surface working from which stone is removed by drilling and blasting, for construction of the works.
Shall	This indicates that a statement is mandatory.
Should	This indicates that a statement is a recommendation.
Soft rock	The term is applicable to rock with a Mohs hardness less than 3.
Subgrade	The material below the pavement and may include in-situ material, fill and improved subgrade.
Surfacing	The uppermost pavement layer which provides the riding surface for vehicles. It will normally consist of one of the following: surface dressing, sand asphalt or asphalt concrete.

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1 Introduction

1.1 General

This Manual was prepared by the Ministry as part of a series of manuals that cover the entire project cycle. The series incorporate best practices, climate change considerations, and recent technologies to enable the provision of road infrastructure that is safe, secure, and efficient.

The Roads Manual is composed of the following documents:

Project Cycle Stage	Manual: Volume or Part/Chapter	Code
A. General	**Procedures and Standards Manual**	**PSM**
	1. General	
	2. Policies	
	3. Procedures Guidance	
	4. Codes of Practice	
	5. Guidelines	
	6. Product/Testing Standards	
B. Planning	**Network and Project Planning Manual**	**NPM**
	1. Road Classification	
	2. Route/Corridor Planning	
	3. Route/Corridor Planning	
	4. Highway Capacity	
	5. Project Planning	
C. Appraisal	**Project Appraisal Manual**	**PAM**
	1. Environmental Impact Assessment and Audit	
	2. Social Impact Assessment	
	3. Traffic Impact Assessment	
	4. Road Safety Audits	
	5. Project Appraisal	
	6. Feasibility Studies	
D. Design	**Road Design Manual**	**RDM**
	1. Geometric Design	
	2. Hydrology and Drainage Design	
	3. Materials and Pavement Design for New Roads	
	4. Bridges and Retaining Structures Design	
	5. Pavement Maintenance, Rehabilitation and Overlay Design	
	6. Traffic Control Facilities and Communication Systems Design	
	7. Road Lighting Design	
E. Contracts	**Works and Services Contracts Manual**	**WSCM**
	1. Forms of contracts	
	2. Standard Specification for Road and Bridge Construction	
	3. Bills of Quantities	
	4. Standard/Typical Drawings	
F. Construction	**Road Construction Manual**	**RCM**
	1. Construction Management	
	2. Project Management	
	3. Site Supervision	
	4. Quality Assurance	
	5. Quality Control	

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Project Cycle Stage	Manual: Volume or Part/Chapter	Code
G. Maintenance	**Road Asset Management Manual**	**RAAM**
	1. Maintenance Management	
	2. General Maintenance	
	3. Pavement Maintenance	
	4. Bridges and Structures Maintenance	
H. Operations	**Road Operation Manual**	**ROM**
	1. Traffic Management	
	2. Vehicle Load Control	
	3. Emergency Services	
	4. Tolling	
I. Monitoring & Evaluation	**Road Design Manual**	**MEM**
	1. Performance Monitoring Manual	
	2. Technical Audits	
	3. Poverty, Gender Equality and Social Inclusion Monitoring	

This Road Design Manual, Volume 3, Part 1 – Ground Investigations and Materials Prospecting is part of the Roads Design Manual made up of a series of volumes and shown below:

Table 1.1 Road Design Manual (RDM) Coding Structure

Vol.	Manual Title	Part Name	Code
1	**Road Design Manual: Vol. 1** Geometric Design	**Part 1** - Topographic Survey	RDM 1.1
		Part 2 – Traffic Surveys	RDM 1.2
		Part 3 – Geometric Design of Highways, Rural and Urban Roads	RDM 1.3
2	**Road Design Manual: Vol. 2** Hydrology & Drainage Design	**Part 1** – Hydrological Surveys	RDM 2.1
		Part 2 – Drainage Design	RDM 2.2
3	**Road Design Manual: Vol. 3** Materials & Pavement Design for New Roads	**Part 1** – Ground Investigations and Material Prospecting	RDM 3.1
		Part 2 – Materials Field and Laboratory Testing	RDM 3.2
		Part 3 – Pavement Foundation and Materials Design	RDM 3.3
		Part 4 – Flexible Pavement Design	RDM 3.4
		Part 5 – Rigid Pavement Design	RDM 3.5
4	**Road Design Manual: Vol. 4** Bridges & Retaining Structures Design	**Part 1** – Geotechnical Investigation and Design	RDM 4.1
		Part 2 – Bridge and Culvert Design	RDM 4.2
		Part 3 – Retaining Structures Design	RDM 4.3
		Part 4 – Reinforced Fill Structures Design	RDM 4.4
		Part 5 – Bridges and Structures Condition Survey	RDM 4.5
		Part 6 – Bridge Maintenance Design	RDM 4.6
5	**Road Design Manual: Vol. 5** Pavement Maintenance, Rehabilitation & Overlay Design	**Part 1** – Pavement Condition Survey	RDM 5.1
		Part 2 – Pavement Maintenance, Rehabilitation and Overlay Design	RDM 5.2
6	**Road Design Manual: Vol. 6** Traffic Control Facilities & Communication Systems Design	**Part 1** – Road Marking	RDM 6.1
		Part 2 – Traffic Signs	RDM 6.2
		Part 3 – Traffic Signals and Communication System	RDM 6.3
		Part 4 – Other Traffic Control Devices	RDM 6.4
7	**Road Design Manual: Vol. 7** Road Lighting Design	**Part 1** – Grid-connected Road Lighting	RDM 7.1
		Part 2 – Solar Road Lighting	RDM 7.2

This Manual must be applied sensibly and flexibly in conjunction with the skill and judgement of the Design Engineer. Compliance with the guidance given in the Manual does not relieve the Design Engineer of the responsibility for establishing that their design is suitable, appropriate, safe and adequate for the purpose stated in the project requirements.

1.2 Objectives of this Part

This Part is intended to provide guidance on planning, implementation and reporting of road alignment ground investigations and materials prospecting for design purposes.

The primary objectives of ground investigations and materials prospecting are as follows:

a. To assess the general suitability of the site and environs for the proposed works.

b. To advise on the relative suitability of different sites, or different parts of the same site.

c. To enable an adequate and economic design to be prepared, including the design of temporary works.

d. To plan the best method of construction; to foresee and provide against difficulties and delays that may arise during construction due to ground, groundwater and other local conditions; in appropriate cases.

e. To explore sources of indigenous materials for use in construction and to advise on the relative suitability of different sites, or different parts of the same site.

f. To select sites for the disposal of waste or surplus materials.

g. To determine the changes that may arise in the ground and environmental conditions, either naturally or as a result of the works, and the effect of such changes on the works, on adjacent works, and on the environment in general.

h. Reporting upon the existing works and investigating cases where failure has occurred.

1.3 Scope of this Part

This Part covers planning and conducting field ground investigations and materials prospecting. Considerations for efficient undertaking of field investigations and guidance in selection of field tests are discussed. In addition to the different types of field investigations, the procedures and tests required for prospecting of material sources such as natural gravel, sand, water and hard stones, are described. Layouts for materials field and geotechnical investigations reports are also provided.

1.4 Organisation of the Manual

This Part of the Manual comprises twelve chapters. The first chapter is an introductory chapter. Major considerations prior to undertaking field investigations are discussed in Chapter two. Chapter three covers the different soil and rock types in Kenya.

Steps for undertaking a desk study, sources of information and the field reconnaissance survey are described in Chapter four. Test methods for the field, alignment investigations, and ground investigations at structures are discussed in Chapters five, six and seven, respectively. The different tests and sampling procedures for alignment materials such as gravels; stone quarries; sand and fine aggregates; and water sources are covered in Chapters eight to eleven, respectively. The final chapter covers the layout of the investigation reports and field forms.

This Part describes the materials sampling and testing programmes applicable to the feasibility and preliminary design stage as well as the detailed design stage of new roads. The reference test standards for field and laboratory tests by which the materials sampled following the procedures provided in this Part can be tested are covered in RDM Volume 3 **Part 2**. The detailed pavement design procedure is covered in RDM Volume 3 **Part 3**.

1.5 Departure from Standards

Where the designer departs from a standard, written approval must be obtained from the Chief Engineer for Roads.

In seeking approval of a departure from standards, a designer should submit the following information according to the standard format prescribed in the preliminaries to thin manual:

1. The number, name, and description of the road section,
2. The design parameter for which a Departure from Standards is desired,
3. A description of the standard, including normal value, and the value of the Departure from Standards,
4. The reason for the Departure from Standards,
5. Any mitigation to be applied in the interests of safety, and
6. Justification for the departure.

The approval of departures by the Chief Engineer for Roads may involve a consultative process in accordance with the guidance in the procedures and guidelines manual, or statutes governing public consultations.

2 Preliminary Considerations

2.1 General

Road design may be divided into two stages, namely the feasibility study and preliminary design stage and the detailed design stage. The detailed design stage is usually followed by construction that requires testing during implementation and supervision. For field investigations, consideration shall be given to health, safety and environmental concerns. Care should also be taken to ensure that all necessary design information is obtained and that trained personnel are present during testing.

2.2 Health, Safety and the Environment

All site investigations for materials, including water sources, shall comply with the stipulated Occupational Safety and Health Act of Kenya and all environmental legislation. Site specific risk assessment and work method statements should be established. It shall be the responsibility of the entity undertaking the work to prepare a Health, Safety, and Environmental plan prior to commencement of any fieldwork for the Client to approve.

All hazards and risks associated with a task shall be identified and the necessary measures to mitigate against their occurrence put in-place. When undertaking any activity that does or can have an impact on safety, either directly or indirectly, risk assessment and management shall be carried out in accordance with legislation and the procedure set out in the Occupational Health and Safety Act of Kenya.

The risk of exposure to environmental hazards such as noise, fire incidents, chemical spills and adverse events of equipment malfunction shall be identified for each activity. Environmental risks such as poor visibility while driving due to heavy rains; heat stroke and/or dehydration due to working in full sun; slipping, tripping or falling on wet rock outcrops or getting stuck in mud; and drowning when working on or near water should also be assessed. Adequate measures shall be put in place for every activity to eliminate or minimise hazards and thereby avoiding the risk.

All workers shall be entitled to the highest possible level of protection against harm to their health, safety and welfare. They shall all be trained as to the necessary safety precautions for undertaking each task. The field team should carry a first aid box. Members must be aware of how to give first aid.

Every worker shall be provided with appropriate personal protective equipment (PPE) to mitigate against the risks identified for each activity. Regular and continuous toolbox talks and trainings shall be conducted to ensure ongoing compliance with best practices in safety. Incident reports shall be filed with the Health and Safety Officer and mitigation measures revised to avoid reoccurrences.

Respect must be paid to local customs and problems, and local contacts. Local Community groups, Local Authorities, Police etc shall be consulted for information and possible contact names before setting out. When undertaking work in hostile environments, it might be necessary for the sociologist to go ahead of the team.

2.3 Personnel for Ground Investigations and Materials Prospecting

A trained Materials/Geotechnical Engineer or Geologist shall always be present during field materials investigation to oversee ongoing activities and ensure that the necessary health, safety and environmental procedures are being followed. Technicians and/or technologists with experience in undertaking the field activities shall be responsible for undertaking the field activities.

Where training of new staff is necessary, care shall be taken to ensure that the safety precautions are put in place and that the accuracy of the field observations is not affected. Field results logged by the Technician shall be approved by the supervising Materials/Geotechnical Engineer who should be present on site.

The Design Engineer shall also be responsible for ensuring that the materials sampled are tested accordingly in the laboratory. The Design Engineer shall also be responsible for approving the laboratory test results. Their signature of approval shall appear on both the field logs and laboratory test results.

2.4 Investigation Strategy

The investigation process shall comprise a desk study, site reconnaissance, submission of a preliminary test plan for approval at the preliminary design stage, and a detailed investigation test plan at the detailed design stage.

All site investigations shall begin with a desk study to identify sources of information such as aerial maps, soil and geological maps, materials reports within the project area. Reference shall also be made to the relevant survey information for the project road. During the desk study project requirements such as materials specifications and road length shall be determined. Possible material sources shall be identified, and a provisional materials map developed.

This shall be followed by a reconnaissance survey to plan the field investigation including the type of investigation, equipment required and any site restrictions. The materials map shall guide the reconnaissance survey along the project length and the investigation plan following thereof. A preliminary testing plan shall be prepared thereafter.

2.5 Project Planning

Before commencing field investigations, all relevant information collected from the desk study should be considered together to obtain a preliminary conception of the ground conditions and the engineering problems that may be involved.

Preliminary investigations are necessary to ensure that the detailed investigation is planned efficiently and that it addresses any gaps identified from the preliminary investigation.

Field investigations should be largely completed before the design is concluded. Therefore, sufficient time should be allowed for field investigations (including dealing with all legal, environmental, contractual and administrative matters, reporting and interpretation) in the overall design programme.

2.6 Control and Monitoring

The preliminary investigation plan and detailed investigation plans shall gain approval from the Client before commencement of field investigations. The imposition of limitations on the amount of field investigation to be undertaken, on the grounds of cost and time, may result in insufficient information being obtained to enable the works to be designed, tendered for and constructed adequately, economically and on time. Additional investigations carried out at a later stage may also prove to be more costly and result in delays.

Consequently, the Design Engineer and Client need to ensure that investigations approved in the detailed investigation plan are adequate to produce a reliable design. It is essential therefore that there is adequate direction and supervision of the work by competent personnel who have appropriate knowledge and experience and the authority to decide on variations to the ground investigation when required.

3 Types of Soils and Rocks in Kenya

3.1 General

Soils can be classified based on their composition such as particle size distribution, plasticity and geological origin. The different soil and rock types in Kenya are described in this chapter. The soils and geological maps of Kenya are given as an indication of materials distribution in Kenya, in Appendix A. The Design Engineer shall consult all relevant documents concerning the project area, such as materials reports, geological and pedological maps and reports during the desk study.

3.2 Classification of Kenyan Soils

3.2.1 Types of Soil in Kenya

There are seven major categories of subgrade soils in Kenya. These can be classified as red friable clays, sandy clays on volcanic rocks, ash and pumice soils, sandy clays on basement rocks, silty loams on gneiss and granite, coastal sands, and black heavy clays (expansive clays). The gravel types in Kenya include lateritic gravels, quartzitic gravels and calcareous gravels. Some forms of weathered rock, soft rock, and coral rag, as well as various types of sand and silty or clayey sands are also available.

3.2.2 Classification of Soils for Engineering Purposes

Alignment soils shall be described and classified in accordance with BS EN ISO 14688-2. **Except that sand soils shall have a gradation of 2 mm to 75 µm, and fine soils shall be classified as soils passing the 75 µm**. This amendment in line with the Kenya national reference is presented in Table 3.1. For guidance on presentation of the results, a form is included in Appendix B.

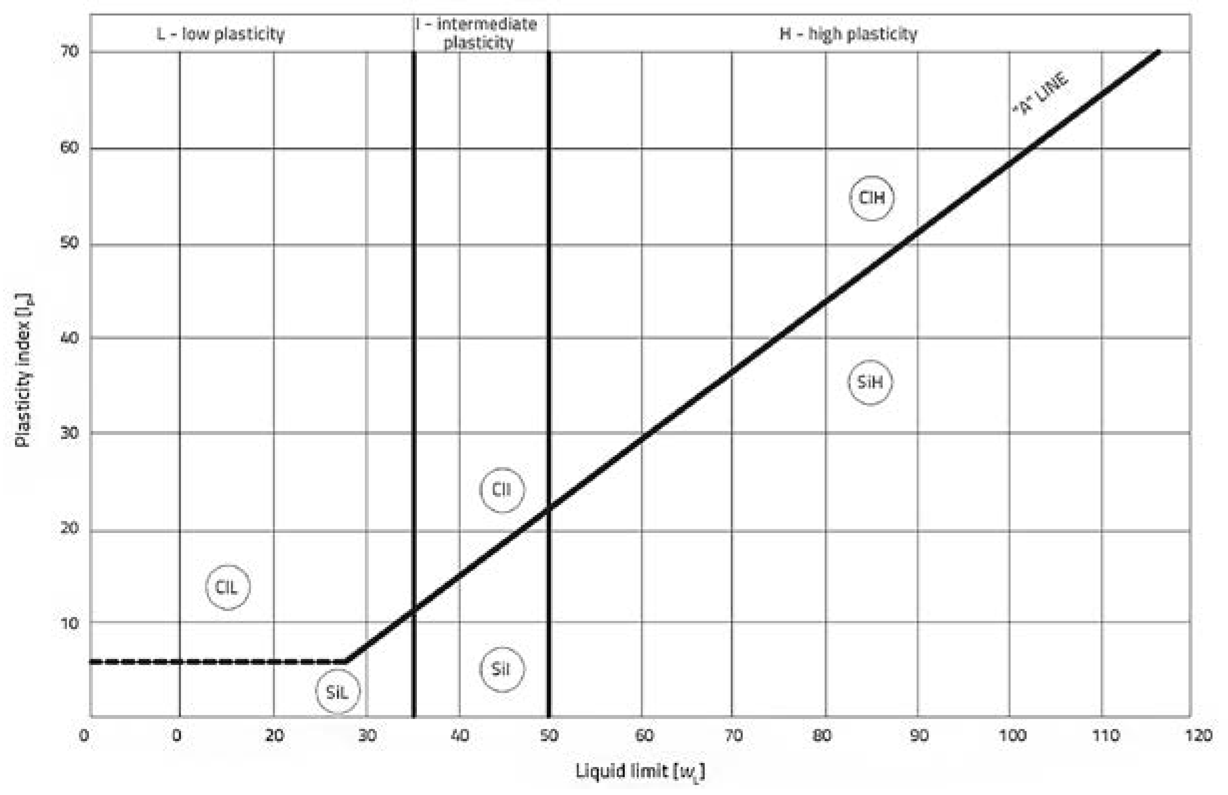
The description shall cover the physical nature and state of the soil based on a visual examination of the soil in-situ or samples taken, simple field tests, site condition and geological history. Soils with similar characteristics and behaviour are classified based on the laboratory test results for gradation and plasticity. The detailed classification procedure is summarised in Table 3.1 and Figure 3.1 to Figure 3.4.

Table 3.1 Kenya Classification of Soil Purposes Based on BS EN ISO 14688-2:2018

Soil Group				Laboratory Identification			Soil Classification	
Division	**Primary Fraction**	**Composite Fraction**	**Group Symbol**	**Fine (% < 0.075 mm)**	**Iniformity Coefficient & Curvature Coefficient**	**Liquid Limit %**	**Symbol**	**Name**
COARSE SOILS less than 35% of the material is finer than 0.075 mm	**GRAVELS** More than 50 % of coarse materials is of gravels size *(coarser than 2 mm)*	Slightly silty or clayey GRAVEL		0 to 5	$c_u \geq 15$ & $1 \leq c_c \leq 3^C$		**GrW**	Well graded GRAVEL
					$6 \leq c_u < 15$ & $c_c < 1^C$		**GrM**	Medium graded GRAVEL
					$3 \leq c_u < 6$ & $c_c < 1^C$		**GrP**	Poorly graded GRAVEL
					$c_u < 3^C$ & $c_c < 1^C$		**GrU**	Uniformly graded GRAVEL
					$c_u \geq 15$ & $c_c < 0.5^C$		**GrG**	Gap graded GRAVEL
		Silty GRAVEL	**Gr**	5 to 15	Subdivide as for **Gr**		**siGr**	Subdivide as for **Gr**
		Clayey GRAVEL		5 to 15	Subdivide as for **Gr**		**clGr**	Subdivide as for **Gr**
		Very silty GRAVEL		15 to 35			**siGrL**	Subdivide as for **clGr**
		Very Clayey GRAVEL		15 to 35		<35	**clGrL**	Very silty GRAVELof Low Plasticity
						35 to 50	**clGrM**	of Medium Plasticity
						50 to 70	**siGrH**	of High Plasticity
						>70	**clGrV**	of Very high Plasticity
	SANDS More than 50% of coarse materials is of sand size *(fiber than 2 mm)*	Slightly silty or clayey SAND	**Sa**	0 to 5	$c_u \geq 15$ & $1 \leq c_c \leq 3^C$		**SaW**	Well graded SAND
					$6 \leq c_u < 15$ & $c_c < 1^C$		**SaM**	Medium graded SAND
					$3 \leq c_u < 6$ & $c_c < 1^C$		**SaP**	Poorly graded SAND
					$c_u < 3^C$ & $c_c < 1^C$		**SaU**	Uniformly graded SAND
					$c_u \geq 15$ & $c_c < 0.5^C$		**SaG**	Gap graded SAND
		Silty SAND	**siSa**	5 to 15	Subdivide as for **Sa**			Subdivide as for **Sa**
		Clayey SAND	**clSa**	5 to 15	Subdivide as for **Sa**			Subdivide as for **Sa**
		Very Silty SAND	**siSa**	15 to 35				Subdivide as for **clSa**
		Very Clayey SAND	**clSa**	15 to 35		<35		Very silty SAND of low plasticity
						35 to 50		Of medium plasticity
						50 to 70		Of high plasticity
						>70		Of very high plasticity
FINE SOILS more than 35% of the materials is finer than 0.075 mm	**SILTS**	Gravelly SILT	**gaSi**	35 to 65		<35	**gaSiL**	Very Silty SAND of Low Plasticity
						35 to 50	**gaSiM**	of Medium Plasticity
						50 to 70	**gaSiH**	of High Plasticity
						>70	**gaSiV**	of Very high Plasticity
		Sandy SILT	**saSi**	35 to 65				Subdivide as for **gaSi**
		SILTS	**Si**	65 to 100				Subdivide as for **gaSi**
	CLAYS	Gravelly CLAY	**gaCl**	35 to 65		<35	**gaCiL**	Very gravelly CLAY of low plasticity
						35 to 50	**gaClM**	of Medium Plasticity
						50 to 70	**gaClH**	of High Plasticity
						>70	**gaClV**	of Very high Plasticity
		Sandy SILT	**saSi**	35 to 65				Subdivide as for **gaCl**
		SILTS	**Si**	65 to 100				Subdivide as for **gaCl**
ORGANIC SOILS								
PEAT								

NOTES (for Figure 3.1): A: *Based-on materials that passed through the 63 mm sieve.*
B: *If an in-situ soil sample contains fragments or blocks or both, then this soil should be described by adding to the soil group name either 'with fragments' or 'with blocks' or 'with fragments and blocks'.*
C: $c_u = D_{60}/D_{10}$; $c_c = (D_{30})2/(D_{10} \times D_{60})$.
D: *If soil contains ≥ 15 % of sand, then the word 'sa' written in lower-case letters should be added before the group name symbol, and the word 'sandy' should be added before the group name.*
E: *If the uniformity coefficient and curvature coefficient do not meet criteria for the good, medium, uniform or gap graded soils, the soil will be classified as poorly graded GRAVEL, GrP, i.e., as poorly graded SAND, SaP.*
F: *Depending on their grading and plasticity, gravels with 5 to 15% of fine particles shall be marked as follows: siGrW - silty well graded GRAVEL, siGrM – silty medium graded GRAVEL, siGrP – silty poorly graded GRAVEL, siGrU – silty uniformly graded GRAVEL, siGrG – silty gap graded GRAVEL, clGrW – clayey well graded GRAVEL, clGrM – clayey medium graded GRAVEL, clGrP - clayey poorly graded GRAVEL, clGrU – clayey uniformly graded GRAVEL, clGrG – clayey gap graded GRAVEL.*
G: *If fine particles contain organic matter, the mark 'or' should be added in lower-case letters in front of the group name symbol, and the word 'organic' will be added before the group name.*
H: *If fine particles in the plasticity diagram are classified as CiL-SiL, then gravel and sand with 5 to 15% of fine particles will be marked as follows: siclGr – silty clayey GRAVEL and siclSa - silty clayey SAND.*
I: *If soil contains ≥ 15% gravel, the mark 'gr' should be added in lower-case letters in front of the group name symbol, and the word 'gravelly' will be added before the group name.*
J: *Depending on its grading and plasticity, the sand with 5 to 15% of fine particles will be marked as follows: siSaW - silty well graded SAND, siSaM – silty medium graded SAND, siSaP – silty poorly graded SAND, siSaU – silty uniformly graded SAND, siSaG – silty gap graded SAND, clSaW – clayey well graded SAND, clSaM – clayey medium graded SAND, clSaP – clayey poorly graded SAND, clSaU – clayey uniformly graded SAND, clSaG – clayey gap graded SAND.*
K: *If the pair of values (wL, IP) in the plasticity diagram is situated above the line A and if 4 ≤ IP ≤ 7 then the soil will be marked with ClL-SiL, as silty CLAY.*
L: *If soil contains ≥ 15% of coarse-grained material, then the mark 'sa' or 'gr' should be added in lower-case letters in front of the group name symbol, and the word 'sandy' or 'gravelly' will be added before the group name, depending on which of the two materials is better represented.*

Figure 3.1 Plasticity Diagram for the ESCS Classification of Soil According to Principles Set in BS EN ISO 14688-2



NOTES *The principal fraction of fine-grained soils is marked with symbols composed of two letters, the first of which is the upper-case letter:*
Si – silt
Cl – clay
Or – organic soil

Figure 3.2 Fuller Description of Gravels and Soils

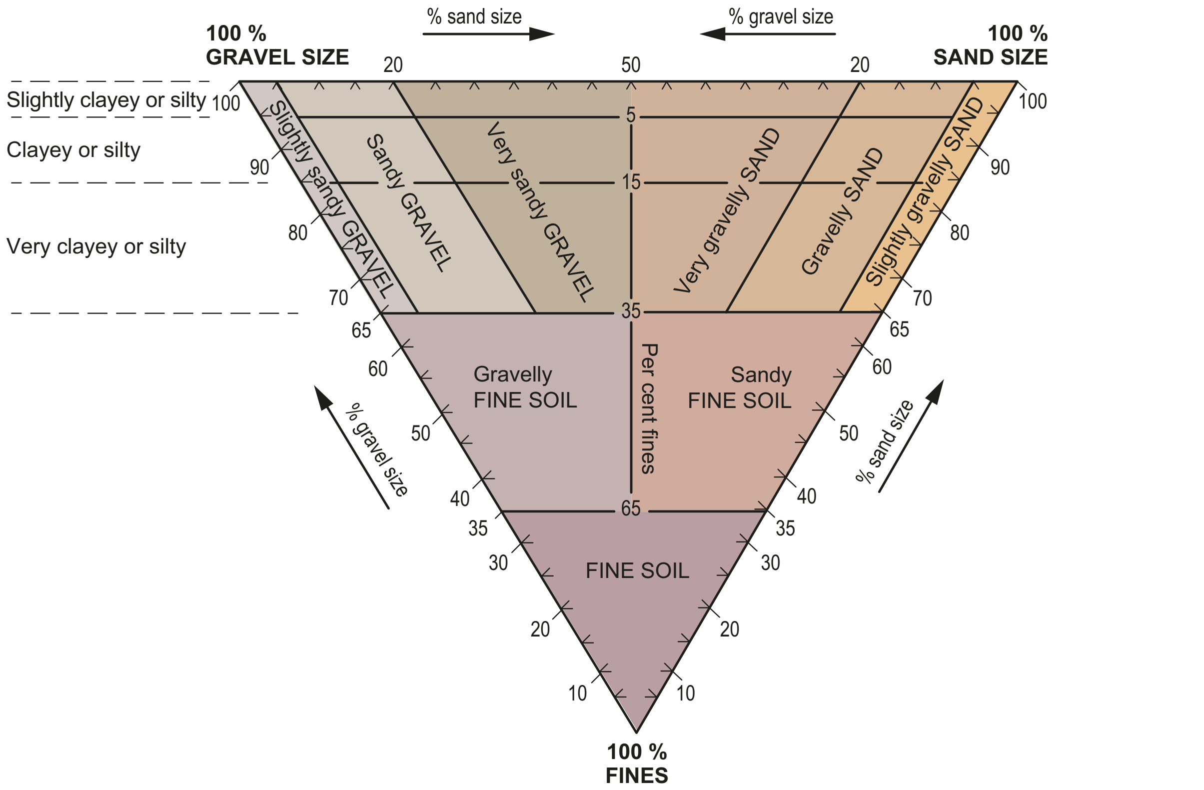


Figure 3.3 The Grading Triangle for Soil Classification (Material Finer Than 60 mm)

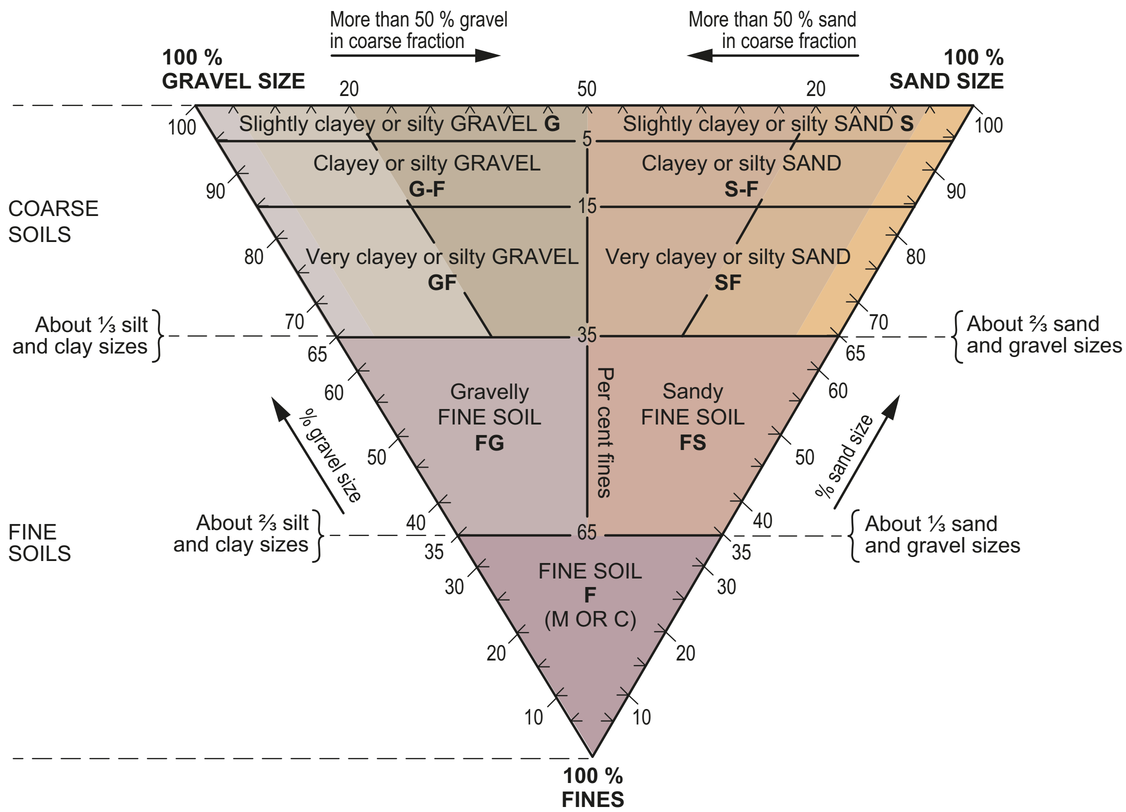
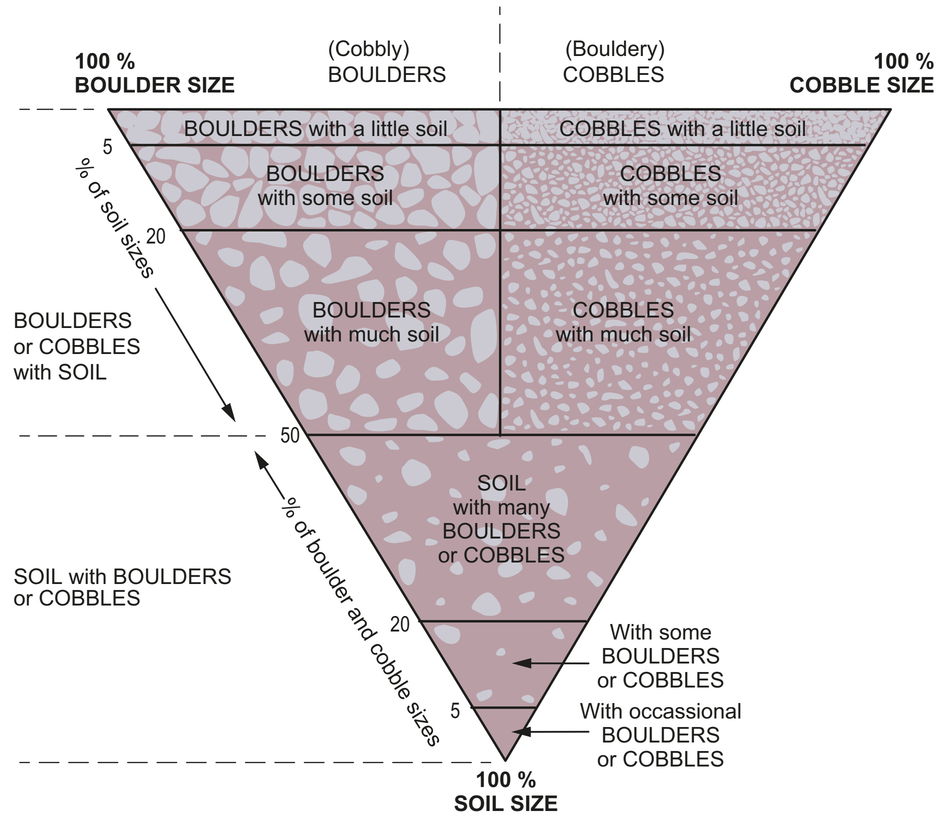


Figure 3.4 Mixtures of Very Coarse Materials (Boulders and Cobbles) and Finer Material



3.3 Subgrade Soils

3.3.1 Classification of Subgrade Soils

The adopted subgrade bearing strength classes in Kenya are as shown in Table 3.2. The CBR is measured at 100 % MDD after 4 days soak using standard compaction effort.

The CBR ranges correspond to the results obtained for materials of the same type, along sections of road considered to be homogeneous. They reflect both the variations of the characteristics of the soil which inevitably occur, even at small intervals, and the normal scatter of test results.

Table 3.2 Subgrade Bearing Strength Classes

Subgrade Class	CBR at 100 % MDD & 4 Days Soak		Surface Modulus (MPa)
	Range (%)	Median (%)	
S1	2 – 5	3.5	40
S2	5 – 10	7.5	65
S3	7 – 13	10	75
S4	10 – 18	14	95
S5	15 – 30	22.5	130
S6	30 – 60	45	200

3.3.2 Classification of the Most Common Kenyan Subgrade Materials

The following materials cover almost all the subgrade materials encountered in Kenya, and they may be classified on the basis of bearing strength, as shown in Table 3.3.

Table 3.3 Classification of Kenyan Subgrade Materials

Type of Material	CBR Strength Class	
	After 4 days soak	At OMC (AASHTOT99)
Black cotton soils	S1	S5
Micaceous silts (decomposed rock)	S1	S3
Other eluvial silts (decomposed rock)	S2	S4
Red friable clays	S3	S5
Sandy clays on volcanics	S3 or S4	S5
Ash and pumice soils*	S3 or S4	S5
Silty loams on gneiss and granite	S4	S5
Calcareous sandy soils	S4	S5
Sandy clays on basement	S4	S5
Clayey sands on basement	S4 or S5	S5 or S6
Dune sands	S4	S4 or S5
Coastal sands	S4	S5
Weathered lava	S4 or S5	S5 or S6
Quartzitic gravels	S4 - S6	S5 or S6
Soft (weathered) tuffs	S4 - S6	S5 or S6
Calcareous gravels	S4 - S6	S5 or S6
Lateritic gravels	S5 or S6	S6
Coral gravels	S5 or S6	S6

**Some of the ash and pumice soils have a very low maximum dry density and a lower Resilient Modulus than might be expected from the measured CBR values. Such soils (Standard Compaction MDD less than 1400kg/m3) cannot be classified for pavement design purposes based on CBR only.*

3.4 Natural Gravels

Natural gravels are defined as rock products that have been partially broken down chemically and physically by weathering. Some of these products may occur in-situ overlying the parent material or may have undergone transport and re-deposition, or re-working of their constituents by water movement and chemical processes within the soil profile i.e., pedogenic material.

The naturally occurring gravel materials can be grouped into three categories, namely;

i. **Weak Rock** - Weak to very weak igneous, sedimentary and metamorphic rocks that may be excavated by mechanical means, including ripping where necessary. This group includes rocks that have been weakened by weathering processes, in-situ.

ii. **Residual Soils and Duricrusts** - Soil-like materials that have been formed largely in-situ by tropical and sub-tropical weathering processes. Such materials may generally be excavated by borrow-pit techniques. Occasionally indurated duricrust may require ripping.

iii. **Transported Soils** - Soil-like materials such as sand and gravel that have undergone processes of erosion, transportation and deposition in addition to weathering. Such materials are generally excavated by borrow-pit techniques.

3.4.2 Types of Natural Gravels

Many different types of natural gravels occur in Kenya, namely lateritic gravels, quartzitic gravels, calcareous gravels, some forms of weathered rock, soft stone, coral rag and conglomerate.

Some of the most common occurring types are described below.

a. **Lateritic Gravels**. Lateritic soils are defined as granular material formed from extensive weathering of rocks in a tropical environment. Laterite is produced when seasonal leaching depletes the zone between the surface and the water table of more readily dissolved minerals leaving hydrated sesquioxides. Lateritic soils are reddish tropical soils that have gained a wide range of utilisation as construction material in roads among other engineering structures.

   The conditions favouring formation of lateritic gravels include:

   i. Parent materials rich in iron and aluminium bearing minerals (ferromagnesian minerals) and prone to reasonably rapid weathering.

   ii. Warm climate with alternating wet and dry seasons such as in the tropics; and,

   iii. Topography that provides a well-drained regime that promotes leaching.

   Hence, lateritic gravels tend to be found on hill slopes, uplands and plateaus, and rarely in low poorly drained areas. The climatic conditions associated with these potential areas is semi-arid with annual rainfall ranging between 750 and 1,250 mm; temperatures range between 15°C and 20°C and altitudes ranging between 600 and 1,500 m.

b. **Quartzitic Gravels**. Quartzitic gravels are as a result of weathering of rocks rich in silica, mainly granitoid gneisses and quartzites. When quartz is the main component in the parent material, it remains in the weathering product as quartz particles leading to an end-product which is granular in texture with laterite forming minerals, kaolinite and sesquioxides forming concretionary products around the quartz.

   These gravel occurrences are associated with steep slopes of hill soils resulting from the weathering of granitoid gneisses and quartzites. They are mainly found on hills and their slopes, uplands as well as on dissected erosional plains.

c. **Calcrete Gravels**. Calcrete gravel material forms exclusively under arid regions as a hard crust of calcium carbonate. The material is formed by a concentration of lime resulting from evaporation and is extremely resistant to attack by weathering in dry environments and is largely impermeable to water movement. Calcrete gravel occurrences are therefore associated with limestone rocks.

d. **Coral Gravels**. Coral gravel soil is a composite soil consisting of finger-coral fragments and silt matrix. In the case of a small content of coral fragments, the mechanical behaviour is governed by the silt matrix, but in the case of a large content of coral fragments, the behaviour is governed by the coral fragments.

   In Kenya, coral deposits are found along the coastal region in places like Lamu, Kilifi, Vipingo and Mombasa among others.

3.5 Rock Types in Kenya

There are three types of natural rock and stone: igneous, sedimentary, and metamorphic.

a. **Sedimentary Rocks.** Sedimentary rocks are formed over time by the accumulation of small particles cementing together, often producing layered rock. Some examples of sedimentary rocks that can be used for crushed stone aggregates include limestone, dolomite, sandstone, and shale.

   There are two main types of sedimentary rocks for construction aggregates in Kenya. These are clastic sedimentary rocks and biochemical sedimentary rocks:

   Clastic sedimentary rocks include conglomerates and breccias, sandstones (which include quartz, feldspathic, lithic, 'clean' sandstones, and muddy sandstones)

   Biochemical sedimentary rocks include limestone and dolomite.

b. **Igneous Rocks**. Igneous rocks are formed from the solidification of molten rock material. They are classified based on their mineral composition, texture, and mode of occurrence. Some common types of igneous rocks include granite, basalt, andesite, rhyolite, and obsidian.

c. **Metamorphic Rocks**. These rocks are formed by the alteration of pre-existing rocks under high pressure and temperature conditions. The most common types of metamorphic rocks used for crushed stone aggregates in Kenya are marble, schist, quartzite, gneiss, and phyllite.

4 Desk Study & Field Reconnaissance

4.1 General

Desk studies and reconnaissance surveys are required to inform planning of preliminary and detailed investigation. They provide essential information on characteristic of the alignment soils, hydrology, availability and properties of construction materials, topography, land use, socioeconomic and political considerations.

4.2 Desk Study

4.2.1 Information from the Desk Study

The desk study shall involve compilation and review information on the project which may include the following:

1. Location of site based on published maps.
2. Construction and maintenance reports from the relevant road agency.
3. Topographical maps from Survey of Kenya, Aerial photographs or satellite images (e.g., Google Earth).
4. Climatic information i.e., rainfall, temperature, and humidity data from metrological department.
5. Site accessibility and statutory restrictions applied to the area by national or local authority.
6. Geological, drainage and soil type information from relevant geological reports.
7. Previous material site investigation reports from MTRD records.
8. Water, power, and sewerage service lines from local agencies.
9. Population and socio-economic development data from Kenya National Bureau of Statistics.

4.2.2 Soils and Geological Maps and Reports

The soils and geological maps are provided in Appendix A. They are available in greater detail from the Ministry of Environment, Water and Natural Resources. They are particularly useful in identifying the likely types of soils to expect in any given project area. This facilitates adequate preparation for field activities. The geological maps provide information on the rock types available in the project area. Knowledge of the rock types are critical in selecting appropriate coring equipment.

In most cases, reports will exist of investigations carried out for other projects in the same area. They are held at the MTRD, or the respective road agency. These reports will contain detail that cannot be obtained from maps. These details will include:

1. Soils and their characteristic values.
2. Rock and aggregate characteristic values.
3. Depths of strata.
4. How the materials were used.

The values from these reports should not be used for design purposes. They should only be used for planning purposes, and for comparison with the results of the investigation for the project under consideration.

4.2.3 Aerial Photographs and Satellite Imagery

Aerial photographs can be used in the preparation and revision of maps and plans, and they can assist in the identification and general assessment of natural and man-made features, including geology, geomorphology, hydrology, and vegetation, on or in relation to a site. They are particularly useful in the assessment of site history such as changes in form, materials, and land use. They can also provide valuable information for the assessment of slope stability.

Aerial photographs, particularly when examined stereoscopically, can often be used to identify, and delineate specific ground features such as the distribution of soil types (e.g., colluvial and alluvial deposits), soil thickness, bedrock type, depth to bedrock, fracture patterns and spacings, as well as local relief.

Accurate topographic maps and plans can be produced from aerial photographs. Large scale plans (scales 1:500 to 1:1000) are usually most appropriate for site investigations of small areas, whereas plans with scales of 1:5000 to 1:20000 are more appropriate for regional studies.

Aerial photographs can be interpreted at a range of scales and levels of detail to provide information valuable to both the design of site investigations and to the interpretation of the results. The design of site investigations such as road corridors can benefit enormously from a preliminary aerial photograph interpretation (API) survey. This can highlight the natural and man-induced characteristics of the terrain, noting hazards and resources that may have a significant effect on the feasibility or design of the project. Even when performed for smaller sites, an API study can often provide useful information on the distribution and thickness of natural and fill materials and may reveal potential problems originating from adjacent land. Sequences of aerial photographs taken at different dates can be compared to determine the location, extent and approximate time of filling and reclamation, and the sequence of development of an area.

4.3 Field Reconnaissance

4.3.1 Information from the Field Reconnaissance

Reconnaissance survey entails visiting local communities and stakeholders for consultations and visual assessment of the road.

The following information is obtained from the consultations with local communities and stakeholders:

1. Economic and social issues such as land use, unemployment, and cultural practices relevant to the project such as handling of sacred sites and trees.
2. Hydrological conditions such as frequency of flooding, water levels and stream flows of river crossings.
3. Road sections with weak alignment soils that are impassable during wet seasons and the nature of impassability.
4. Availability of materials, etc.

4.3.2 Inspection of Existing Road Corridor

The existing road corridor shall be inspected for the following assessment:

1. Road drainage, stream and river crossings and extent of flooding of water crossings and low-lying areas.
2. Location of all possible bridge sites and water crossings.
3. Road reserve restrictions i.e., trees, building encroachment and services.
4. The extent of earth and gravel sections and trafficability.
5. Alignment soil types and particularly weak subgrade soils.
6. Gravel type and gravel wearing course layer thickness.
7. Road profile and shape as an assessment of water shedding capacity and road drainage.
8. Surface erosions.
9. Riding quality/safety and influencing factors.
10. Dust.
11. Moisture condition.
12. Swamp crossings.
13. Road surface conditions and noting defects such as rutting, shear deformation, potholes, over size material, corrugations and loss of camber.

4.3.3 Drainage and Erosion

It is important to ensure that the drainage system is functioning well. A thorough assessment of the existing road drainage system is necessary, including the following elements:

1. Culverts:
   - i. Adequacy of opening (size, flooding, length of culvert).
   - ii. Inlet and outlet conditions (ponding, silting, erosion, headwalls).
   - iii. Structural strength (condition of concrete or other materials).
2. Low level structures (causeways, drifts, etc.) and bridges:
   - i. Flood levels and time of closure.
   - ii. Adequacy of existing structure to cope with floods.
   - iii. Structural condition.
   - iv. Width.
   - v. Erosion.
3. Surface drainage:
   - i. Standing water due to rutting, etc.
4. Drainage channels:
   - i. Adequacy of side drains (shape of drain, ponding, silting, erosion).
   - ii. Catchwater drains and cut-off drains (shape of drain, ponding, silting, erosion). Mitre drains (frequency, shape of drain, ponding, silting, erosion).
   - iii. Down chutes (condition, erosion).

Erosion is closely related to drainage and depends on soil type, grade, climate and site conditions. A general assessment of erosion potential is needed for embankments, cuttings, road reserve and borrow areas, leading to design of anti-erosion measures where necessary.

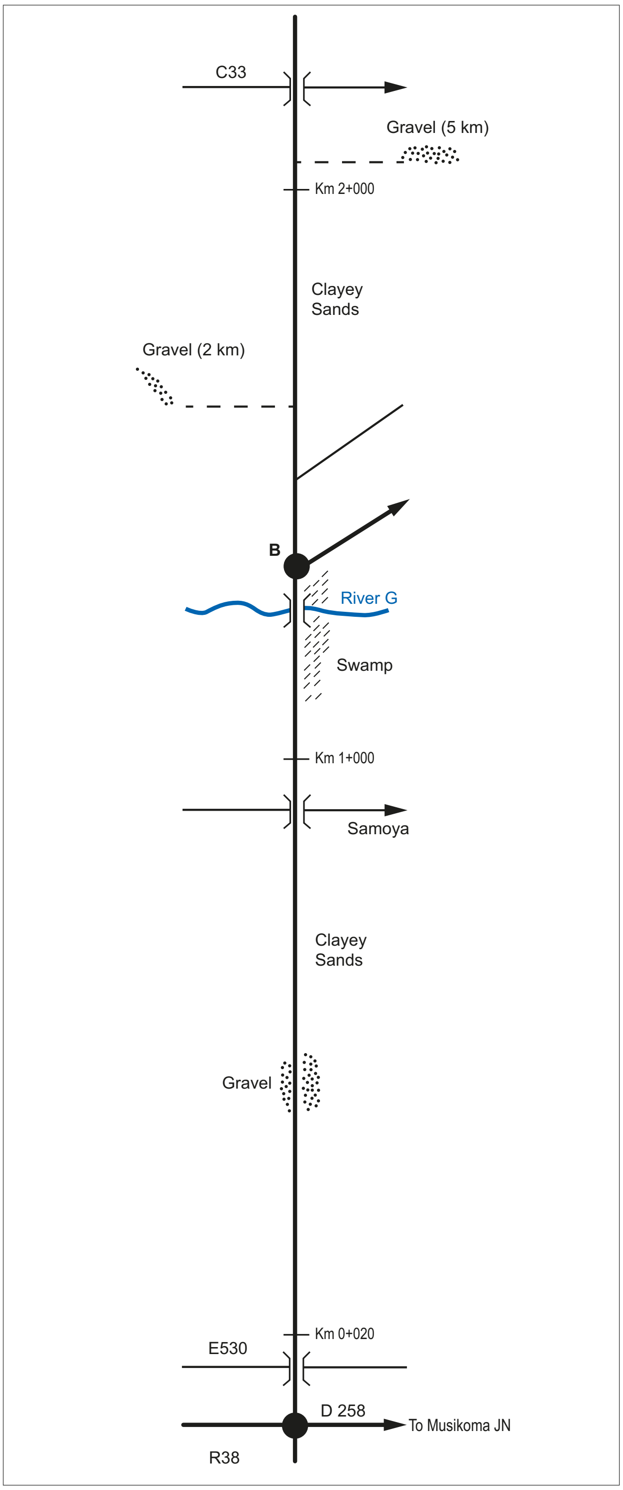
4.3.4 Field Reconnaissance Report

A preliminary survey report may include:

- A strip map as shown in the example given in Figure 4.1 alignment soil types, sources of gravel, river crossings etc.
- A Matrix of Preliminary Observations and the Proposed Interventions as shown in the examples given in Table 4.1, Table 4.2, and Table 4.3.

This shall be followed by preparation of the plans for preliminary and detailed field surveys detailing the sites to visit, resources and equipment required.

Figure 4.1 Example of Strip Map Showing Road Inventory



4.4 Earlier Uses and State of Site

If a site has been used for other purposes in the past, this can have a significant effect on the present intended use. A careful visual inspection of a site and the vegetation it sustains shall be undertaken to determine if there was interference (such as quarries, waste tips, manmade fill, and possible ancient monuments) with the natural subsoil conditions at some time in the past. The relevant bodies should be consulted if any interference is suspected at the site.

For sites where radioactive materials are suspected, a radioactive survey shall be undertaken before any excavation commences. Following the confirmation of radioactive materials presence, radiation safety experts shall be consulted to provide guidance on the appropriate procedures and protective measures.

Table 4.1 Sample Matrix of Preliminary Observations for Road Alignment

Chainage (Km + m)	Length (Km)	Observations				
		Road Surface Type	Terrain	Alignment Soil and Drainage	Gravel/Rock Sources	Defects

Table 4.2 Sample Matrix of Preliminary Observations of Material Prospecting

Chainage (Km + m)	Offset/ coordi-nates	Observations					Remarks/ Advice
		Terrain	Physiography	Accessibility	Soil/Rock Outcrops	Utilities/ Services	

Table 4.3 Sample Matrix of Preliminary Observations for Geotechnical Investigations for Structures

Location	Coordi-nates	Observations					Remarks/ Advice
		Terrain	Physiogra-phy	Accessibil-ity	Soil/rock outcrops	Utilities/ Services	

5 Selection of Appropriate Field Test Methods

5.1 General

This chapter presents guidance on the selection of appropriate field test methods to obtain information required for design. The details of the individual field test methods are described in Chapter 5.4.1 on alignment soils investigations and Chapter 7 on structures.

Survey equipment such as GPS may be used to establish the coordinates of a point. Alternatively, sight lines and distances from local features, where these are present and on the ground and identifiable on plans of the proposed locations, may be used.

The location and elevations of investigation points should be established in relation to an appropriate coordinate system and datum, such as the National Grid and Ordnance Datum. The accuracy required of the surveying should be specified and/or agreed before the start of the investigation. Utilities should be identified before any intrusive work commences.

5.2 Field Tests

Field tests are particularly valuable where the preparation of representative laboratory samples is complicated by one or more conditions such as: where discontinuities exist in the bulk mass of the material; in-situ stress state conditions vary from that in the laboratory specimens; disturbance and remoulding of a representative sample could alter the results if it were to be tested in the laboratory; the lack of cohesion would make it difficult to obtain a sample; and where the zone of interest is inaccessible to sampling equipment. Large scale field tests should be used where the mass characteristics of the existing site or ground might differ significantly from characteristics determined in the laboratory. For example. the settlement of embankments, in-situ shear strength, etc. The selection of appropriate field tests is mostly governed by the data, and samples required for design. Field tests should be undertaken by trained personnel in accordance with the detailed procedures outlined in BS 5930 and BS EN ISO 18674. Table 5.1 shows the applicable of field tests for various data requirements.

5.3 Exploratory Holes

Exploratory holes consist of excavations or boreholes for purposes of making visual descriptions of the soils or rocks obtained, and for taking samples for further tests. They may provide preliminary information for undertaking detailed ground investigations.

When drilled boreholes are used, information about soil strata thicknesses, depth, and general characteristics (e.g., Atterberg limits) may be obtained.

Rotary cored boreholes can also be used for obtaining rock cores for detailed laboratory testing for foundation design for structures.

For excavations such as test pits, adequate samples may be obtained for detailed laboratory tests. However, test pits are often limited in depth to about 3 metres, for safety reasons. Test pits shall be marked with red warning tape during excavation. At the end of the workday, all completed excavations shall be covered up. Incomplete test pits shall be marked with red warning tape and securely covered with materials such as wooden planks that can support weight and prevent individuals from falling in.

The detailed recording of the strata, soil and rock types obtained from boreholes should be undertaken by a certified Geotechnical Engineer or Geologist.

Determination of the unconfined groundwater level can be made by observation in an open borehole or excavation. It should be noted that water level observations in an open borehole or excavation are frequently not indicative of equilibrium conditions and a considerable period of time might be required for the water level to reach an equilibrium unless the ground is reasonably permeable. Observations of water level in an open borehole or excavation should be made at regular intervals until it is established that the water level has reached an equilibrium.

Table 5.1 Applicable Field Tests for Various Ground Conditions

Test Group	Device	Ground Type							Soil Parameters										
		Hard Rock	Soft Rock	Gravel	Sand	Silt	Clay	Peat	Profile	u	ϕ'^{A}	su	Mv	Cv	k	Go	σh	OCR	$\sigma\varepsilon$
Penetrometers	**Dynamic Probing**	-	3	2	1	2	2	2	2	-	3	3	-	-	-	3	-	3	-
	Mechanical (CPTM)	-	3	3	1	1	1	1	1	-	3	3	3	-	-	3	3	3	-
	Electric (CPT)	-	3	3	1	1	1	1	1	-	3	2	3	-	-	2	2	2	-
	Standard Penetration Test (SPT)	-	3	2	1	2	1	2	2	-	3	3	-	-	-	3	-	3	-
	Resistivity Probe	-	3	-	1	1	1	1	2	-	2	3	3	-	-	-	-	-	-
Pressuremeters	**Pre-bored**	1	1	2	2	2	1	2	2	-	3	2	2	3	-	2	3	3	3
	Self-boring	-	2	-	2	2	1	2	2	1[B]	2	2	2	1[B]	2	1[C]	1	2	1[C]
	Full displacement (FDP)	-	3	-	2	2	1	1	2	-	3	2	3	3	-	1[C]	3	3	3
Others	**Vane**	-	-	-	-	-	1	2	3	-	-	1	-	-	-	-	-	2	2
	Plate Load	2	1	2	2	1	1	1	-	-	3	2	2	3	3	1	3	2	2
	Borehole Permeability	1	1	1	1	1	1	2	-	1	-	-	-	2	1	-	-	-	-
	Hand Auger	-	-	-	2	1	1	1	2	-	-	-	-	-	-	-	-	-	-
	Mechanical Auger	3	1	2	2	2	2	2	2	-	-	-	-	-	-	-	-	-	-

NOTES: Applicability: *1 = high, 2 = moderate, 3 = low, – = none*

Soil parameter definitions: *u = in-situ static pore pressure, ϕ' = effective internal friction angle, su = undrained shear strength, Mv = constrained modulus, cv = coefficient of consolidation, k = coefficient of permeability, Go = shear modulus at small strains, σh = horizontal stress, OCR = overconsolidation ratio, $\sigma\varepsilon$ = stress-strain relationship.*

A: *Depends on soil type.* ***B:*** *Only when pore pressure sensor is fitted.* ***C:*** *Only when displacement sensor is fitted.*

5.4 Geophysical Field Investigations

Geophysical investigations may be used to map subsurface geology and ground water, measure physical and/or engineering properties of the ground or to detect the presence of utilities. In road alignment surveys, geophysical methods may be used for ground investigations, resource assessment such as determining the depth and quantity of potential material borrow area and hardstone quarry, and determination of engineering properties of the ground to guide the depth at which to locate foundations for structures, and depth to the ground water table.

Geophysical methods, presented in Table 5.2, may be used during preliminary site investigations to select suitable methods for obtaining an overview of areas where little is known about the subsurface or to supplement the information collected by more detailed exploratory investigations. The risks of the geophysical survey not returning the information required should be evaluated and discussed prior to the commissioning of the survey.

5.4.1 Preliminary Geophysical Investigations

The benefits of a reconnaissance geophysical survey should be assessed at an early stage in a ground investigation to assist the planning of the subsequent intrusive investigation. At the preliminary design stage, results from geophysical tests may be used to determine the feasibility/ appropriateness of the method used and if any refinements are necessary to enable the use of the method at detailed design.

5.4.2 Detailed Geophysical Investigations

It may also be necessary to establish correlations between geophysical test results and underground phenomena to yield useful results rapidly and economically. Results from drilled boreholes may be used at the detailed design stage to establish correlations.

5.4.3 Guidance on Use of Geophysical Tests

The Design Engineer should provide the geophysical expert with all information relevant to the requirements and planning of the geophysical survey. Prior to choosing the geophysical test to use, consideration should be given to the physical properties to be measured, the resolution and depth of investigation required. Guidance according to BS 5930 for the use of different geophysical test methods in alignment surveys is presented in Table 5.2.

A geophysical trial survey may be undertaken at the site to assess the suitability of the proposed geophysical techniques for the investigation of the geological problem in some cases. The results of the trial geophysical survey should be used to refine the specification of the main survey or, in some cases, lead to a decision not to proceed with any further geophysical work.

Alternatively, a combination of two or more geophysical or intrusive techniques may be required to build a complete and accurate picture due to variations in detecting contrast between the geophysical tests. A combination of geophysical data sets can allow a more detailed and robust interpretation to be made. On-site assessment of geophysical data should be encouraged to allow adjustment and optimisation of the survey layout to improve the final product.

The programme for the geophysical investigation should be designed to include boreholes positioned to calibrate the interpreted ground model derived from the geophysical information and to obtain detailed information on specific problem areas indicated by geophysical anomalies. The data from the borehole records or exploratory excavations should be used to add detail to ground model and constrain the geophysical interpretations.

If the borehole and the geophysical survey programmes are carried out at sites where small-scale geological features might be present, failure of the geophysical surveys to detect any such feature, for example a narrow zone of shearing in the rock mass, should not be taken to mean that such features do not exist.

Table 5.2 Suitability of Geophysical Test Methods to Obtain Ground Investigation Data

Geophysical Method	Ground Investigation Data									
	Depth to rock	Strati-graphy	Lithology	Fractured Zones	Fault Displace-ments	Dynamic Elastic Moduli	Density	Rippability	Cavity Detection	Buried Artefacts
Seismic										
Refraction	4	4	3	3	4	3	1	4	1	1
Reflection:land	2	2	2	2	4	2	0	1	2	1
Reflection:marine	4	4	2	2	4	0	0	1	1	2
Crosshole	2	2	3	3	1	4	1	2	3	2
Electrical										
Resistivity tomography	4	3	3	2	3	0	0	1	2	2
Induced polarisation	2	2	3	1	0	0	0	0	0	0
EM and resistivity profiling	3	2	2	4	1	0	0	0	3	4
Other										
Ground penetrating radar	2	3	1	2	3	0	0	0	3	4
Gravity	1	0	0	0	2	0	2	0	4	1
Magnetic	0	0	0	0	2	0	0	0	2	4
Borehole										
Self potential	2	4	4	1	1	0	0	0	1	1
Single point resistance	2	4	4	0	0	0	0	0	0	0
Long and short normal, lateral resistivity	2	4	4	0	0	0	0	0	0	0
Natural gamma	2	4	4	0	0	0	0	0	0	0
Gamma-gamma	3^A	4	4	0	0	0	0	0	0	0
Neutron	2^A	4	0	0	0	0	3^A	0	0	0
Fluid conductivity	0	1	0	0	0	0	1	0	2	0
Fluid temperature	0	0	1	0	0	0	0	0	1	0
Seismic (velocity)	3	4	3	0	0	3	2	1	2	0

KEY: 0: not considered applicable; 1: limited use 2: used, or could be used, but not best approach, or has limitations; 3: excellent potential but not fully developed; 4: generally considered an excellent approach, techniques well developed; A: in conjunction with other electrical or nuclear logs

5.4.4 Interpretation of Results

Geophysical tests should be undertaken by a trained specialist who can direct the test and interpret the results. There should be close collaboration between the site Geologists, Design Engineers and Geophysicists in the interpretation of the geophysical data. Many geological boundaries are transitional, which can lead to a margin of uncertainty in the interpretation of the geophysical data when related to the engineering or geological boundary.

The survey results should be processed and interpreted using all available geophysical data, direct observations from boreholes and/or sampling, to input to the evolution of the interpretative ground model. The geophysical interpretation should indicate, and quantify where possible, the uncertainties that remain in the interpreted ground model.

5.4.5 Reporting Requirements

The final report should incorporate all the geophysical results, presented in the agreed format and scales, together with any correlation with drilling results and any information used in interpreting the ground model. The report should typically contain the following:

a. Objective of the investigation.

b. Statement of the information available at the start of the survey (e.g., from the desk study, field reconnaissance, ground investigations to date and previous geophysical surveys).

c. Details of the equipment and the acquisition parameters used.

d. Descriptions of any difficulties with equipment or environmental conditions or access that are relevant to the accuracy or coverage of the data acquired.

e. The processing functions applied to the raw data before interpretation.

f. A description and graphical representation of the interpretations made, illustrated by plots of all the acquired data, or example sections of data as agreed, such that it is clear to the Design Engineer the basis upon which the interpretations have been made.

g. The accuracy and resolution of the information derived from the survey, referencing borehole or other ground investigation data available as appropriate, referring in particular to the limitations of the information acquired.

h. Recommendations for any further ground investigation (geophysical, or targeted intrusive).

5.5 Field Instrumentation

5.5.1 Overview

Instrumentation refers to methods and equipment used in ground investigations to monitor movements and strains, total stresses and pore water pressures associated with known or expected ground behaviour. These behaviours are often a result of construction processes, potential stability failures, subsidence, and ground response in large-scale field trials. The major types of instrumentation used in ground investigation are piezometers for measuring groundwater pressures, and inclinometers and extensometers for measuring ground movements, soil moisture and temperature sensors. Generally, instrumentation should be undertaken in accordance with BS EN ISO 18674.

The Design Engineer should note that instruments might malfunction and give no measurements, give erroneous results, or that the installation of instrumentation could affect behaviour of the ground, particularly with respect to earth pressure measurements. The limitations of any instrumentation should be taken into account (in consultation with the manufacturer), particularly for long-term measurements.

5.5.2 Piezometers

Groundwater measurement installations and groundwater measurement methods should conform to BS EN ISO 18674-4.

1
2
3
4
5
Selection of Appropriate Field Test Methods

A standpipe piezometer is a device consisting of a tube or pipe with a porous element on the end, or with a perforated end section surrounded by or wrapped with a filter, which is sealed into the ground at the appropriate level. It is normally installed in a borehole.

Hydraulic piezometers normally consist of a small piezometer tip (a water filled chamber with porous, normally ceramic walls), small-bore water filled plastic tubes and a remote pressure measuring device such as a pressure transducer and electrical readout, or more simply a Bourdon gauge. Hydraulic piezometers are frequently installed directly in trenches, but can also be installed in boreholes.

Pneumatic piezometers consist of two gas-filled tubes connecting a measuring point to a valve located close to a porous element. When the gas pressure in the input line equals the water pressure in the porous element, the valve opens, the gas flows around the system and can be detected as it emanates from the return tube. The gas supply is then shut off and the pressure in the supply tube is monitored as it decays. The pore water pressure is taken to be the final steady pressure developed when the valve closes.

5.5.3 Inclinometers

Inclinometers are used for measuring displacements across a line in, for example, embankments, slopes, piles, diaphragm walls and tunnelling. Each inclinometer consists of a tube (known as the inclinometer access casing) with four orthogonal internal grooves, a probe (known as the inclinometer probe) and a readout device. Information about horizontal and inclined inclinometers, together with other methods of measuring settlement and heave can be found in BS EN ISO 18674.

5.5.4 Extensometers

Extensometers are used for measuring changes of distance between two or more measuring points located along a measuring line in, for example, settlement of embankments, slopes, and piles. Two types of extensometers are commonly used, magnetic probe extensometers and rod extensometers. Extensometer installations and measurements should conform to BS EN ISO 18674.

5.5.5 Moisture Sensors

These sensors are used to assess water content in soils, providing critical data for geotechnical and environmental monitoring. The standard emphasises sensor reliability, precision, and compatibility with the specific soil and site conditions. Installation techniques play a crucial role in ensuring accurate results. The sensors should be installed at the correct depth and orientation, minimising soil disturbance during placement to preserve the natural soil structure. Careful backfilling with material matching the surrounding soil is recommended to prevent air gaps that could skew readings. Proper calibration of the sensor after installation, along with sealing cables and connections to avoid water ingress, is essential. Moisture sensor installations and measurements should conform to BS EN ISO 18674.

5.5.6 Temperature Sensors

These sensors used to measure thermal variations in soils and pavement layers. Installation techniques are critical to ensure effective thermal coupling between the sensor and the surrounding material. Sensors must be positioned at appropriate depths and locations, avoiding external heat sources or disturbances unless intended for specific studies. During installation, any disruption to the natural conditions should be minimised, with backfilling materials carefully selected to replicate the thermal properties of the in situ material. Proper calibration of sensors is essential before and after installation to ensure consistent accuracy. Additionally, protective measures, such as sealing sensor connections and safeguarding cables from moisture, temperature fluctuations, and mechanical stress, are recommended. BS EN 14577 also stresses comprehensive documentation of the installation process to maintain data traceability and ensure the reliability of long-term monitoring projects.

6 Alignment Soils Investigations

6.1 General

Alignment soils investigations will normally begin with a desk study of the available project data such as reports, maps and the alignment profile. Field investigations will then be conducted to determine the subgrade conditions on which the pavement is to be supported, earthworks operations at road cut and embankment sections, and soils and foundation conditions at river crossings such as bridges and box culverts. The methodology to be followed and the required laboratory tests are detailed in this chapter. Means of identifying problematic soils on site, as well as confirmatory tests in the laboratory, are also included.

6.2 Alignment Subgrade Sampling and Field Tests

Alignment soil investigations to confirm subgrade properties shall be divided into tests for the preliminary design stage, detailed design stage and the construction stage.

Field investigations for alignment soils shall include test pit excavation, Dynamic Cone Penetration (DCP) tests and field density tests. These should be located along the alignment as well as the lateral extent of anticipated excavation to ensure material representation. The tests shall be staggered along the road corridor to ensure representative samples are obtained. All field test results shall be included in the Appendix of the project road's Materials Report.

6.2.1 Dynamic Cone Penetration Tests

DCP tests shall be carried out at 1 km intervals at the preliminary design stage. For the chosen route option, the interval shown in Table 6.1 shall be used at the detailed design stage. The DCP tests shall supplement the information obtained from the test pits and should be located equidistant between test pits. The position of each DCP point, number of blows and the corresponding depth shall be accurately determined and recorded. The test procedure and equipment description are provided in RDM 3.2.

6.2.2 Test Pit Excavation and Logging

At the preliminary design stage, test pit excavation and sampling shall be done at 2.5 km intervals. Test pits shall be dug 1 m x 1 m in plan to at least 0.5 m below the expected formation level and shall in no case be less than 1.5 m for a new alignment, unless rock or another material impossible to excavate by hand is encountered.

The position of each test pit shall be accurately determined and recorded. In every test pit, all layers, including topsoil, shall be accurately described in the test pit log and their thicknesses measured. All layers more than 300 mm (except topsoil) shall be sampled. The soils shall be identified and described in accordance with BS EN ISO 14688-1.

Groundwater conditions and the depth to water table shall also be recorded in the log. The soil vertical profile may be logged manually or using software. For the materials report, the log of each trial pit shall be accurately drawn, and coloured photographs of the vertical profile included.

Table 6.1 Testing Interval at Detailed Design Stage

Road Classification	Interval	
	Test Pit Excavation	Dynamic Cone Penetration (DCP)
Trunk roads and Primary roads	250 m	250 m
Secondary and Tertiary roads	500 m	500 m

1
2
3
4
5
6
Alignment Soils Investigations

6.2.3 Field Density Tests

The Sand Replacement Method (see RDM 3.2) should be used wherever possible for alignment tests. The sand used in the test must be free flowing, clean and dry. The test site should be levelled, and necessary precautions taken to ensure there are no vibrations close to the testing site. The volume of soil removed shall be dependent on the maximum particle size of the soil.

6.3 Existing Pavement Layers and Gravel Wearing Course

6.3.1 Sampling Procedure

Measurements of thickness and width of existing pavement layers shall be recorded for every excavated test pit. Where more than 100 mm of existing gravel wearing course is in place on the road and where the shape is adequate, samples shall be tested for suitability for reuse as either subbase, or for improved subgrade. One sample per kilometre of existing gravel wearing course shall be taken for testing. It is recommended that samples be taken at the test pit where the gravel layer is thickest.

Undisturbed samples shall be taken over the full depth of the layer by taking a vertical slice of material. If they are to be preserved at their natural moisture content, they shall also be sealed in an airtight container or coated in wax.

6.3.2 Frequency of Sampling and Testing

During the preliminary design stage, test pit excavation and sampling shall be done at 2.5 km intervals and DCP tests done at 1 km intervals. For the chosen route option, the interval shown in Table 6.1 shall be used at the detailed design stage.

The samples taken from the alignment shall be tested in an accredited laboratory and classified based on the test results in accordance with the BS EN ISO 14688-2 and the amendments in section 3.2.2. Sufficient materials shall be obtained to carry out the following classification tests:

i. Grading to 75 µm.

ii. Atterberg Limits.

iii. Compaction test (specified according to material and layer).

iv. Natural moisture content.

v. 1-point CBR at 95% MDD (4.5 kg rammer) if existing material is to be used as sub-base, and 98% MDD if existing material is to be used as base.

vi. 3-point CBR and swell measured after 4 days' soak on samples moulded at 93 %, 95 % and 100 % MDD (2.5 kg rammer) and Optimum Moisture Content (OMC) (2.5 kg rammer) if existing material is to be used as subgrade.

NOTES:

1. *CBRs shall normally be measured after 4 days soak or until there is no further swell for areas that are likely to be flooded from the hydrological analysis. In dry areas (annual rainfall less than 500 mm), CBR shall be measured after 4 days soak to ensure the subgrade is resilient to the effects of climate change.*

2. *The moisture contents after soaking shall be measured, both on the whole CBR specimen (by weighing it after soaking) and on a sample taken from beneath the plunger, after testing.*

The results from the laboratory testing, combined with the relevant field observations, will enable a classification of the subgrade soils to be made in accordance with the BS EN 14688-2.

The subgrade bearing strength shall then be classified according to the procedure detailed in Section 3.3.1.

6.4 Investigations at Sections of Cut

These investigations should as a minimum consider the types of materials in the cut; sub-grade materials and their strength; moisture regime; level and movement of groundwater; and slope stability. It is necessary to examine not only the sides of the road for possible slope movement but also potentially unstable areas within the vicinity of the road.

Natural slopes with a history of instability often need surface and subsurface investigations. Possible indications of instability shall be determined through a desk study of topographic maps, aerial maps, and site reconnaissance.

At the preliminary design stage, hand augers or similar means of exploration shall be used for investigating subsurface conditions for shallow cuts (≤ 6 m) and where site access for large drilling equipment is restricted. A hand or power auger shall be used to drill holes to the depth required at sections where test pits are impossible to dig (cut depth > 2 m).

For investigation of deep cuts (> 6 m), at the preliminary design stage, subsurface conditions shall be determined from the desk study and site reconnaissance visit. To minimise mobilisation costs, the information obtained shall be used to prepare a test plan for the detailed design stage. However, where the project budget allows, a minimum of one exploration bore hole shall be drilled at each section of cut.

At detailed design, a minimum of one borehole shall be drilled along each proposed cut slope less than 6 m in height. For deep cuts, drilling shall be done at a spacing of 50 m or up to 100 m where the soil does not vary significantly, to a minimum depth of 0.4 times the cut height or 2 m below the bottom of cut elevation or 3 m into the bedrock, whichever is greater. The position of each test hole shall be accurately determined and reported.

Tests such as the Cone Penetration Test (CPT) may be used to provide additional information for the stratigraphic profile and to evaluate in-situ strengths.

For rock cuts, discontinuity characteristics and weathering should be determined for design purposes. Rock shall be identified and described in accordance with BS EN 14689.

Field testing shall also be aimed at assessing the quantities of the various earthwork categories (i.e., rock, rippable or normal material). These should be presented in the materials report and reflected in the Bills of Quantities.

Field loggings should include depth to water table, in-situ testing such as Standard Penetration Test (SPT), and depths at which undisturbed samples have been collected. SPT data shall be taken where there are changes in strata or at 1.5m intervals. Samples should be gathered from the soil zones most likely to control slope behaviour.

Soil samples shall be obtained to perform laboratory index tests such as particle size analysis, natural moisture content, unit weight and Atterberg limits. Sampling should also be performed to determine the strength characteristics of the soil for the purpose of cut slope stability assessment and the evaluation of cut material as borrow sources. The choice of which type of strength test to perform should be based on expected stress conditions in the soil in relation to the anticipated failure mode and failure surface.

6.5 Investigations Below Embankments

A desk top study shall be conducted to determine the geological origin and nature of the embankment foundation material. This shall be followed by a review of the alignment to determine embankment locations and prepare a test plan.

Preliminary investigations at embankments ≤ 3 m in height shall constitute a minimum of one test pit along the centreline of the embankment every 50 m. The test interval may be increased to 100 m where the soil does not vary significantly. At the detailed design stage, boreholes shall be drilled at areas where thick, soft deposits and potentially unstable ground is present to a minimum depth 0.8 to 1.2 times the embankment height or to hard stratum.

For the preliminary design of high embankments (> 3 m), a minimum of three exploration points shall be required at critical locations to determine the existing subsurface conditions for stability analysis. These shall be drilled to a minimum depth of twice the embankment height. The depth could be made shallower if the drilling goes through bedrock or deeper if the soft material thickness is greater than twice the embankment height. In the latter case, drilling should continue until competent material is encountered. At detailed design stage, the Design Engineer shall decide if additional tests such as extra boreholes, cone penetration tests or DCP tests are required to address any gaps.

For bridge approach embankments, at least one borehole shall be drilled at abutment locations to a depth deeper than the river floor at the detailed design stage.

Disturbed samples shall be collected to conduct index tests (soil gradation, Atterberg limits, water content) of the foundation material while undisturbed samples shall be taken to determine the strength properties (shear strength and consolidation) of the foundation material for evaluation of bearing capacity and settlement.

6.6 Investigations of Approaches to River Crossings

Alignment investigations at approaches to bridges shall be to a minimum depth of 2 m below the formation level. Tests at approaches may include test pit excavation and dynamic probing tests to give an indication of the subgrade and if any treatment at the approaches will be required. Ground investigations for foundations at river crossing structures such as bridges and box culverts is covered in Chapter 7 of this Part.

6.7 Investigations of Problematic Soils

Problematic soils such as expansive soils, dispersive soils and collapsible soils pose engineering challenges to pavement function if not identified at the design stage. During construction, these soils require treatment based on the design recommendations to enable proper performance of the pavement over its design life. The field observations and laboratory tests required to identify these problem soils are detailed below.

6.7.1 Expansive Clays

A desktop study of the geological maps and related materials reports shall be conducted to determine if the project road goes through areas with expansive soils. These are typically areas with vertisols. During the site reconnaissance, sections of road with flat, poorly drained environments and large shrinkage cracks or fissures on a clay deposit shall be identified for further investigation. These soils are mainly found in the area of south-east Nairobi, south-east Kisumu, west of Nanyuki, the plains around Soit Ololol escarpment, and the Coastal Strip. They may occur in pockets in other locations other than the above.

During the field reconnaissance, the information provided in Table 6.2 shall be collected to determine expansivity of clays. Typical features of expansive soils are given in the second column.

Table 6.2 Features of Expansive Clays

Soil Description	Typical Features of Expansive Clays
Consistency when dry	Upon drying, expansive soils become hard, with clods that are difficult to break apart.
Consistency when wet	When moist, these soils feel very sticky and plastic to the touch, indicating a high clay content.
Structure	Wide cracks during dry periods due to shrinkage. These cracks are a visible indication of high plasticity and shrink-swell potential. In addition, the presence of slicken-sided fissures
Appearance	Some expansive soils exhibit a shiny or greasy look when moist, often due to their high clay content.

Extended investigations are advisable if the conditions in Table 6.2 indicate the likelihood of expansivity of the soil.

Extended investigations include simple additional laboratory tests to estimate expansiveness and shall be routinely employed where special measures against damage from expansive soils are proposed in the design. These include:

1. Shrinkage Limit (ASTM D4943-89).
2. PI_w>20%, where PI_w = Plasticity Index tested on fraction <425 µm, weighted for the sample's actual content of particles <425µm as follows: PI_w = PI x (% passing 425 µm).
3. Determining the activity, A_c of the soil sample. An activity value greater than 1.25 is indicative of active clays with a high potential for expansion. A-values of less than 0.75 indicate inactive (good) soils. Further investigation of soils with values in between 0.75 and 1.25 will be at the discretion of the designer.

   Activity = Plasticity Index / (% by weight finer than 2 µm). The percentage by weight finer than 2 µm is determined through the sedimentation test (hydrometer analysis) in accordance with BS EN ISO 17892-4.

Following confirmatory laboratory tests, expansive soils shall be classified as described in RDM 3.3.

6.7.2 Dispersive Soils

A desktop study shall be carried out on topographical, geological, and related materials reports to identify low-lying areas with gently rolling topography and relatively flat slopes. The site reconnaissance shall identify areas with surface erosion as evidenced by jagged, sinuous ridges and deep rapidly forming channels and tunnels.

Indicator tests shall be conducted on samples to confirm the need for further tests for dispersivity. The following procedure shall be followed in the field to determine if confirmation in the laboratory is necessary.

1. Collect soil aggregates (1 – 2 cm diameter) from each in the soil profile.
2. If moist, dry the aggregates in the sun for a few hours until air-dried.
3. Place the aggregates in a shallow glass jar or dish of distilled water or rainwater.
4. Leave the aggregates in water without shaking or disturbing them for 2 hours.
5. Observe and record if you can see a milky ring around the aggregates.

If the sample forms a cloudy suspension with a ring of particles at the water surface and around larger lumps, a confirmatory test such as Exchangeable Sodium Percentage (ESP) based tests, Pinhole Test, Crumb Test, Double Hydrometer Test, pH, and Dissolved Salts in the pore water test shall be conducted on the soil sample.

6.7.3 Collapsible Soils

A desktop study shall be carried out on topographical, geological, and related materials reports to identify areas with loess and windblown silts along the project road. Samples shall be taken at these sections for conducing index tests in the laboratory. Typically, collapsible soils have 50 to 90 % silt particles.

The double oedometer test for assessing the response of a soil to wetting and loading at different stress levels should be carried out to confirm the potential degree of collapse of the material.

6.7.4 Saline Soils

The presence of soluble salts, i.e., NaCl, Na_2CO_3, $NaHCO_3$, (but not gypsum, Na_2SO_4, which is only slightly soluble) in pavement or earthwork materials, or more critically in the subgrade and/or groundwater can cause damage to prime coats and thin surfacings.

This is a significant risk in arid climates because of the migration of these salts to the surface as a result of evaporation. Coastal areas, or possibly areas in the vicinity of the saline lakes in Kenya, are most at risk from this mode of damage.

Electrical conductivity tests can be conducted in the laboratory or the field to determine the content of soluble salt rapidly but indirectly. Chemical analysis on a few samples can be conducted to determine the precise configuration of soluble salts, and related to the conductivity. The total soluble salts (TSS) can be measured; however, it is important to ascertain the dominant salt type for more detailed design and construction control, particularly if salt levels are significant.

6.7.5 Organic Soils

These commonly occur in swamp areas and require special investigations to evaluate ground stability and potential for excessive settlement. Loss on ignition tests shall be conducted to determine the organic matter content of soil samples.

6.7.6 Halloysite

Halloysite soils are clayey materials often formed from volcanic ash or weathered feldspathic rocks. The presence of halloysite as a major constituent of the residual soils can be predetermined based on the following properties:

1. The position of test results of plasticity index and liquid limit plot to the right of the 'A' line on the plasticity chart (Figure 3.1).
2. Higher than normal optimum moisture contents (20 % - 35 %).
3. Low angle of internal friction and low undrained shear strength due to their fine-grained nature and smooth particle surfaces.

Presence of halloysites can be confirmed by measuring the change in X-ray diffraction pattern after treating the sample with ethylene glycol or formamide.

7 Ground Investigations for Structures

7.1 General

This chapter describes the different field tests applicable to structures such as bridges, box culverts, retaining walls, among others. The exploration of a site requires the boring, sounding and sampling of all strata likely to be significantly affected by the structural load. Field tests and observations may be necessary to evaluate the structural properties of the foundation materials. Best practice for obtaining reliable test results has also been included. It is important that experienced personnel are responsible for supervising and interpreting the obtained test results. Ground investigation tests and depths at shallow and deep foundations for river crossings are also provided.

7.2 Test Pit Excavation and Logging

Test pits shall be dug 1.5 m x 1.5 m in plan to a depth of 3.0 m below the existing ground level unless rock or another material impossible to excavate by hand is encountered.

The position of each test pit shall be accurately determined and recorded. In every test pit, all layers, including topsoil, shall be accurately described in the test pit log and their thicknesses measured. All layers of more than 300 mm (except topsoil) shall be sampled. In the field soils shall be identified and described in accordance with the Kenyan soil classification based on BS EN ISO 14688-2:2018.

Test pits may be used for obtaining samples. Alternatively, samples maybe obtained using an open sampler, core sampler, auger sampler or a piston sampler.

Groundwater conditions and the depth to water table shall also be recorded in the log. The soil vertical profile may be logged manually or using software. For the materials report, the log of each trial pit shall be accurately drawn, and coloured photographs of the vertical profile included.

7.3 Dynamic Probing

The Dynamic Probing test is used to assess the relative density and strength characteristics of soils, particularly in identifying variations in soil stiffness and compaction. This test is conducted by driving a steel rod or probe into the ground using a hammer of known weight and drop height. Standard equipment includes a 63.5 kg hammer dropped from a height of 750 mm, but modifications may be necessary for specific soil types. The number of blows required to drive the rod to drive the rod a set distance, commonly 10 cm or 20 cm, and note any variations with depth is recorded. The test should be performed in a vertical position to avoid angular misalignment of the rod, which can skew results. Typically, tests are performed in increments of 0.5 m to a depth of 20 m, or until refusal (a consistent blow count).

The number of blows required for each increment of penetration can indicate soil compaction or density. High blow counts suggest stiff or dense soils, while low blow counts suggest loose or soft soils.

Probe results are very useful for assessing the depth and degree of compaction of buried fill, making comparative qualitative assessments of ground characteristics, and in supplementing the information obtained from trial pits and boreholes. The primary use of dynamic probing is to interpolate data between trial pits or boreholes rapidly and cheaply. Therefore, probing should first be carried out adjacent to a trial pit or borehole where ground conditions are known, and then extended to other areas of the site. For more precise assessments, the test may need to be combined with other geotechnical tests, such as Standard Penetration Testing (SPT), to understand soil behaviour better.

Results can be influenced by soil heterogeneity and the presence of large particles (e.g., gravel or cobbles). The test provides relative values, so for accurate shear strength and stiffness, complementary testing may be needed.

In fill or completely decomposed rock, the maximum depth to which a probe can be driven is about 10 m. To minimise damage to the equipment, probing should terminate when the blow count reaches 100, or when the hammer bounces and insignificant penetration is achieved.

7.4 Cone Penetrometer Test

The cone penetration test (CPT) consists of driving a 600 cone into the ground at a constant rate and recording the force required to drive the cone. The test is not suitable for use in dense gravel, coarse gravel, cobbles or rocks and should be terminated when these soils are encountered.

The CPT equipment may be mechanical or electrical. Mechanical cones shall only be used for preliminary assessment of sites. The CPT shall be carried out by specialist contractors with experience undertaking the test and interpreting results.

To ensure accurate interpretation of cone penetration test (CPT) results, including cone resistance, sleeve friction, and/or pore pressure during penetration, the following guidelines should be followed:

1. Selection and documentation of the specific type of cone and friction sleeve used, as their design can significantly influence the measurements. Ensuring the cone type is suitable for the soil conditions and testing objectives.
2. Performing supplementary soil borings alongside penetration tests to provide reliable soil stratification data and enhance the interpretation of CPT results.
3. Evaluating the effects of groundwater conditions and overburden pressure on test results, applying necessary corrections to account for these influences.

Interpretation of in-situ stress measurements shall be done by a specialist with experience undertaking the test and using the results for design. Assumptions made based on the above considerations, as well as any other assumptions that might be made by the Design Engineer, shall be included in the ground investigation report as well as the interpretative report.

7.5 Standard Penetration Test

The standard penetration test (SPT) involves using blows from a 63.5 kg hammer falling through 760 mm to drive a sample tube into the ground at the bottom of the borehole. The number of blows required to drive the sampling tube 450 mm into the ground is recorded.

In assessing blow counts, the following features shall be considered:

1. Groundwater conditions. The presence of groundwater can influence the resistance encountered during penetration. In saturated conditions, the soil may become softer, leading to lower blow counts. Conversely, in dry conditions, the soil may be harder, requiring more blows. It is crucial to record the groundwater table level and, if applicable, perform tests both in saturated and unsaturated zones to account for moisture content variations.
2. The influence of the overburden pressure. The overburden pressure, which is the weight of the soil and any water above the penetration point, directly affects soil resistance. Higher overburden pressure typically increases soil compaction and resistance to penetration, resulting in higher blow counts. To accurately interpret blow counts, the depth of the borehole and the thickness of the soil layers should be documented, as these will influence the overburden pressure.
3. The composition and consistency of the soil significantly affect blow counts. For instance, the presence of cobbles, coarse gravel, or boulders can create significant resistance and may cause fluctuating or high blow counts. In such cases, the interpretation of blow counts should account for the possibility of encountering large, dense particles that can distort typical soil behaviour. A visual inspection of the sample and borehole should be conducted to identify such materials, and adjustments should be made when comparing with standard penetration test (SPT) charts.

   By considering these factors, a more reliable and accurate interpretation of blow count data may be made, which can then be used for geotechnical design.

7.6 Vane Shear Test

The Vane Shear Test is used to determine the undrained shear strength of cohesive soils, particularly clays. It involves inserting a cruciform vane attached to the end of a solid rod into the soil at the desired depth, then rotating the vane until the soil fails, and measuring the torque required for rotation. This torque is directly related to the soil's shear strength.

The procedure for conducting the vane shear test is outlined in BS EN ISO 22476-9. It is particularly effective for cohesive, fully saturated soils, with undrained shear strengths up to 100 kN/m². The test causes minimal disturbance to the soil, making it especially useful for sensitive clays, where it often provides more reliable results than laboratory tests on undisturbed samples.

The test is most suitable for uniform, cohesive soils, such as clays, where the soil is homogeneous and fully saturated.

For sandy soils, soils containing shells, or coarse-grained soils with large particles, the test results should be interpreted with caution, as the vane may not rotate uniformly, or the results may not accurately reflect shear strength.

In plastic clays, discrepancies between field vane shear strength and laboratory values tend to increase as the plasticity of the soil rises. Therefore, results may be higher than those obtained from laboratory tests.

Organic soils with rootlets or soils containing coarse particles may also yield erroneous results due to interference with the vane's penetration and rotation.

7.7 Pressure Meter Test

In the pressure meter test, a probe is inserted into a pocket below the bottom of a borehole or directly into the appropriate size of borehole and expanded laterally by compressed air or gas. The applied pressures and resulting deformations are measured and enable the strength and deformation characteristics of the ground to be investigated.

Readings are taken at the ground surface on pressure and volume gauges which are connected to the central cell by means of a back-pressured annular plastic tube. The pressure tube and probe must be calibrated on site. The pressure meter test can be used in soil or weak rock, but it is not suitable for stronger rock since the instrument is limited by its sensitivity to the tube calibration. The test shall be carried out according to BS EN ISO 22476-4.

In assessing the values of the limit pressure and the pressure meter modulus, the following should be considered:

1. The type of equipment. It is essential to ensure that the pressuremeter is appropriately calibrated and that the pressure cells, expansion sleeves, and other components are suitable for the expected soil conditions.
2. The procedure used to install the pressure meter in the ground. Factors such as the hole diameter, and installation rate should be carefully monitored. Any deviation from the standard installation procedure can lead to altered results, particularly in heterogeneous or sensitive soils.
3. The limit pressure represents the point at which the soil reaches its failure or yield condition during the test. If the limit pressure is not reached during the pressuremeter test due to test constraints or limitations in the soil's response, it is often necessary to extrapolate the data to estimate the limit pressure. In such cases, a moderate and conservative extrapolation of the pressure-displacement curve can be used. This extrapolation should be based on the observed trend of the data, considering factors such as soil type, stress-strain behaviour, and the likelihood of soil failure at higher pressures.

7.8 Field Density

The density of soil can be measured by a range of field tests such as sand replacement, water replacement and core cutter test methods. These methods comprise the removal of a representative sample of soil from the site and then the determination of its mass and the volume it occupied before being removed.

The water content of the sample should be representative. Ideally, the weighing should be done on-site; if this is not possible, the entire sample should be preserved until it can be weighed, taking care to avoid loss of water.

7.8.1 Sand Replacement Test

The sand replacement test may be used to determine field density of pavement layers. The sand used in the test must be free flowing, clean and dry. The test site should be levelled. The sides of the excavated hole prepared for the measurement should be trimmed, smooth and regular. Field density tests for structures shall be determined according to BS 1377-9:1990, Clauses 2.1 and 2.2. The standard describes two test variations, one for fine soils and sands and another suitable for fine soils, sands and gravels. These test methods are unsuited to soils containing a high proportion of coarse gravel or larger particles. The method should not be used in soils where the volume of the hole cannot be maintained constantly. It also loses accuracy in soils where it is difficult to excavate a smooth hole because the test sand added into the hole cannot easily occupy the full volume.

7.8.2 Water Replacement Test

The water replacement test method shall be carried out in accordance with BS 1377-9:1990, Clause 2.3. The method is normally used in coarse and very coarse soils (including rockfill) when the other methods for determining the field density are unsuitable because the volume excavated would be unrepresentative. It consists of excavating a hole large enough to obtain a representative sample, lining the hole with flexible polyethylene or similar sheeting and then determining the volume of water required to fill the hole.

The accuracy of the results of this test can be enhanced by attention to the following details:

1. The hole should be made as large as possible.
2. The sides of the hole should be made as smooth as possible.
3. As thin a gauge of polyethylene as possible should be used, consistent with it not puncturing too easily.

7.8.3 Core Cutter Test

The core cutter test method shall be carried out in accordance with BS 1377-9:1990, Clause 2.4. The test point should be level and firm, and clear of surface debris. The method depends upon being able to drive a cylindrical cutter vertically into the soil without a significant change of density and retaining the sample inside it so that the known internal volume of the cylinder is completely filled. It is, therefore, restricted to fine soils that do not contain gravel and that are sufficiently cohesive for the sample not to fall out, and to chalk soils. The cutter and sample should be extracted by carefully excavating the surrounding soil and retrieving the unit without disturbing its contents. Any excess soil should be trimmed flush with the ends of the cutter using a straight edge. It might be preferable in cohesive and sensitive soils to trim soil the specimen into a cylindrical shape, slightly larger than the cutter diameter before driving the cutter through it and retrieving the unit.

7.9 In-situ Stress Measurements

The stresses existing in a ground mass before changes caused by the application of loads or the formation of a cavity within the mass are referred to as the initial in-situ state of stress. These stresses are the result of gravitational stress and residual stresses related to the geological history of the mass.

Data on the initial in-situ state of stress in rock and soil masses before the execution of works are important in design. The most favourable orientation, shape, execution sequence and support of large and complex underground cavities, and the prediction of the final state of stress existing around the completed works, are all dependent on knowing the initial in-situ state of stress. Measurements of in-situ stress have shown that in many areas the horizontal stresses exceed the vertical stress, which in turn often exceeds that calculated, assuming that only gravity is acting on the ground mass.

An estimate of in-situ stress in soils can be obtained. The equipment used generally provides an estimate of horizontal stress only. To obtain an estimate of both total and effective stresses, the pore water pressure in addition to the total stress shall be measured.

Interpretation of in-situ stress measurements shall be done by a specialist with experience undertaking the test and using the results for design. Stress measurements may be made using electrical strain gauges, photo-elastic discs, solid inclusions and systems for measuring the diametral change of a borehole. In-situ stress measurements shall be done according to BS 5930.

7.9.1 Stress Measurements in Rock

Stress measurements may be made using electrical strain gauges, photo-elastic discs, solid inclusions and systems for measuring the diametrical change of a borehole. Some equipment is designed to measure stress change with time, or stress change due to an advancing excavation, whereas other equipment is designed to obtain an instantaneous measurement of stress. The technique selected should be chosen in relation to the rock material, mass quality and water conditions.

To determine the triaxial state of stress at a given point, measurement should be made in at least six independent directions. It is, however, desirable to have the extra data for better evaluation by statistical methods of error distribution.

7.9.2 Stress Measurements in Soils

The response of soil masses to applied loads should be made by obtaining reliable data on their strength and deformation characteristics; as these are stress-dependent, a knowledge of the in-situ state of stress assists in their evaluation by laboratory testing.

Direct in-situ measurements of the initial state of stress in soils is difficult because the disturbance created by gaining access to the ground mass is usually non-reversible, as well as being several times that produced by a stress-relieving technique. Most techniques that have been developed suffer from the disturbance that their instruments create in the ground on insertion.

It is usual to measure horizontal stress only and to make assumptions concerning the level of vertical stress from overburden depth. Total stress only may be measured, so to determine the effective stress conditions the pore water pressure at the test level has to be measured or assumed.

7.10 In-situ Shear Tests

In-situ shear tests on soil may be carried out either within boreholes or near the ground surface. A sample of ground shall be prepared and tested in-situ. As a rough guide, the sample dimension should be at least ten times that of the largest particle; in rock, the sample size should reflect the roughness of the rock discontinuity being tested.

The direct shear test should be designed to measure the peak shear strength of the in-situ material as a function of the stress normal to the sheared plane. A sample of ground, prepared and tested in-situ, should be subjected to direct shear, using a stress system similar to that of the laboratory shear box tests. The samples should be selected to include one or more discontinuities, if this is what is to be tested. The orientation of the discontinuities should be selected as relevant to the stress conditions being considered.

The orientation of the sample and the forces applied to it should be governed by the direction of the forces that become effective during and on completion of the works but should be modified to take account of the orientation of significant discontinuities. In many cases, however, to facilitate the setting-up of the test, the sample should be prepared with the shear plane horizontal. The normal and shearing stresses should be imposed as forces applied normally and along the shear plane. However, an inclined shear force passing through the centre of the shear plane may be used, as this tends to produce a more uniform distribution of stress on the shear surface.

The sample shall be subjected to direct shear following the procedure described in BS 5930. The stresses applied in the testing programme should be within the range of the relevant working stresses at the site, including those applied by the final structure, if appropriate. More than one test is normally required to obtain a sensible design value.

7.11 Bearing Tests

7.11.1 Plate Load Tests

The plate load test is probably the most common vertical bearing test in use. In-situ vertical loading tests involve measuring the applied load and penetration of a plate being pushed into a soil or rock mass. The test can be carried out in shallow pits or trenches, or at depth in the bottom of a borehole or pit. In soils, the test is carried out to determine the shear strength and deformation characteristics of the material beneath the loaded plate. The test shall be carried out according to BS 1377-9:1990, Clause 4.1 for soils. The ultimate load is often not attainable in rocks, where the test is more frequently used to determine the deformation characteristics.

The test is usually carried out either under a series of maintained loads or at a constant rate of penetration. In the former, the ground is allowed to consolidate under such a load before a further increment is applied; this will yield the drained deformation characteristics and also strength characteristics if the test is continued to failure. In the latter, the rate of penetration is generally such that little or no drainage occurs, and the test gives the corresponding undrained deformation and strength characteristics.

It should be emphasised that the results of a single loading test apply only to the ground which is significantly stressed by the plate; this is typically a depth of about one and a half times the diameter or width of the plate. The depth of ground stressed by a structural foundation will, in general, be much greater than that stressed by the loading test. For this reason, the results of loading tests carried out at a single elevation do not normally give a direct indication of the allowable bearing capacity and settlement characteristics of the full-scale structural foundation. In order to determine the variation of ground properties with depth, it will generally be necessary to carry out a series of plate tests at different depths. These should be carried out such that each test subjects the ground to the same effective stress level it would receive at working load.

7.11.2 Long-term Load Tests

A long-term maintained load test should be carried out in accordance with BS 1377-9:1990, Clause 4.2. The long-term settlement of fills is usually of much greater significance to the satisfactory functioning of structures built on the site than the movements that occur during construction. A variation of the bearing test can be used and is known as the long-term maintained test. This test usually consists of casting a concrete slab on the surface of the fill and loaded by a deadweight which can be applied either by a skip or skips filled with sand or other suitable material (often referred to as the BRE skip test) or simply kentledge. The settlement of the pad is observed with time and referenced to a stable datum remote form the test.

The actual period over which the test is carried out is inevitably a compromise between the theoretically desirable requirement of a period comparable with the life of the structure and the practical requirement of early development of the site. A month would seem to be a minimum for the test. It would be highly desirable for tests to be carried out over periods of 3 to 6 months, whenever possible.

7.12 Geohydraulic Testing

Geohydraulic testing refers mainly to in-situ permeability tests and occasionally infiltration tests. It is often necessary to understand the groundwater regime within which a project is to be constructed for the correct evaluation of the soil parameters for the design of the structure and its foundations, the design and implementation of temporary works to enable construction of the works and the protection of the environment. The guidance given in BS EN 1997-2 and BS EN ISO 22282-1 should be followed.

For most types of ground, field permeability tests yield more reliable data than those carried out in the laboratory, because a larger volume of material is tested, and because the ground is tested in-situ, thereby avoiding the disturbance associated with sampling. Permeability tests should be carried out by suitably experienced persons; execution of the borehole tests requires expertise, and small faults in technique can lead to errors of up to one hundred times the actual value. Even with considerable care, an individual test result is often accurate to one significant figure only. Accuracy can be improved by analysing the results of a series of tests. In many types of ground, however, particularly stratified soil or fractured rock, there might be very wide variations in permeability, and the important measure of the permeability of the mass of ground may be determined by a relatively thin stratum of high permeability or a major fracture.

Before carrying out any tests, it is important to identify the aquifer and understand whether it is confined or unconfined. The determination of in-situ permeability by tests in boreholes involves the application of a hydraulic pressure in the borehole different from that in the ground, and the measurement of the rate of flow due to this difference. The pressure in the borehole may be increased by introducing water into it, which is commonly called a 'falling head' or 'inflow test', or it may be decreased by pumping water out of it in a 'rising head' or 'outflow test'. The pressure may be held constant during a test (constant head test) or it may be allowed to vary (a variable head test). The technique is applicable only to the measurement of permeability of soils below groundwater level. The measurement of the permeability of unsaturated or partially saturated zones is extremely difficult. A variety of tests is available, ranging from the simple, which can nevertheless be used to investigate complex situations, to the sophisticated; the interpretation of the data is crucial. It is important to establish the normal fluctuations within the aquifer.

7.13 Selection Criteria for Ground Investigation Methods

A ground investigation is required to determine the foundation conditions of structures such as bridges or box culverts, retaining walls among others. A desk top study shall assess the geology at the structure location, and a test plan for the preliminary design shall be prepared. Choice of the tests to use at the different design stages may be made from the tests described above subject to the level of detail required for design.

Table 5.1 showing the suitability of field tests for various data requirements may be used in choosing the test to use. The preliminary investigation shall be sufficient to give an indication of the type of foundation required i.e., shallow or deep foundation.

Samples shall be collected to conduct index tests and strength tests such as shear strength and compressibility. Table 7.1 provides a guide for selection of ground investigation tests and sampling methods at preliminary design and detailed design stages.

Preliminary investigations shall be to a depth where competent material of suitable bearing capacity (i.e., stiff to hard cohesive soil – undrained shear strength greater than 50 kPa, compact to dense cohesion-less soil or bedrock whichever is shallower). The depth of investigation at detailed investigations shall be guided by the detailed design.

At detailed design, the depth and tests undertaken shall be dependent on the type of foundation supporting the superstructure. Note that the exploration programme can be adjusted based on the variability of the anticipated ground conditions. Greater investigation depths should always be selected, where unfavourable geological conditions, such as weak or compressible strata below strata of higher bearing capacity, are presumed.

Table 7.1 Selection Criteria for Ground Investigation Methods

Preliminary Investigations		Detailed Investigations	
Soil type	**Suitable Tests**	**Foundation Type**	**Suitable Tests**
Fine Soil	**Field tests:** CPT, DP, FVT, SPT **Sampling**: OS, TP, PS	Pile foundation	**Field tests:** CPT, DP, FVT, SPT, PIL, PMT **Sampling:** PS, OS, CS
		Shallow foundation	**Field tests:** CPT, DP, FVT, PMT **Sampling:** PS, OS, CS, TP
Coarse Soil	**Field tests:** CPT, DP, SPT **Sampling:** AS, OS, TP	Pile foundation	**Field tests:** CPT, DP, SPT, PIL **Sampling:** OS, TP
		Shallow foundation	**Field tests:** CPT, DP, SPT, PMT, PLT **Sampling**: OS, TP
Rock	**Field tests:** CPT, MWD, PLT **Sampling:** CS	Pile or shallow foundation	**Field tests:** MWD, mapping of discontinuities, PMT **Sampling:** CS

NOTES:
Field tests: *CPT – Cone penetration test, DP – Dynamic probing, FVT – Vane shear test, MWD – Measuring while drilling, PIL – Pile load test, PLT – Plate load test, PMT – Pressuremeter test, SPT – Standard penetration test.*
Sampling: *AS – Auger sampler, CS – Core sampler, OS – Open sampler, PS – Piston sampler, TP – Test pit sampling.*

7.13.1 Shallow Foundations

A minimum of two boreholes per substructure shall be required for bridge piers or abutments ≤ 30 m wide and a minimum of four borings per substructure for bridge piers or abutments greater than 30 m wide. Additional exploration points may be provided where erratic subsurface conditions are encountered.

Boring shall be to a depth greater than 6 m or 3 times the smaller side length of the foundation, b_F below the lowest point of the foundation of the structure, za; whichever is greater. i.e., the greater of

- $z_a \geq 6$ m
- $z_a \geq 3b_F$

The boring shall be terminated at a depth where competent material of suitable bearing capacity is encountered. If bedrock is encountered, investigation depth shall be a minimum of 3 m into competent bedrock and a minimum of z_a = 5 m in poor rock. The rock investigation should be sufficient to characterise compressibility of infill material in bedding planes where applicable.

For raft foundations, the depth of investigation shall be greater than 1.5 times the smaller side of the foundation below the founding depth. Two to six investigation points per foundation shall be required based on the complexity of the structure.

7.13.2 Deep Foundations

A minimum of two boreholes per substructure shall be required for bridge piers or abutments ≤ 30 m wide and a minimum of four borings per substructure for bridge piers or abutments greater than 30 m wide. Additional exploration points may be provided where erratic subsurface conditions are encountered.

For drilled shaft foundations, at least one borehole should be drilled for each shaft where the diameter of the shaft is greater than 1.5 m, especially for shafts socketed into bedrock.

All borings should extend through unsuitable strata such as unconsolidated fill, peat, highly organic materials, soft fine-grained soils, and loose coarse-grained soils to reach hard or dense materials. Boreholes shall extend to a minimum depth of:

- $z_a \geq b_g$
- $z_a \geq 5$ m
- $z_a \geq 3D_F$

below the lowest point of the foundation of the structure, z_a. The larger of the three depths shall be considered. Where b_g is the smaller side of the rectangle circumscribing the group of piles forming the foundation at the level of the pile base and D_F is the pile base diameter.

If rock is located at a shallower depth, drilling can be stopped at a minimum of 3 m into competent rock or a minimum of z_a = 5 m in poor rock or a length of rock core equal to at least three times the shaft diameter for isolated shafts or two times the maximum shaft group dimension, to determine the characteristics of rock within the zone of foundation influence.

For shafts socketed in rock, drilling shall continue to a depth of at least two shaft diameters below the planned elevation of the shaft toe. Due to the high cost of drilling rock-socketed shafts, conditions should be confirmed at each shaft location during investigation.

7.13.3 Special Considerations

Attention should be paid to soil profiles having soft and compressible soils or thin layers of soft soil, liquefiable soils, presence of problem soils (collapsible, expansive, or dispersive soils), and sinkholes. These pose design challenges such as settlement in shallow foundations and down drag for piles. The Design Engineer shall have to make special considerations for such cases.

Furthermore, the Design Engineer needs to be mindful of soil profiles containing cobbles and boulders and/or gravels and sands as these will affect the construction of drilled shafts.

8 Investigations for Natural Gravel Sources

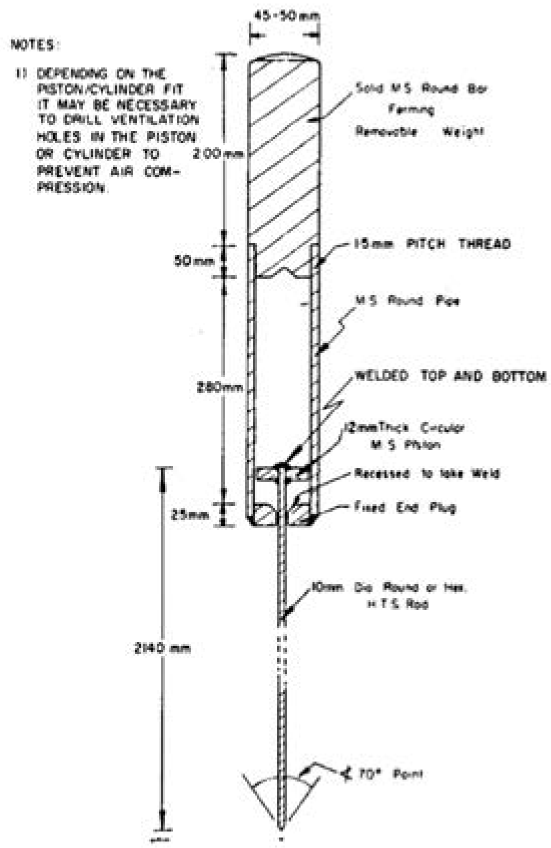
8.1 General

This chapter covers the steps followed in obtaining sources of natural gravel. Details for the field tests required during prospecting have also been provided. Laboratory tests for determining the suitability and to guide the choice of borrow pit have also been identified.

8.2 Test Pit Excavation and Logging

At the preliminary design stage, the approximate areal extent of the borrow pit shall be demarcated with stakes. A DCP or calcrete probe (in sandy areas) can be used to determine the extent. The calcrete probe consists of a piston and a 2 m steel rod driven into the ground with a 70° cone. The equipment set up is shown in Figure 8.1. Where feasible, borrow pits should be spaced to obtain the most economic use of materials.

Figure 8.1 Illustration of the Calcrete Probe (after Netterberg, 1969)



The minimum thickness of deposit normally considered workable shall be one metre. However, there may be instances when thinner horizons must be exploited, as no suitable alternative exists. The absolute minimum should depend on the area of the deposit and the thickness of overburden. (If there is no overburden, as may be the case in arid areas, horizons as thin as 300 mm may be workable).

Test pits shall be dug on a 50 m grid, through the full depth of the layer(s) proposed for use. This can be reduced to 25 m spacing if the material is highly variable within a short distance. A minimum of 5 test pits shall be required for each proposed borrow pit.

The location of each proposed borrow pit shall be indicated on a key plan indicating its distance from the start of the route, the chainage offset from the centreline and GPS co-ordinates.

A site plan of each proposed borrow pit shall be prepared, showing the characteristic features of the site, the position of each trial pit (GPS co-ordinates), means of access, haulage distance from the road and expected quantity. The quantity of material must be carefully estimated. Any potential problems such as boulders, presence of water and environmental factors of concern in the area should also be identified. The name(s) and contact of the landowner should also be provided for future use at construction.

In every test pit, all layers, including topsoil and overburden, shall be accurately described and their thicknesses measured. The test pit log shall indicate if there is a possibility for deeper exploitation bearing in mind the environmental implications.

The log of each test pit shall be accurately drawn and included in the Materials Report. All layers proposed for use shall be sampled. The sample shall be taken over the full depth of the layer proposed.

8.3 Frequency of Sampling and Testing

Samples as per the minimum quantities provided in Table 8.1, should be taken to carry out tests to determine the main materials, processes, and additives to be used, and percentages of additives required.

At least one sample shall be taken from each positive test pit, even if the volume represented is small, for gradation and Atterberg Limits tests.

At least one large sample, whether mixed or re-sampled, is required per 10,000 m^3 of material proposed for use. Large samples for Compaction and CBR tests shall be obtained by either of the following methods:

1. **Mix Method:** Large samples shall be obtained by mixing 'small' identification samples. A mix must be representative of a workable area. All the 'small' samples to be incorporated in a mix shall be of the same type of material and must have fairly consistent identification characteristics (Grading and Atterberg Limits). Within each borrow pit, the mixes shall be chosen to adequately cover the range of materials proposed for use.

2. **Re-Sampling Method:** In consideration of the gradation and Atterberg Limits results, large samples shall be obtained by re-sampling from typical existing test pits which are representative of the various categories of material found within the potential borrow pit area.

Each large sample shall be submitted to the following tests:

a. Grading to 0.075 mm sieve.

b. Atterberg Limits.

c. Compaction test (modified compaction 4.5 kg rammer).

d. CBR and swell at 4 days soak, on specimens moulded at OMC (modified compaction) at 3 levels of compaction, normally around 90, 95 and 100 % MDD (modified compaction). The moisture contents after soaking shall be measured on a specimen taken from below the plunger and the whole sample.

Note: *For the types of gravel susceptible to crushing during compaction, adequate samples should be collected to allow for use of one specimen at each moisture content to be tested.*

In addition to the foregoing tests, the Los Angeles Abrasion (LAA) and the Aggregate Crushing Value (ACV) of the coarse particles shall be determined for at least one typical sample from each site of gravelly material.

8.4 Mass of Sample Required

The total mass of sample required depends on the tests to be carried out, the grading of the material (its maximum particle size, in particular) and its susceptibility to crushing during compaction.

For general guidance, Table 8.1 shows the minimum mass of sample required for various sequences of tests and typical materials, namely:

1. Fine grained soil (Max. particle size: 2 mm).
2. Coarse grained gravel (Max. particle size: 40 mm), not susceptible to crushing during compaction.
3. Coarse grained gravel (Max. particle size: 40 mm), susceptible to crushing during compaction.

Table 8.1 Minimum Mass of Sample Required for Soils and Gravel

Tests Required	Fine Grained Soil (max. particle size 2 mm)				Coarse Grained Gravel (max. particle size 40mm) not susceptible to crushing				Coarse Grained Gravel (max. particle size 40 mm) susceptible to crushing			
Grading	*	*	*	*	*	*	*	*	*	*	*	*
Atterberg Limits	*	*	*	*	*	*	*	*	*	*	*	*
Compaction		*	*	*		*	*	*		*	*	*
CBR (3 points)			*	*			*	*			*	*
CBR (1 point)		*				*				*		
Treatment Tests				*				*				*
Minimum Sample Mass (kg)	10	20	35	80	20	60	70	200	20	100	120	250

The masses indicated in Table 8.1 include some allowance for drying, wastage and rejection of coarse fragments where necessary.

8.5 Choice of Borrow Pits for Detailed Design

The information obtained at the preliminary design stage will enable a selection of the most suitable borrow areas to carry forward to the detailed design stage. Consideration shall be given to the following factors:

1. Location of the proposed borrow areas, to minimise haul and obtain the most economic use of materials.
2. Quality of the materials.
3. Ease of working (land acquisition, clearance of the site, access, overburden, thickness of exploitable horizon, etc.)

An indication of where the material is to be used on the alignment shall be included in a materials utilisation schedule. If the compaction and CBR tests show that the available natural materials do not meet the quantity or quality requirements, treatment tests shall be carried out on the relevant large samples.

8.6 Treatment Tests

Information obtained at the preliminary design stage will enable the Design Engineer to decide which borrow pit materials require treatment and the nature of that treatment (i.e., type of additive and approximate percentage needed, method of mixing, etc.).

Firstly, if it is suspected that the chemical composition of the material may give rise to detrimental reactions, the following chemical tests shall be carried out:

a. Organic matter content.

b. pH value.

c. Sulphate content.

Then, if the material appears to lend itself to treatment, the representative large sample (as defined above) shall be mixed with the additive chosen based on the plasticity properties of the material. Three amounts of additive shall be chosen to give an indication of the treated material's characteristics. The following tests shall be carried out:

a. Compaction test (modified compaction) on the large sample mixed with the amount of additive expected to be appropriate (usually the intermediate value of the three).

b. CBR and/or Unconfined Compressive Strength (UCS) at 7 days cure plus 7 days soak on specimens moulded at OMC and 95% MDD, with each of the 3 amounts of additive. CBR tests apply to modified materials, whereas UCS apply to stabilised ones (The results of the Preliminary Design stage should allow the distinction between 'modification' and 'stabilisation' to be made).

c. Atterberg Limits on one set of 3 specimens for each of the additive's percentages.

At least one large sample per 10000 m^3 of material proposed for treatment shall be submitted to the above tests.

9 Investigations for Hard Stone Sources

9.1 General

Potential sources of stone shall be identified at the preliminary design stage from a desk study of geological maps and previous material reports. Those visually considered suitable, in terms of stone quality and quantity, shall then be further investigated. Practical considerations concerning the exploitation of the potential quarries, such as access, ease of working, overburden, etc. should be noted.

The location of each potential source of stone shall be indicated on a key plan. A site plan of each potential quarry shall be prepared, showing the characteristic features of the site (including outcrops) and the means of access and location.

9.2 Sampling and Testing

Hand sampling from existing faces or outcrops shall be carried out during the preliminary design stage. At least three samples shall be taken from each potential source. The position of each sampling point or group of sub-sampling points shall be accurately determined and reported on the site plan. Each sample shall be accurately described, from a geological and mineralogical viewpoint. Great care shall be taken to ensure that the samples are obtained from sound rock and not from a superficial horizon of weathered rock.

Each sample shall have sufficient material to carry out the following tests at the preliminary design stage:

a. Los Angeles Abrasion (LAA).

b. Aggregate Crushing Value (ACV).

c. Sodium Sulphate Soundness (SSS) (or magnesium sulphate soundness).

d. Plasticity Index on LAA fines.

e. Mineralogical analysis.

Hand-packed stone and cobblestone for use as paving may be extracted from trachyte, basalt, granite or hard sandstone rock. 4-days soaked CBR at 95% modified MDD, ACV, LAA and plasticity index tests shall be conducted on samples for use as hand-packed stone. For cobble stones, water absorption, compressive strength, specific gravity and LAA tests shall be conducted on samples to determine their suitability for use.

9.3 Mass of Sample Required

Each sample shall have sufficient material to carry out the tests required for the intended use as detailed in RDM 3.2. The sample size required for aggregates shall be dependent on the tests to be carried out. Minimum sample sizes are presented in Table 9.1.

Table 9.1 Minimum Sample Size for Aggregates

Tests Required	Solid	Stone
LAA	*	*
ACV	*	*
SSS		*
Specific gravity	*	*
Bitumen affinity	*	*
Crushing		*
Grading		*
Flakiness index		*
Compaction		
Minimum Sample Mass (kg)	100	200

9.4 Choice of Quarry for Detailed Design

To further guide which quarries to use at detailed design and planned construction, seismic refraction methods such as seismic refraction tomography, or electrical resistivity methods such as electrical resistivity tomography (ERT), ground penetrating radar (GPR) may be used as a non-destructive test to determine the thickness and extent of rock strata. Guidance on choosing suitable geophysical tests for ground investigations, interpretation of results and reporting requirements are provided in Section 5.4.

Interpretation of rock quality from geophysical tests is dependent on rock type, subsurface lithology, weathering intensity/degree, fractures and faults, water content, rock deformation, pores connectivity, permeability, rock alteration, and rock association. Ground truthing using exploratory methods may be required during construction to confirm the findings. Information obtained at the preliminary design stage will enable a selection of the most suitable quarry sites to be made, based on stone quality, location, access, and ease of working. Each selected potential quarry site shall be investigated as follows:

Boreholes shall be drilled on a 50 m grid to prove overburden, quantity, and quality of stone. The core diameter should be 76 mm to recover stone in sufficient quantity for testing. However, a minimum coring diameter of 55 mm maybe acceptable. The log of each borehole shall be accurately recorded, drawn, and included in the Materials Report.

Where cuts are to form part of the road alignment, consideration is to be given to drilling at these locations at the final design stage, as potential hard stone sources. This shall be undertaken at intervals of 50 m along the centreline of the alignment at deep cut locations.

The position and level of each borehole and each sampling point shall be accurately determined and recorded on the site plan, after the quarries have been drilled. Samples of fresh rock shall be obtained by hand or pneumatic drilling from existing faces and outcrops. Great care shall be taken to avoid sampling from a superficial horizon of weathered rock and to ensure the samples are representative of the stone to be used.

Depending on the consistency of the stone and whether it is an existing or a new quarry, 5 to 10 samples are required per quarry. Each sample shall contain sufficient material to carry out the following tests:

a. Los Angeles Abrasion (LAA).
b. Aggregate Crushing Value (ACV).
c. Sodium Sulphate Soundness (SSS).
d. Plasticity Index on LAA fines & Plasticity Index on Material passing the 425 µm sieve.
e. Specific Gravity (oven-dry method).
f. Bitumen Affinity (for stone proposed for use with bitumen).

Chemical and petrographic tests should be carried out on at least two representative samples from each quarry.

One large sample shall be obtained from each quarry, to be representative of the stone to be used. This large sample shall be crushed with a small crusher (and not broken by hand), to a maximum size depending on the proposed use of the stone (usually ranging from 20 to 40 mm). The crushed stone shall be submitted to tests a) to f) above and, in addition, to the following tests:

a. Grading to 0.075 mm sieve.
b. Flakiness Index.
c. Sand Equivalent.
d. Compaction test (Vibrating Hammer method), when appropriate.

10 Investigations for Natural Sand Sources

10.1 General

This chapter covers the steps followed in obtaining sources of sand. The field tests required during prospecting and the necessary laboratory tests for determining the suitability of the sand source have been identified.

10.2 Sampling and Testing

A desk study shall be conducted to determine locations of sand deposits such as alluvial plains or near rivers. Hand augering or digging of trenches may be used to pick samples for testing. The sand used in concrete works and as an additive in mechanical stabilisation or bituminous mixes should be predominantly angular. A sample of at least 10 kgs shall be collected from each source. The following tests shall be conducted for each of the sand sources:

a. Gradation.

b. Specific gravity.

c. Sand equivalent.

d. Clay and silt content.

10.3 Mass of Sample Required

The sample size required for aggregates shall be dependent on the tests to be carried out. A minimum mass of 13 kg shall be picked for sand samples at each source. This shall be used to conduct tests to determine the suitability of the sand for use in road works. For concrete mix design, a larger sample should be picked subject to the number of trials that are to be undertaken.

10.4 Choice of Sand Source for Detailed Design

Information obtained at the preliminary design stage will enable a selection of the most suitable sand source to be made, based on gradation requirements, cleanliness, location, access, and ease of working. The use to which the sand is to be put shall be borne in mind when choosing to discard a sand source. In case of insufficient quantities or quality of readily available natural sand, the possibility of using fine aggregates, sourced from the chosen quarries, should be investigated at the detailed design stage and construction.

11 Investigations for Water Sources

11.1 General

It is important to identify available suitable water sources for all road projects, in areas where water is scarce such as north-eastern Kenya, sub-surface sources may need to be identified. A desk study of topographical and hydrogeological maps can be used to identify potential water sources, which shall be confirmed during the reconnaissance survey.

11.2 Sampling and Testing Open Surface Water Sources

Ground water measurements in open sources maybe based on the measurement of a free unconfined groundwater surface (i.e., at atmospheric pressure). Section 5.5 of this manual provides details on groundwater measurement using piezometers. At the preliminary design stage, water samples shall be taken to conduct the qualitative tests below:

a. Chloride content

b. Sulphate content

c. Total dissolved solids

d. Total solids in suspension

Any problems regarding the availability of surface water for construction shall also be identified during the preliminary design stage. In such cases, potential sites for drilling water supply wells shall be identified at the detailed design stage for further investigation at construction.

11.3 Drilling and Sampling Sub-Surface Water Sources

In areas where water is scarce, such as semi-arid and arid environments, it is important to locate sub-surface sources of water for construction purposes. Hydrogeological surveying techniques in combination with electrical resistivity geophysical investigation methods such as the electrical resistivity tomography maybe used to determine suitable ground water sources. These methods have the ability to identify groundwater sources and determine the anticipated yield and quality of the water.

Hydrogeological surveying techniques include horizontal electrical profiling and vertical electrical profiling to determine the variation of electrical resistivity in the lateral and vertical direction, respectively. Hydrogeological surveys should be conducted prior to drilling a well to ascertain the quality and quantity of water available at a particular location.

The hydrogeological survey report shall contain a detailed evaluation of the water-bearing levels of rocks and their capability for filtration and an assessment of the intrinsic ability of these rocks to either store or resist water. Information on the pressure, type and quality of the underground water, and the intensity of the water flow through pores or fractures shall also be included in the report.

Based on the hydrogeological conditions at the location, the water pressure in a confined section shall be measured using an electrical transducer, or less commonly a hydraulic or pneumatic piezometer. Groundwater measurement installations and groundwater measurement methods should conform to BS EN ISO 18674-4.

Exploitation of groundwater sources shall be in coordination with the Ministry of Water, Sanitation and Irrigation since they have the necessary equipment (geophysical and mechanical) and personnel. BS EN ISO 22282 provides further guidance on geohydraulic tests. Nevertheless, the Design Engineer should be aware of the following key points. The use of hollow-stem augers is recommended. The minimum recommended external diameter is 150 mm. This has the advantages that:

1. A head can be attached to the first flight and cuttings are rotated to the surface as the borehole is advanced. A pilot bit can be held at the base of the first flight with drill rods to prevent cuttings from entering. When the bit is removed, formation samples can be obtained through the auger using split-spoon or thin-wall samplers.
2. Generally, fluids do not need to be introduced; therefore, ground water quality alteration usually is avoided. In formations of sand, infiltration of sand and water into the augers causes them to bind. This can be alleviated by adding clean potable water so that the quality of the water to be sampled is not altered.
3. Hollow-stem augers allow for well installation directly through the auger into non-cohesive material. When water builds in the well, it can then be pumped out and sampled for laboratory analysis.

Groundwater sampling should be carried out in accordance with BS EN ISO 22475-1 for conducting qualitative tests.

11.4 Choice of Water Sources for Works

The choice of water source for works shall be guided by the results of qualitative tests on the water. The use to which water is to be put should be borne in mind. Necessary environmental and social concerns shall be addressed before a water source is feasible for construction works.

12 Reports and Field Forms

12.1 General

Information collected in the field should be recorded on the respective field forms prior to entry and storage on a computer. The necessary laboratory tests to be conducted on the collected samples should also be identified during the site investigation and recorded. A factual report shall be prepared based on the outcome of the field and laboratory investigations. This shall be followed by an interpretative report that will provide input to the design and construction recommendations. The minimum requirements for these records are provided and can be adjusted subject to the individual project scope.

12.2 Field Investigation Forms

Information collected from field investigations for test pits, DCP tests and borehole logs shall be presented in the respective forms. Typical forms for recording data from test pits, DCP tests and boreholes are included in Appendix C of this manual.

The following should be recorded on all logs: project name; title of investigation; GPS location of each test point; elevation; date of exploration; test point number; a depth scale such that the depth of sampling, tests and change in ground conditions can be readily determined; termination depth; ground water level and sheet number (where applicable) e.g., ‘sheet 2 of 2’.

For boreholes the following additional information shall also be included: method of forming borehole e.g., cable percussion or rotary; make and model of plant used; diameter of borehole; diameter of casing and depth to which the casing was taken; depths of observation wells or piezometers where these have been installed, together with details of the installation, preferably in the form of a diagram; groundwater levels measured subsequent to the completion of piezometers, unless recorded separately; and core recovery for each run.

12.3 Sampling Forms

All samples shall be labelled immediately after being taken from a borehole or test pit excavation. For hand samples of rock, the reference number should be recorded by painting directly on the surface of the sample or by attaching a label. Samples should then be wrapped in several thicknesses of paper and packed in a wooden box.

The label shall show all necessary information about the sample, and an additional copy shall be kept separately from the sample. The label should be marked with indelible ink and properly stored to protect it from damage during transportation and storage. The sample itself should carry more than one label or other means of identification so that the sample can still be identified if one label is damaged.

The label should have the following information, where relevant:

1. Project name.
2. Reference number and location of the field test.
3. Reference number of the sample.
4. Date of sampling.
5. Brief visual description of the sample.
6. Depth at which the sample was acquired.
7. List of tests to be conducted on the sample.

12.4 Reports

Two types of report shall be prepared at the end of the site investigation, i.e., a factual materials/geotechnical report and an interpretative report. The factual report shall detail the tests conducted during the investigation and the results obtained. The interpretative report shall detail how the materials results have been incorporated into the design of the project road. The interpretative report should be submitted before the completion of the detailed design.

12.4.1 The Factual Report

The factual report shall contain all the data necessary for the subsequent interpretation and use of the field tests. The report shall describe the site and test procedures followed, present summary tables and diagrams of field and laboratory test results. The detailed field and laboratory forms shall be provided in the appendices to the report.

An indication as to the factual report layout is presented below:

I. **Introduction** – include when the work was undertaken, nature of investigation, location, purpose and scope of the investigation.

II. **Site description** – include description of the geographical location of the project, location map, site conditions at the time of investigation.

III. **Geology** – include description of the site geology and the sources of the information for the identified soil and rock types in the area. The topography of the area including major landforms such as hills and ridges or valleys, marshes and creeks may be included in this section.

IV. **Field work** – include an account of the methods of investigation and testing used, a description of all equipment used, a drawing indicating the positions and elevations of all field tests such as test pits, boreholes etc. Detailed logs with coloured photographic evidence shall be included in the appendix.

V. **Laboratory test results** – include an account of the laboratory test methods (where the test is not standard)/standards followed and tables of the test results. Where the test procedures are covered by recognised standards, reporting of the results should be in accordance with the standards. Detailed laboratory test results forms and datasheets shall be provided in the appendix.

The factual geotechnical report following conducting of geotechnical investigations shall contain information as follows:

a. A statement on the purpose and rationale of the investigation.

b. Site description and geology.

c. A description of the work carried out, including reference to the specification and standards adopted and any deviations from them.

d. Exploratory hole logs, including details of any instruments installed.

e. Measurements, observations and test results (where separate from other exploratory holes).

f. Laboratory test results.

g. Monitoring data.

h. Site location plan.

i. Detailed site plan showing all exploratory hole locations.

j. A single copy of the photographic volume.

12.4.2 The Interpretative Report

The interpretative report shall contain the analysis of ground data and its application to the proposed design. An indicative layout of the report content is presented below.

1. **Data analysis** - the data on which the analysis and recommendations are based shall be clearly indicated and the process leading up to the choice of design parameters explained.
2. **Sources of material** – the quality of the sources of material for pavement layers and surfacing, concrete aggregates, and filter material shall be analysed; recommendations shall be made based on stabilisation or modification outcomes where applicable; quantities and areas with excavated material suitable for fill shall also be identified; recommendations on the methods and standards of compaction shall also be provided.
3. **Design** – provide details of design considerations such as the design subgrade CBR, type and thickness of pavement, slope stability analysis and proposed stabilisation methods, advice on monitoring unstable slopes, stability of embankment foundations, reinforcement spacing and length and the stability of mechanically stabilised earth walls, assessment of the rate and amount of settlement, proposed ground improvement methods, recommendations for side slopes, locations with problem soils and proposed mitigation, choice of construction materials and methods; ground model, parameter derivation and foundation design at bridges.

   Note:

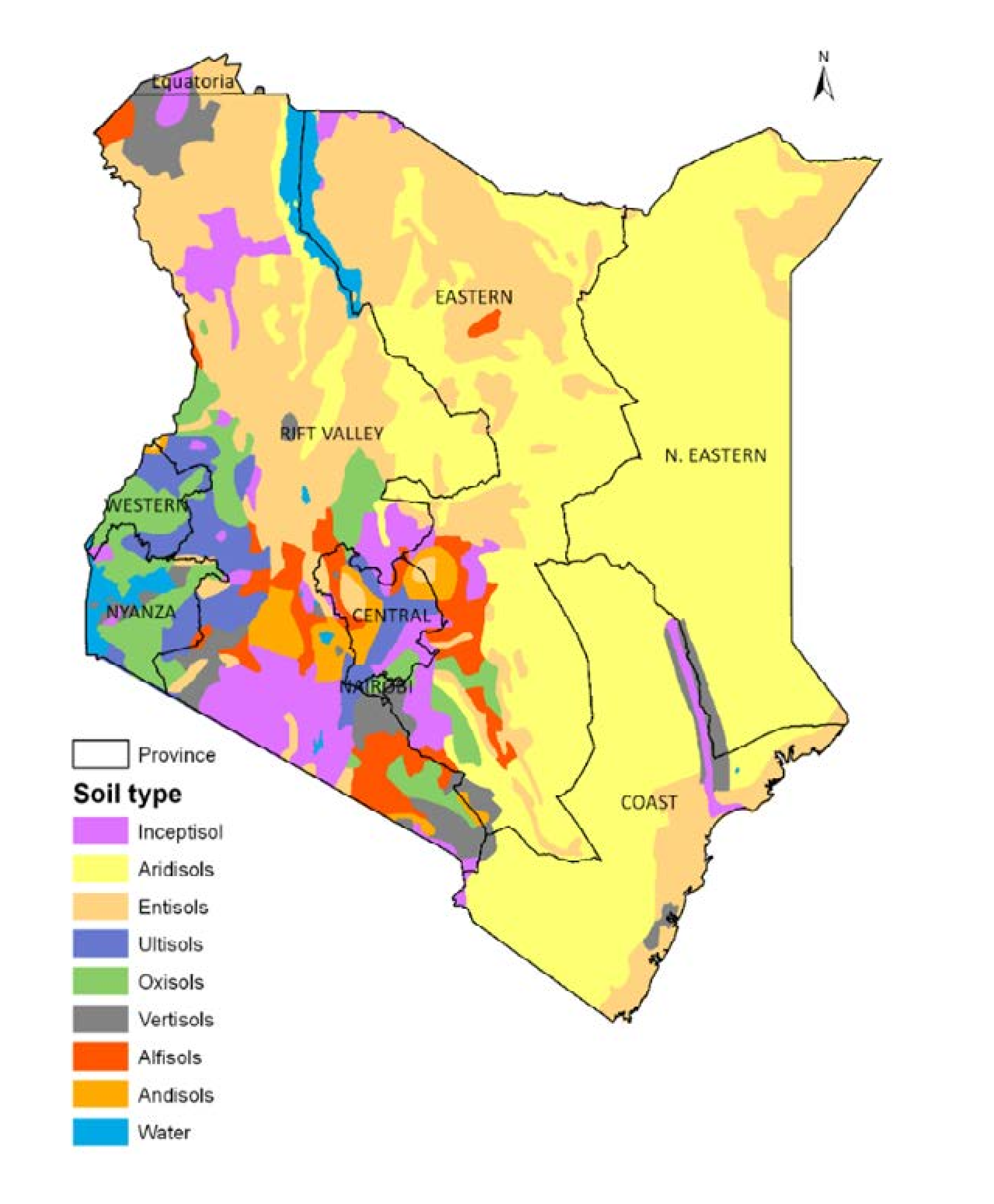
   a. *Borehole data shall be presented in cross sectional profiles and the relevant soil parameters presented on the cross sections.*
   b. *The material utilisation schedule shall be presented in this report and the bulking factor considered when determining the sufficiency of available material.*
4. **Construction measures** – comments and recommendations shall be provided on construction measures for open excavations, ground water management, ground improvement, methods of driving or constructing piles, and grouting.
5. **Calculations** – where calculations have been made, they shall be included as an appendix, and a clear indication of the methods used given in the body of the report.
6. **Conclusion and design recommendations** – a summary of the design outcomes shall be presented in this section.
7. **References** – all published works referred to in the report should be listed.

For geotechnical designs, the assumptions, data, calculations and results of the verification of safety and serviceability shall be recorded in a geotechnical design report, which shall be provided to the client.

Appendix A

Relevant Kenya Maps

Figure A.1 Soil Map of Kenya



For detail see: *Regional Centre for Mapping of Resource for Development https://opendata.rcmrd.org/maps/rcmrd::kenya-soils-map/about*

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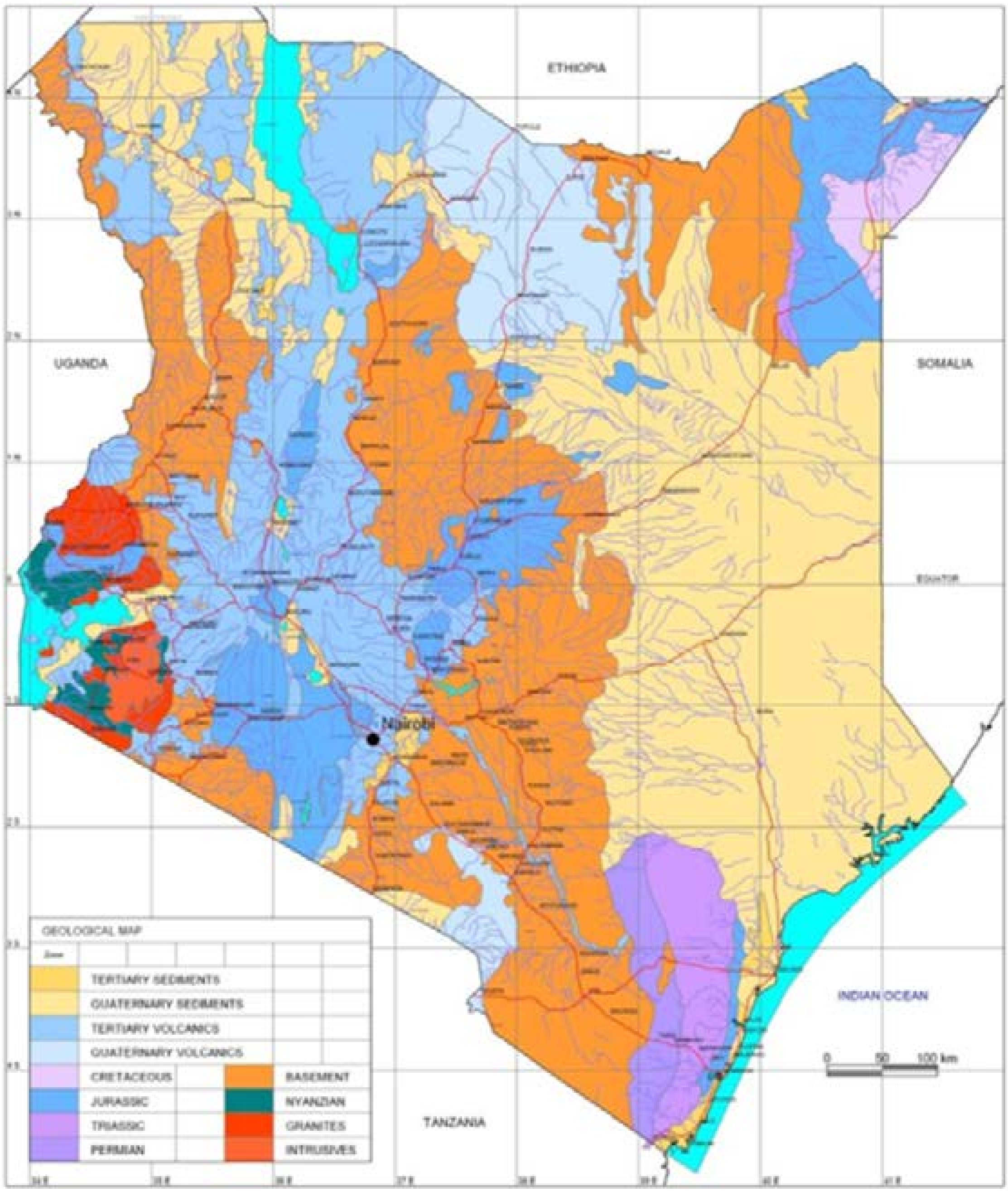
Appendix A

Relevant Kenya Maps

Figure A.2 Geological Map of Kenya

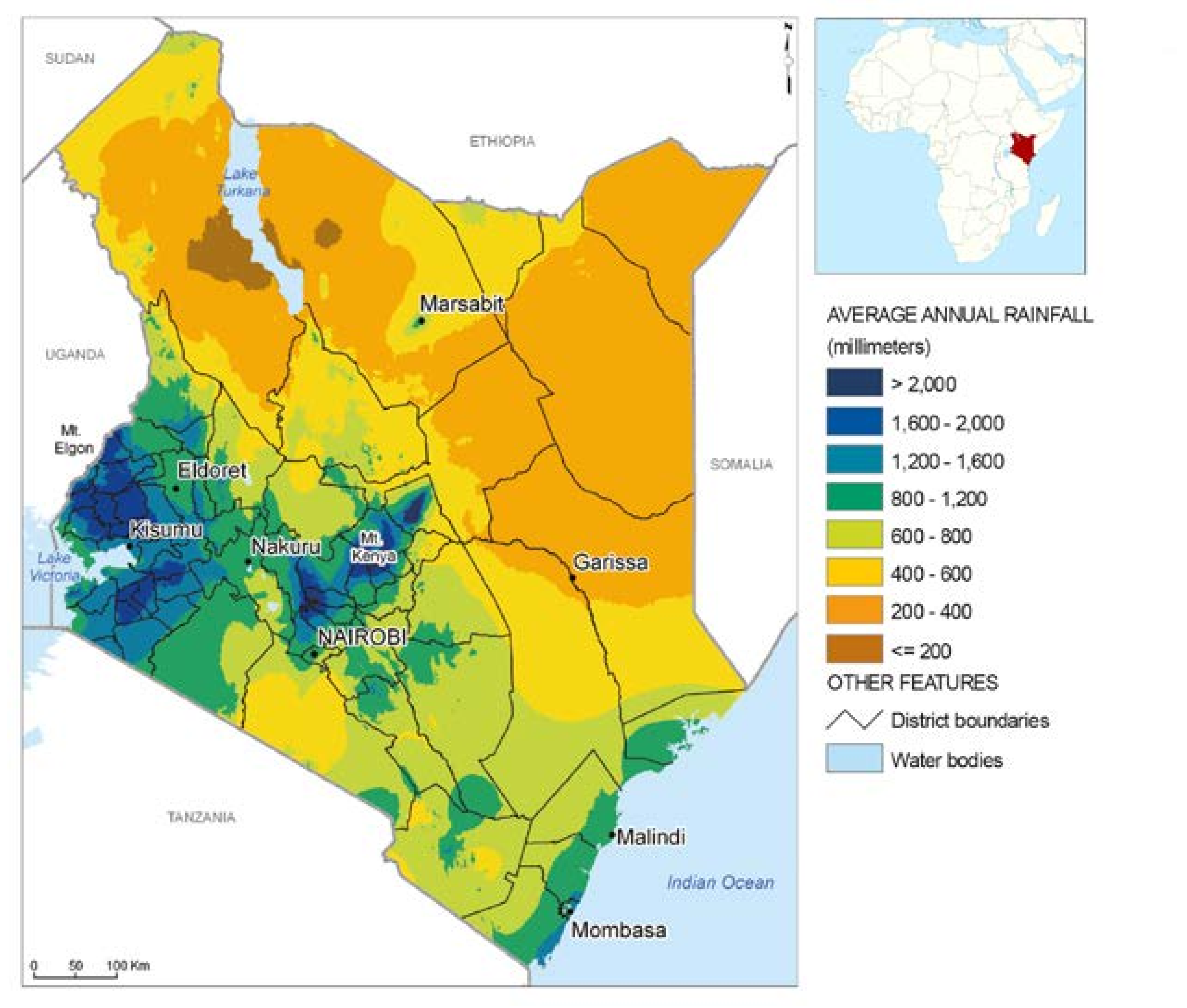


For detail see: *National Geodata Centre (NGDC) https://ngdckenya.bgs.ac.uk/project/webmaps/*

Appendix A

Relevant Kenya Maps

Figure A.3 Average Annual Rainfall Distribution in Kenya



Source: *Physical Environment - Clinical Breath Analysis (google.com). Detailed climatic data (rainfall, evaporation, and temperature) may be obtained from Kenya Meteorological Department.*

Appendix B

Classification of Alignment Soils

Table B.1 Alignment Soil Test Results Form

Chainage	TP No.	Sample Description	Geo-Reference (UTM -Arc 1960)		% Passing Sieve Size (mm)													LL	PL	PI	LS	PM	MDD	OMC	CBR (Swell)	Material Classification	
			Easting	Northing	50	37.5	20	10	5	2	1.18	0.6	0.425	0.212	0.15	0.075	0.063									Soil Group	Bearing Strength Class

Notes:

(i). This form should be presented in A3 paper size and included in the materials report.

(ii). Material type description shall be in accordance with the particle distribution chart of BS EN ISO 14688-2. The ESCS is summarised in this Part (RDM 3.1). Triangular diagrams are also provided in Section 3.2. Particle size ranges and nomenclature of soil groups are summarised in Table 3.1.

Appendix C

Typical Log Forms

Table C.1 Typical DCP Data Recording Form

Project Name:		**Client:**	
Project No.:		**Consultant:**	
Chainage (km):		**GPS coordinates**(elevation):	
Location:		**Layers removed**	
Position from centreline: (Right or Left)		**Surface type:**	
Offset (m):		**Surface condition:**	
Lane number:		**Surface thickness:**	
Direction:		**Weather:**	
Zero error:		**Test date:**	
Tested by:		**Approved by:**	

Number of blows	Depth (mm)	PI (mm/blow)

Remarks

Sheet No.:		**of:**	

Appendix C

Typical Log Forms

Table C.2 Typical Test Pit Field Log

TEST PIT FIELD LOG			
Project Name:			
Client:			
Consultant:			
Position from centreline:		Offset:	
Logged by:		Trial pit No.:	
Checked by:		Method of excavation:	
Date excavated:		Co-ordinates (elevation):	
Sample & Tests	**Depth (m)**	**Face**	**Description**
Remarks:			**Plan** (not to scale):
Photo reference:			
			Legend:

Appendix C

Typical Log Forms

Table C.3 Typical Field Sampling Form

SAMPLING FORM	
Project Name:	
Client:	
Sampling Date:	
Sampling Number:	
Sample Depth:	
Visual Description of Sample:	
Tests to be Conducted:	
Sampled By:	

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Appendix C

Typical Log Forms

Table C.4 Typical DPL Field Log

Project Name:			
Client:		**Consultant:**	
Coordinates (elevation):		**DPL No.:**	
Logged by:		**Layers Removed**	
Checked by:		**Sheet No.**	of

Depth *(m)*	**Blows** *100 mm*	**Depth** *(m)*	**Blows** *100 mm*	**Depth** *(m)*	**Blows** *100 mm*	**Depth** *(m)*	**Blows** *100 mm*
0.5		3.5		6.5		9.5	
1.0		4.0		7.0		10.0	
1.5		4.5		7.5		10.5	
2.0		5.0		8.0		11.0	
2.5		5.5		8.5		11.5	
3.0		6.0		9.0		12.0	

Appendix C

Typical Log Forms

Table C.5 Typical Field Borehole Log

Project Name:		**Job No.:**		**Borehole No.:**	
Location:				**Sheet No.:**	
Coordinates:				**Logged by:**	
Elevation:				**Checked by:**	
Contractor:				**Date of works:**	**End:**

Daily Progress	Flush Run (%)	Core Barrel	Depth of casing (size) m (mm)	Sample				Legend	Depth (m)	Reduced Level (m asl)	Description of Materials
				Field Tests, Samples, and Instrumentation	Core						
					Rec (%)	RQD (%)	SPT				

Remarks:				Legend:	Plant Used:
					Type of Boring/Drilling:
					Flushing Medium:
Morning/evening water level:					Diameter of Boring/Drilling:
Date:		Casing:			Casing Tubes:
BH Depth:		Water:			

Appendix C

Typical Log Forms

Table C.6 Typical Field Log Form for Vane Shear Test

Project:	
Client:	
Chainage:	
Date of Testing:	
Height of vane (h), **cm:**	
Diameter of the vane (D), **cm:**	
Spring constant (K), **kg-cm:**	
Rotation of vanes, deg/sec:	
Applied Torque, kg-cm:	
Shear strength of soil, kg/cm^2:	
Difference in degrees while torque application, deg:	

Sl No.	**Initial Reading** (°)	**Final Reading** (°)	**Difference** (°)	**Spring Constant** (kg-cm)	**Torque** (T)	**G** (m asl)	**S = TxG**	**Avg. S** (kg/cm^2)

Appendix C

Typical Log Forms

Table C.7 Typical Field Log Form for the Plate Load Test

Project:	
Client:	
Chainage:	
Location:	
Depth of pit:	
Diameter of Plate:	
Date of Testing:	

Sl No.	Date	Time (Hrs:min)	Pressure (kg/cm^2) On ram	Pressure (kN/m^2) On Plate	Dial Gauge Readings (L.C.-0.01mm)				Average Reading	Settlement (mm)
					A	B	C	D		

Appendix C

Typical Log Forms

Table C.8 Typical Field Form for the Pile Load Tests

Project:	
Client:	
Chainage:	
Location:	
Pile Size:	
Date Driven:	
Design Load:	
Type of hammer used:	
Depth of hole bored before driving the pile:	
Length of test pile in contact with the soil:	
Elevation at the bottom tip of the test pile:	
Load	**Gauge Reading**

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HARAMBEE
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Materials Testing & Research Division
State Department for Roads
Ministry of Roads and Transport
Machakos Road, Industrial Area
P.O. Box 11873 - 00400
NAIROBI

State Department for Roads
Ministry of Roads and Transport
Works Building
Ngong Road
P.O. Box 30260 – 00100
NAIROBI