Mining Surveys with GIS Application

A Contemporary Introduction for Engineers and Geoscientists

A practice-oriented training module

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"I'm of the persuasion that higher education must undergo a sweeping pedagogical re-engineering and accommodate more **pracademics** to help produce **work-ready STEM graduates**. In the grand order of things, the path to profound proficiency in any trade begins with **learning** it diligently, then **practising** it meticulously, and climaxing in **teaching** the trade passionately by re-interpreting and simplifying complex concepts for **shared understanding and meaning.** Teachers are privileged to experience generational transitions and cultivate **adaptitude** as they teach, learn, and relearn more times than anybody else out there."

The author's opening proclamation at the monthly **IBD Youth Talent and Career Fair** series.

https://impactborderlessdigital.com

Foreword

In the dynamic and ever-evolving fields of mining surveys and GIS, the module "Mining Surveys with GIS Application: A Contemporary Introduction for Engineers and Geoscientists" provides current knowledge and practical insights. To keen readers, this module addresses the urgent need in Africa for modern, practice-oriented, and locally relevant training of surveyors, resources engineers, and geoscientists. Readers will be empowered with the industry-grade knowledge and skills required in today's evolving mining and geoscience industries.

The author, a scholar in Engineering Surveying, Mine Surveying, and GIS, brings to this module not just his expertise but a legacy of transforming complex concepts into readily accessible and engaging learning experiences. His reputation, built over years of dedicated mentorship, teaching, and attention-grabbing lectures, has impacted beyond the classrooms of Taita Taveta University (TTU) and penetrated numerous institutions throughout Africa, shaping countless young minds and careers.

This module is a culmination of the author's extensive journey through diverse academic, professional and research landscapes. From the intricate responsibilities of aligning a long hydropower tunnel project in Kenya to his multifaceted roles of a consultant, policy analyst, business development manager, and thought leader, his diverse experience is a treasure trove of geospatial expertise and wisdom. His 20-plus years in multidisciplinary sectors have equipped him with insights critical to navigating the rapid technological advances of the 21st century.

Beyond his professional endeavours, the author is a trailblazer in inspiring the youth as he actively participates in youth mentorship through several initiatives, such as his self-founded Impact Borderless Digital (IBD) platform, the FIG Mentoring Programme for Africa, and the recent Kenya's Presidential Digital Talent Programme. His prolific contributions extend to journal reviews and management, keynotes, organisation and moderation of panels, discussant roles, and authoring and editing a wide array of books, academic and policy papers, and opinion pieces. These roles make profound his contribution as a thought leader, mentor, and knowledge influencer.

Recognition of such stellar achievements knows no boundaries. The author's global standing is manifest in recent accolades including the 2008 US Barry Richmond Award for System Thinking, winning the prestigious 2020 ACCESS 'University of Ideas' Competition for Lecturers on Employability Promotion at Higher Education Institutions in Africa, and being recognised in 2023 by Enactus Kenya as Outstanding Faculty Advisor and in 2017 as Outstanding Reviewer by Elsevier. These honours are a testament to his volunteerism with increasing impact and influence globally.

As you embark on this module, prepare to be immersed in a learning experience that is as enriching as it is enlightening, guided by a mentor whose expertise and passion for teaching are as profound as his commitment to shaping the future of engineering and geosciences in Africa and beyond. Therefore, I firmly call upon every learner, practitioner, and teacher in surveying and geomatics, resources-related engineering, and geosciences to spare time and go through this module entirely.

Dr.-Ing. Godfrey Ogonda, School of Surveying and Spatial Sciences
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Preface

The ever-evolving stages of the industrial revolution situate the mineral resource sector in a position of strategic social and economic significance. Why? The key reasons revolve around the currents of the evidently mineral-driven mainstream of the present and future civilisations. The world is increasingly witnessing a convoluted web of complex economics and polarising geopolitics of minerals. Earlier civilisations also relied on minerals and metals, though to a lesser extent due to the lower population and standard of living of the past.

Today's rising living standards and global population drive a shift to higher mineral consumption rates. Technological advances, demographic shifts, geoeconomic fragmentation, and climate change Key examples can be seen in the increasing per capita consumption of iron ore and steel with increasing living standards as seen in steel consumption of less than 1 tonne/capita in Africa against 5 tonnes/capita in China and more than 12 tonnes/capita in high-income countries, the increasing adoption of electric vehicles and high-end consumer electronics, the growing importance of the policy of pursuing the concepts of circular economy and green economy, and the need to decarbonise the material value chain in the face of climate change and the ensuing climate crisis and adaptation emergency.

Interest in mining is growing beyond land, into the sea and to space. With space technology gaining currency as a potent modifier of civilisation, including the prospects for quantum information science, space/aerospace research is attracting scientific curiosity while calling for new materials adapted to the unique conditions in space. Minerals constitute the materials required for such bold and adventurous extra-terrestrial missions.

Consequently, mining sector governance has become a key area of concern. Applied precision science is critical to meeting the key policy objectives of sustainability, transparency, openness, stakeholder participation, compliance monitoring, fairness, equity, safety, efficiency, and productivity, among others. Mining surveys, which are fundamentally engineering surveys applied to address the planning, design, production, facility management, and environmental monitoring needs in the mining industry and the sector in general, aid in ensuring high accuracy and precision.

Young minds are adding a strong voice to the vision that the modern mining sector should align with. In my experience, young mining engineering graduates from Taita Taveta University (TTU), Kenya's premier university of mining and resource management, have been sharing key testimonies about the importance and rewards of studying surveying and GIS as they interact with experts in the job market. Since 2014, I have been teaching the BSc mining engineering students surveying and GIS units, spread out from the third to the fifth year. Their industrial attachment and post-graduation experience confirms surveying and GIS as critical employability skills.

Several reasons could be advanced for the recent lowering of the barriers to entry into the practice of mining surveys with related GIS application. First is the widespread availability of survey instruments and tools, as well as Earth observation services that provide ready data and easily accessible imagery for GIS analysis. Second is the ubiquity of land-related rights and other human rights issues that demand spatial precision and spatially enabled models for effective resolution within the complex mining-environment-society nexus. Thus, a practice-oriented module that demystifies the key concepts, principles and applications of surveying and GIS in mining should be resourceful to all the people actively engaged in the mining sector.

The contents of this module have mainly drawn on my experience in Kenya as a tunnel surveyor and university lecturer in engineering surveying, mine surveying, and GIS. As a geospatial and systems modelling expert, a youth mentor, and a member of several professional bodies and societies including the System Dynamics Society, I have benefitted from international networking. The material shared here reflects the dividends of professional networking and reinforces the contents of a modern book on Geomatics I co-authored in 2023, which I hereby recommended as a reference book for further topics with details on executing modern surveying and geomatics engineering assignments. The book is **Project Design for Geomatics Engineers and Surveyors**, Second Edition (2023) by Clement Ogaja, Nashon Adero, and Derrick Koome.

Reinforced by my international exposure to various pedagogical environments, including but not limited to Kenya, Germany, and Finland, I am of the persuasion that the future demands more of a broad-based and interdisciplinary knowledge acquisition, with the sharp end tipping in targeted skills development. This module addresses this growing demand among today's lifelong learners. To support youth skills development and quality education with structured mentorship, I founded Impact Borderless Digital (IBD), a youth mentorship platform that features the IBD Talent Academy and the IBD Education Fund.

Finally, I wish every student, trainer, or practitioner a happy and productive reading of this simplified and practice-oriented manual. I dearly value every feedback on the quality of the contents and what needs to be enhanced in the next editions.

Adero

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Module Overview

Digital platforms for disseminating knowledge have become a new normal in the post-pandemic education landscape. Practice-oriented modules depicting the evolving arc of knowledge from various disciplinary perspectives are resourceful in meeting the dynamic education and training goals of a new era in a world recovering from the ravages of COVID-19.

A module on mining surveys addresses an urgent and important gap, being a segment that does not have many specialists yet technological innovations in surveying and interest in Africa's mining sector continue to advance. Designed to be an instructor-led module covering **five days (20 hours)**, this module is meant to be a concise yet rich and compelling introduction for engineers and geoscientists engaged in various professional ways in the mining sector. The module is designed to provide students, practitioners, and scholars with current insights into the application of surveying to mining while outlining the rich prospects and opportunities of geospatial technologies that transcend terrestrial applications to include offshore solutions. It contains exercises drawn from practical cases, which bring to life the otherwise abstract concepts and theories characterising advanced surveying.

The significant content of modern aspects of mining surveys makes this module an exciting training resource that will equip learners to confront challenging survey assignments in the mining sector innovatively. Upon completion, the learners will have developed competencies in providing an insightful reinterpretation of the prospects of surveying and mapping for the future of mining as a fabric of modern civilisation.

Key Definitions

Earth observation (EO): Refers to capturing data and information on the Earth and its component systems mainly through remote sensors (remote sensing), but also supplemented and enhanced by ground-based controls and surveys.

Geoid: An equipotential surface approximating the mean sea level.

Geo(spatial): Describes data, methods, and tools which are referred to, or associated with, specific locations in the real world.

Geoprocessing: Refers to the automated processing of GIS data using a suite of tools in GIS software for analysis, modelling, and management of the datasets to reveal new information.

Georeferenced: Specifically used to mean that the data and attributes in question are linked to a well-defined reference system of locating features on, below, or above the Earth's surface.

GIS: Geographic(al) Information System. To capture its broader and evolving meaning in this study, this module redefines GIS as an intelligent digital geospatial nervous system with adaptive means of delivering integrated solutions, mapped to scale to support transparent decisions within a democratised, inclusive and evolving engagement cycle.

GNSS: Global Navigation Satellite Systems – the collective term for all the satellite systems providing navigation and positioning services, namely, GPS, GLONASS, Galileo, Compass/Beidou, and others in the making.

Immersive technologies: Technologies which extend reality by integrating virtual contents and emulating the physical world, in this case specific to virtual reality (VR), augmented reality (AR), and mixed reality (MR).

Machine learning (ML): Considered a subset of artificial intelligence, machine learning uses computer algorithms to build data-driven models that improve automatically through self-learning to make predictions and decisions as guided by training data and experience, without any explicit programming to do so. Also considered as part of ML are: deep learning, probabilistic learning, reinforcement learning, transfer learning, decision trees, and genetic algorithms.

Map: The author defines a map as a selective abstraction of real objects over a given time period on a chosen surface to scale using a standard mathematical reference model of the Earth which, for the Earth's portion being represented, best preserves the key features of interest: size, shape, direction, or distance.

Mineral: Occurring in the form of ores from which they can be extracted at reasonable economic costs through the process of mining, “mineral” in this case is a naturally occurring product of geological processes which is inorganic, solid, crystalline with a fixed structure, and with a chemical composition which is either fixed or varying within certain defined limits.

Mining block: This is a spatial unit, essentially a cadastral unit, specified to be bound by a given number of arc-seconds of latitudes and longitudes (graticule). According to Kenya’s Mining Act of 2016, a mining block has the dimensions are 15” of latitude by 15” of longitude in the satellite geocentric WGS84 system.

Mining cadastre: This refers to the system of registering land-based interests in, and rights to, the ownership and operation of a mine. Through an online portal, the mining cadastre enhances online applications for legal permits and spatial verifications.

1. Purpose of the Module

This training module is designed to equip learners with fundamental knowledge in surveying and mapping as applied to meet the key data and accuracy requirements for sound design, integrated planning, spatial analysis and modelling, and similar geodata-related and multi-criteria decision-making in the mineral resources sector. The **target groups** are **senior college students** engaged in studies and research related to mining and natural resource management, **practising engineers**, and **natural resource managers** whose principal study and research interests or occupational engagements are, or will be, in the mining sector. The module has been designed to run for **five days (20 hours).**

The module learning outcomes (MLO) are hereby defined as the ideas, skills, and competencies the course participants should be able to articulate and implement, theoretically and practically, after completing the module. By the end of this module, the participants should be able to deliver effectively on these MLOs:

MLO 1: Demonstrate a satisfactory level of cultural fluency with the keywords used in mining surveys and the relevant GIS application

MLO 2: Identify the main spatial data, spatial information, and modern survey instruments, accessories and tools needed to effectively plan, design, implement, maintain, and monitor various stages of mining given different spatial settings – terrestrial, offshore, airborne, or spaceborne.

MLO 3: Demonstrate the significance, fundamental concepts, and applications of surveying and mapping techniques and technologies within the evolving global mining industry and the wider mining sector in general.

Purpose of the Module

MLO 4: Apply the acquired knowledge to address social, environmental, economic, as well as research and policy questions that need explicit spatial metrics to resolve through an integrated multicriteria approach, primarily using modern geographic information systems.

Since this module has key contents reflected in a book co-authored by the module author, the book is recommended as reference material for enhanced breadth and depth in surveying and mapping: **Project Design for Geomatics Engineers and Surveyors, Second Edition (2023)** by Clement Ogaja, Nashon Adero, and Derrick Koome.

1.1 Motivation

For many, the disruptive prospects of 5G and onwards (e.g., 6G and so on) in data transmission, driverless and flying cars, miniaturisation and uncrewed aerial systems, extended reality and the metaverse, the quantum revolution in computing, secure networks and cryptography, and big data may appear to be overly captivating, on the bleeding edge, and resting on the distant horizon at best. From confirmed cases by early adopters, these are cutting-edge innovations that will soon reach technological maturity and eventual saturation in the not-so-distant horizon. Space and time remain key elements in parametric decision-making, made possible using precise spatio-temporal parameters. As a result, there is growing interest in actionable location-based intelligence and similar proceeds and products of advanced geospatial technologies and innovations. including the spatial data generated within the big data ecosystems that support automation and various applications of artificial intelligence (AI) and machine learning.

The mining sector is not spared these disruptive changes and is also poised to be among the key beneficiaries of these developments. Mining as an enterprise requires business model innovation to thrive, hence well-informed de-risking mechanisms. Sector-wide risk modelling relies on explicit spatial metrics to derive actionable location-based intelligence on the risk landscape. Based on the procedures and products of surveying and spatial models, solutions in support of long-term de-risking mechanisms with parametric policies can be achieved.

In the mining industry, technological innovation in in-situ instrumentation and remote data capture are driving a major transformation in the routine practices and labour participation models. New jobs, such as workflow programmers who can optimise human-to-machine matching for maximum outputs, are expected to rise. Understanding the fundamentals of mining surveys is, consequently, a key prerequisite for active engagement in transforming the mining sector outcomes.

1.2 The Context

Mining surveys deal with the accurate geospatial measurements needed to plan, design, implement, assess, and monitor mining activities including their environmental impacts while ensuring safe practice and post-mining environmental responsibilities. Large-scale mining activities involve the construction of access routes and structures on the surface and underground, all of which demand accuracy and precision in geolocation as well as vertical and horizontal alignments.

The principles of engineering surveys apply at the finer stages where stringent positional accuracy requirements are necessary. Engineering surveys find application in land-based engineering infrastructure and construction projects such as drainage channels, tunnels, roads, bridges, tall buildings, railways, airports, dams, among other human-made structures.

This module covers the key practical aspects of surveying and mapping in aid of planning, designing, setting out, constructing, maintaining, and safety monitoring of activities and structures in a mining environment as well as carrying out measurements for quantitative estimates. Imagery-based solutions from terrestrial, airborne and spaceborne technologies usually find applications in assessing and monitoring the mining environment and in 3D models and analytics that aid in quantitative estimates (e.g., estimating stockpile volumes from laser scanning, analysing classifying land use and land cover changes from aerial photography obtained using aircraft or drones or satellite imagery from space satellites dedicated to Earth Observation services, among others).

The future of the mining sector is attracting growing curiosity, especially in Africa as a young player in the sector and a rich reserve of at least 30% of the world's known hydrocarbon and mineral resources. In the mining sector, the Fourth Industrial Revolution or Industry 4.0 has informed new agenda on mining innovations under Mining 4.0. There are ready examples in automation, robotics, artificial intelligence, extended reality or immersive technologies, among others. Sustainable mining practices are expected to benefit from such advances.

Geodata or geospatial data and Earth Observation (EO) technologies are central to developing and scaling multicriteria spatial decision support systems to be responsive to the fast-changing demands of sustainable mining. Engineering surveys are critical to ensuring accuracy and precision in planning, designing, setting out, implementing, maintaining, and condition monitoring of the works associated with both surface and underground mining activities. Advances in terrestrial, offshore, airborne and spaceborne surveying and mapping technologies continue to enhance safety, productivity, and efficiency in the mining sector including addressing land-related human rights and meeting environmental monitoring and management imperatives.

1.3 Training and Assessment

This practice-oriented module will be covered through interactive sessions as well as self-learning using uploaded guides. Problem-based learning, project-based examples, and group assignments will be used to improve the quality of delivery and engagement. Coursework will account for 50% of the assessment and a final written examination will account for the remaining 50%. The grading will range from **5.0** (less than 40% - fail) to **1.0** (more than 85% - excellent). The intermediate grades from 4.0 to 1.0 will vary by 0.3 and 0.7 as follows: 3.7, 3.3, 3.0. 2.7, 2.3, 2.0, 1.7. 1.3, and 1.0.

2. General Considerations

2.1 The Rich History and Evolution of Surveying

Historical backgrounds enable learners to gain insights into the subtle and sublime evolutionary stages of any disciplinary field, while simultaneously appreciating the amazing transdisciplinary megatrends defining modern times. As one of the oldest fields, Surveying is no exception. Surveying practice has evolved from the use of crude tools and chain and plane table surveying to modern spaceborne, airborne and sensor-based solutions generating big data on a daily basis.

Surveying and mining share a rich history that dates back to the ancient times, 3000 BC. Egyptian surveyors subdivided the land by the Nile River three millennia ago. The first recorded land register in **Egypt** was created and farm boundaries were re-established following floods of the Nile River. The **Great Pyramid at Giza** was built in 2700 BC. **Land-based taxation** purposes motivated developments in surveying towards a more accurate determination of land boundaries in Egypt around 1400 BC, laying part of a firm foundation for advancing the practice of **cadastral surveys**.

The Greek advanced the science of geometry and invented the **dioptre** in the third century BCE as a precursor to the modern theodolite, 120 BC standing out for major improvements in Geometry thanks to the Greek. In 300 AD, land surveying was established as a profession by the Romans, and land surveyors established the basic measurements under which the Roman Empire was divided, yielding a tax register of conquered lands. The Romans advanced the practice of surveying to the fields of **surface mining** and **tunnelling**. **The Roman empire became the first civilisation to employ an official land surveyor.**

Napoleon Bonaparte (1769–1821) was enthusiastic about accurate land surveying and precise maps and thus made a key contribution to advancing the practice of surveying and mapping. **Alexander von Humboldt**, a German naturalist and explorer, further advanced the application of surveying and mapping to more abstract areas including **climate studies** and the distribution of **biota**, laying the foundation for modern **biogeography**.

In **Germany**, historical mining activities influenced land surveying to lean towards determining the land rights attached to mining blocks. Natively referred to as ***Markscheidewesen*, mine surveying** got established as a profession in Germany. The historical mining of **silver** in Saxony started in the early **12th century**. To date, the Saxon city of Freiberg is known as ***Silberstadt*** (Silver City) and it hosts the world's oldest university of mining, **Technische Universität Bergakademie Freiberg (TUBAF).**

The **Agrarian Revolution** gave way to the advent of the 18–19th **century Industrial Revolution** in the UK, which led to the wide recognition of mine surveying as a profession. In the 18th century, **triangulation** method, based on the measurement of angles, was used to build a hierarchy of networks to allow point positioning within a country. **Theodolite**, a survey instrument, and **plane table** surveying technique were introduced. In 1854, **John Snow** mapped out cholera outbreak in London and successfully linked the source to a contaminated water pump.

The compelling need for more accurate surveys for boundaries and public works following these revolutions and the need to expand scale led to further developments in both **plane** surveys and **geodetic** surveys in 1800 AD. Geodetic surveys are applicable to large areas, over which the curvature of the Earth must be part of the considerations during measurements and computations (usually more than 300 km^2).

Later on in the 20th century, remarkable developments in the surveying profession, some only expressible as leaps and bounds, took place. The remarkable epochs and milestones are hereby chronicled:

- **1957/58:** The space age starts with the launch of the first artificial satellite, Sputnik 1, by the Soviet Union in 1957, followed by Explorer 1 using cosmic rays by the USA in January 1958 – the first to detect Van Allen radiation belt
- **1960s:** The invention of the **laser** made it possible to measure distances with greater accuracy, leading to the development of laser-based surveying instruments such as **total station**
- **1970s:** The advent of **satellite technology** made it possible to determine precise locations on Earth using signals from satellites, leading to the development of Global Positioning System (GPS) technology
- **1980s:** The introduction of electronic distance measurement (EDM) revolutionised surveying by allowing for more accurate measurements over longer distances
- **1990s:** The use of Light Detection and Ranging (LiDAR) technology became more widespread, allowing for highly accurate mapping of terrain and structures. LiDAR found application in flood prevention planning and environmental monitoring by generating accurate elevation data (DTM)/topographical mapping for modelling floodplains and identifying flooding risks towards designing preventive interventions. Again, LiDAR found application in seismic risk assessment by mapping geological features and in urban planning
- **2000s:** LiDAR application extended to precision agriculture, archaeology for mapping ancient ruins buried under dense vegetation and in forestry for measuring tree heights, assessing canopy density, and monitoring deforestation. Surveying began to incorporate unmanned aerial vehicles (UAVs), also known as drones, which can capture high-resolution images and data from above. President Bill Clinton led the removal of "selective availability" to allow civilians more accurate GPS navigation services. In 2014, the Nobel Prize in Physiology or Medicine celebrated the "inner GPS" in human brain cells and place cells, a province surveyors can celebrate too as an innate navigation system
- **2020s:** Surveying is expected to continue to evolve with the integration of artificial intelligence (AI) and machine learning (ML) technologies, which can automate data

> processing and analysis. LiDAR technology has become essential for disaster management, e.g., LiDAR-assisted derisking models for floods and similar disasters, and for autonomous vehicles, enabling them to create high-resolution, real-time 3D maps of their surroundings for safe navigation. It is also used in robotics for precise navigation, computer vision for object detection, and GIS for generating accurate digital elevation models and 3D city models. The integration of AI and ML into LiDAR systems enhances data processing and analysis, while advancements in quantum technology and 5G will further improve **Quantum LiDAR** with capabilities and applications across various industries, including space exploration. Through miniaturisation, future developments focus on making LiDAR systems smaller, more efficient, and cost-effective, with an emphasis on cybersecurity. Cybersecurity standards are also becoming a priority to protect the data collected by LiDAR systems from potential threats.

Advances in **space technology, digital revolution, miniaturisation**, and **technology convergence** are at the forefront in shaping the waveform and trajectory of modern megatrends in surveying and mapping. The geodata-driven digital revolution has radically redefined the profession and practice of surveying and mapping, introducing amazing prospects for geospatial careers in a future that will see a quantum leap in data transmission speeds and data processing technologies – thanks to 5G, automation, artificial intelligence, and machine learning, among others.

Recent advances in terrestrial, marine, airborne and spaceborne technologies for positioning, navigation and Earth observation have influenced unprecedented growth in geospatial data, essentially contributing to the “big data” revolution. Ready examples are found in modern laser scanners, radar, drones, mini-, micro- and nano-satellites, and Global Navigation Satellite Systems (GNSS).

The modern surveyor is a professional person with high academic qualifications and technical expertise and whose role keeps evolving with the data-driven digital revolution and fast-changing geoinformation technologies. The well-known

Knowledge Doubling Curve also explains the blurring of disciplinary boundaries. It is, therefore, common nowadays to come across surveyors rightly rebranded as geospatial or geomatic(s) engineers.

The developments we experience today draw on the modern-day sensors and computing technologies, a digital revolution enabling the handling of vast databases of geographically referenced data. Geomatics is the interdisciplinary expertise required to manage and extract optimal value from such resourceful spatial data and information.

So, what is Geomatics?

Geomatics combines traditional and modern aspects of surveying and mapping including airborne and spaceborne technologies, essentially using location-based data (spatial data) to deliver accurate and precise metrics which are critical to demarcating land and property boundaries for registering ownership rights (cadastral surveys); land administration; land use planning; engineering and construction projects; positioning and navigation on, below, or above land and water; and providing actionable location-based intelligence in aid of planning, management and monitoring assignments for business, public and civil society sectors. In an era when decision support increasingly demands big data and reliable real-world information, these application areas are gaining currency and prominence.

Geomatics has evolved over the decades. In 1975, Bernard Dubuisson published the scientific term *Geomatique* (French), later popularised in Canada over the period 1981–1982 as *Geomatics* (English translation) by Michel Paradis, a surveyor. Later, Geomatics got adopted as a degree course by engineering faculties in Australia and the United Kingdom and has since evolved to be an attractive interdisciplinary field. It is nowadays common to find **Geomatics (Engineering)** or its variants in **Geospatial Engineering** and related space technologies among well-established university programmes in Kenya and globally.

The International Federation of Surveyors (FIG) formalised the definition of a surveyor as adopted by the General Assembly on 23 May 2004 as follows:

A surveyor is a professional person with the academic qualifications and technical expertise to conduct one, or more, of the following activities:

i. to determine, measure and represent land, three-dimensional objects, point-fields and trajectories;
ii. to assemble and interpret land and geographically related information;
iii. to use that information for the planning and efficient administration of the land, the sea and any structures thereon; and
iv. to conduct research into the above practices and to develop them.

In terms of detailed functions, the roles of a surveyor are universally recognised as follows. The text describes various professional tasks carried out by surveyors, which can involve activities related to land and sea, often in collaboration with other professionals. These tasks include:

i. Measuring and defining the size, shape, position, and contour of Earth's features, as well as monitoring changes.
ii. Positioning and monitoring objects, structures, and engineering works on, above, or below the Earth's surface.
iii. Developing, testing, and calibrating sensors, instruments, and systems for surveying purposes.

iv. Using spatial information from various sources, such as imagery, and automating data acquisition processes.

v. Determining land boundaries, both public and private, including national and international borders, and registering them with relevant authorities.

vi. Designing and managing geographic information systems (GIS) for data collection, storage, analysis, and dissemination.

vii. Analysing, interpreting, and integrating spatial data in GIS, including visualization and communication through maps and digital devices.

viii. Studying natural and social environments, measuring land and marine resources, and using data for urban, rural, and regional development planning.

ix. Planning, developing, and redeveloping urban or rural properties, including land and buildings.

x. Assessing property values and managing urban or rural properties, including land and buildings.

xi. Planning, measuring, and managing construction works, including cost estimation.

Surveyors consider legal, economic, environmental, and social factors relevant to each project during these activities.

Surveyors are essential to the mining industry as they provide critical geospatial information for decision support involving all the other mining disciplines. Mining surveyors ensure the accurate measurement of areas and volumes mined as well as the representation of the surface and underground conditions on mining plans with the required spatial exactitude.

Engineering surveys are typically more stringent in accuracy requirements with tolerances for most linear measurements being a few millimetres, unlike assignments such as cadastral, boundary and topographic surveys where tolerances of several centimetres are allowed. The continuing evolution in industry dynamics has introduced other granular subdivisions of Geomatics, which apply the fundamental principles of engineering surveys: construction surveys, mining surveys, control surveys (both horizontal and vertical), topographic(al) surveys, detail surveys, route surveys, building surveys, hydrographic surveys, and so on.

Mining surveys, as part of applied precision science and engineering, utilise geospatial metrics to guide mining activities while making use of the principles of surveying, geodesy, mining, and geology. Practitioners may view mining surveying as a special category of applied engineering surveying, which is a geomatics discipline providing the knowledge and skills needed to conduct accurate geospatial measurements which are mainly used in construction projects.

Deformation monitoring to ascertain the performance and health conditions of completed physical infrastructure projects and related facilities is a key task executed through engineering surveying. The survey procedures help in ensuring that project planning and design, quality control, and quality assurance are strictly observed to ensure project implementation according to design standards and tolerances.

2.2 Fundamental Principles and Concepts

Engineering and/or mining surveys are critical to the operation and maintenance of engineering structures. In common practice, engineering surveys are applicable to land-based engineering infrastructure and construction projects, such as drainage channels, tunnels, roads, bridges, tall buildings, railways, airports, dams, among other human-made structures. Due to the short distances involved in practice, the principles of plane surveying apply to both engineering and mining surveys, treating the Earth as flat. In some industry settings, very highly accurate surveys are necessary to meet the demanding standards of precision, an aspect of industrial metrology. This is a clear contrast to geodetic surveying, which involves extensive areas for which the curvature of the Earth must be considered (comparison shown in Table 2-1).

Table 2-1: *Comparison of plane surveying and geodetic surveying*

Survey Type	Earth's Surface Assumption	Degree of Accuracy	Level Line Assumption	Plumb Line Assumption	Area Covered	Instruments
Plane Surveying	Straight	Low	Straight	Parallel	Small (<300 km^2)	Tape, chain, theodolite, etc.
Geodetic Surveying	Spherical	High	Spherical	Not parallel	Large (>300 km^2)	Precise instrumentation & modern technology e.g., GNSS

Horizontal control through **traversing** and vertical control through **levelling** techniques are essential to carrying out engineering surveys. **Chainage** (e.g., 1 + 050 to mean 1.05 kilometres from the starting point) is used to give reference to a specific location from a given starting point when carrying out horizontal control. Horizontal alignment for infrastructure such as roads, railways, or tunnels requires horizontal control to achieve the design standards, guided by a network of known (reference) points. Vertical alignment is also necessary for engineering and mining projects because slopes or gradients must be set out to allow for accurate elevation differences, motion, and material flows within designed safety margins. Benchmarks (BM) and/or Temporary Benchmarks (TBM), which are points of known elevation, are set up to guide vertical control surveys.

During preliminary planning stages and initial excavations, the tolerances may be in the order of several centimetres, but they are improved to millimetres during final works, for example, when setting out **invert levels** for concrete lining in a drainage channel or a hydropower tunnel. It is standard practice to determine the most suitable instrument and the accuracy that any given engineering or mining surveying exercise demands. The common instruments used for horizontal control are **optical solutions** (total stations, electronic theodolites), **mobile devices** with GNSS receivers (such as handheld GNSS or even smartphones), **geodetic solutions** (geodetic GNSS receivers), and **laser** precision instruments. For vertical control, automatic levels are the engineer's choice due to their ease of operation and high accuracy in determining **orthometric heights** (H), which are heights referred to the geoid as opposed to the less accurate **ellipsoidal heights** (h) obtained from satellite-based positioning using GNSS receivers.

Surveyors use **checks** to ascertain the accuracy of horizontal and vertical control. Having at least three known points to start with is recommended to ensure the required **redundancy**. The checks can take the form of a mathematical formula, such as confirming if the sum of the interior angles measured for a polygon adds up to the expected value, or if a loop traverse returns a computed value that matches the known value at the starting point. If the error is small or relatively small, it is usually distributed proportionately among the occupied points, assuming a linear relationship. If the errors are gross and the instrument has been confirmed to be accurate through standard tests or calibration, then the survey exercise must be repeated.

2.3 Common Instruments and Accessories

The instruments and accessories shown in Fig. 2.1 are commonly used in engineering surveys. Curves and slopes are normally set out precisely using optical survey instruments.

FIGURE 2.1

Common instruments and accessories for engineering surveys. Photo credit: Nashon Adero, Taita Taveta University Survey Lab, 17-09-2022

Being precise and easy to use, automatic levels have become the industry standard for vertical control. Experience is key to setting up the instrument on a tripod (Fig. 2.2) and taking accurate readings on a vertically held levelling staff. Determining elevation differences (ΔH) and deducing the reduced levels of the points of interest are achieved using two standard methods: Height of Collimation Method and Rise and Fall Method. The former is the faster and preferred method.

FIGURE 2.2

Students learning to operate an automatic level. Photo credit: Nashon Adero (Taita Taveta University, Kenya).

Digital levels, which are more expensive and sophisticated, use barcodes to give digital records of elevation, a highly convenient feature for engineering surveys when higher speed, accuracy, and precision are desired in a project.

Determining the position of underground structures:

A **gyrotheodolite**, or surveying gyro, is particularly very useful in mining surveys. It comprises a gyroscope mounted to a theodolite and is the main instrument for orientation in mine surveying and tunnel engineering, where there is no clear view of the sky and hence GNSS cannot work. A gyrotheodolite is used to determine the orientation of true north, except at or near (within 15 degrees of) the poles, where meridians converge, and the east-west component of the Earth's rotation is not to the extent that can help obtain reliable results. It is used to measure angles in both the vertical and horizontal planes. Its theodolite measures angles in the horizontal plane and the gyroscope measures angles in the vertical plane. The gyrotheodolite can also measure the area, volume, and orientation of structures.

By measuring the angle and distance to known points, a gyrotheodolite can be used to determine the position of underground structures, such as ore bodies, underground excavations, and support pillars. However, the use of a gyrotheodolite is limited by the geometry of the Earth. The Earth is not a perfect sphere but is an oblate spheroid, which means that the direction of gravity varies from place to place. This can cause errors in the measurements taken by a gyrotheodolite, particularly in areas of high gravitational anomaly. At or near (within 15^0 of) the poles, the **meridians converge** and the east-west component of the **Earth's rotation** is insufficient to obtain reliable results from a gyrotheodolite. In addition, the gyroscopic platform of the instrument is affected by the rotation of the Earth, which means that it needs to be regularly calibrated to maintain accuracy. These limitations need to be taken into account when using a gyrotheodolite in mine surveys and tunnel engineering.

2.4 Emerging Geospatial Technology Frontiers

The demand for visually shared evidence with actionable and location-based intelligence is pushing the boundaries of geomatics applications. As such, physical planning as well as strategy and policy design are increasingly becoming geodata-driven enterprises leveraged by internet connectivity and advanced computer-aided systems. These developments are the essence of the Fourth Industrial Revolution and the subsequent revolutions expected in a rapidly changing world.

Robotics and **computer vision** have led to remarkable evolutions in geospatial technologies. One particular evolution is the integration of **Simultaneous Localisation and Mapping (SLAM)** technology with 3D laser scanning, which dates back to the 1980s and has since been enhanced with deep learning for improved feature extraction and environmental studies. Further advances in SLAM are expected from rapid developments in miniaturisation, Internet of Things (IoT) sensors, extended reality, and edge computing.

These laser-based technological advances producing 3D data models are supporting the creation of **digital twins** for facility and infrastructure management, including **Building Information Modelling (BIM)**. They also aid in surveying and mapping restricted areas lacking GNSS access (GNSS-denied corridors), such as underground mines and canyons in vegetated and built-up areas, such as densely populated cities. Integrated geodata-driven models are becoming increasingly necessary to support sustainable facility and infrastructure development and management cycles. As shown in Fig. 2.3, the relevant applications include the planning, design, development, maintenance, and monitoring of infrastructure.

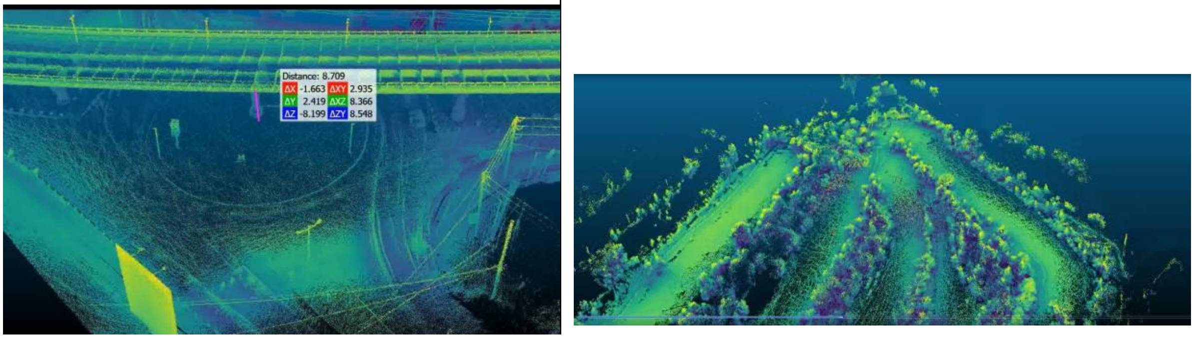


FIGURE 2.3

Product of handheld 3D laser scanner (GoSLAM) for Langata Road overpass, Nairobi. The overpass was estimated to be 8 m above the ground level here. Credit: Surveyor, Peter G. Ndirangu.

Product of handheld 3D laser scanner (GoSLAM) for the Kenya Railways Golf Course, Nairobi. Creating digital twins made easier with LiDAR. Credit: Surveyor, Peter G. Ndirangu.

The desire to create an inventory of building plans for old buildings, which mostly lack the original building plans, can be achieved using the laser-based SLAM technology. A similar case has been shown in Fig. 2-4, depicting a case in Kenya of progressing from a 3D model of a building to extracting the building plan, complete with its key geometric elements. In Figure 2-5 is a block model produced at Taita Taveta University.

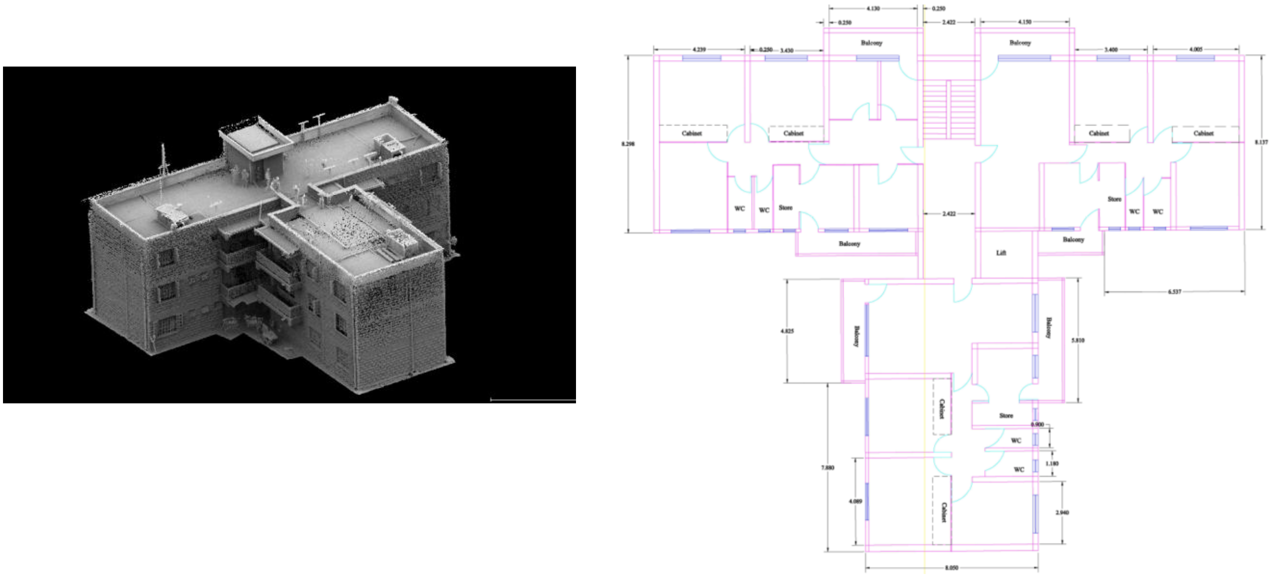


FIGURE 2.4

A building block model scanned using a handheld 3D laser scanner (GoSLAM LiDAR).

The derivative, a building plan from LiDAR. Credit: Surveyor, Peter Ndirangu.

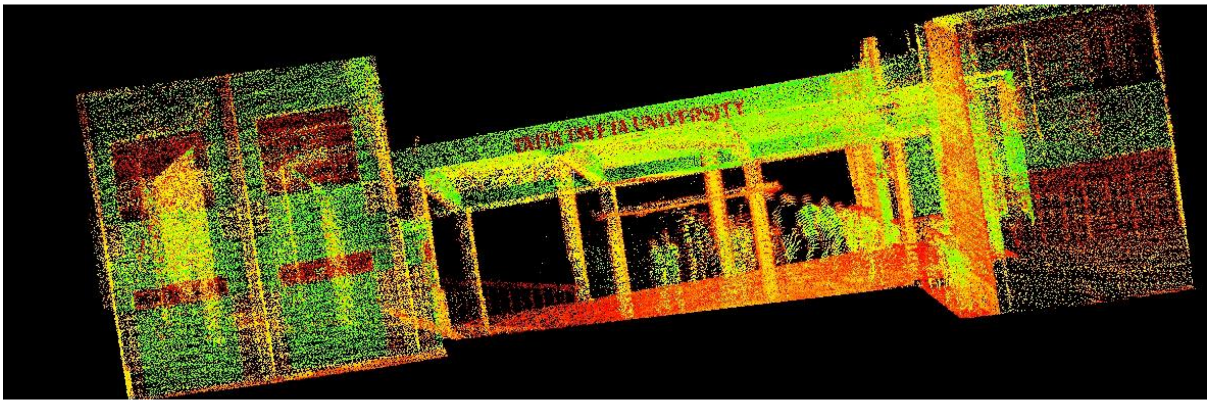


FIGURE 2.5

A model of Taita Taveta University Main Campus Administration Block generated using a handheld 3D laser scanner as part of the GIS Day practicals on 15 November 2023. (Credit: GoSLAM LiDAR by Surveyor Peter Ndirangu).

Satellite-based solutions for positioning, navigation, and earth observation are upgrading progressively to offer hitherto unattainable levels of accuracy and precision. In this league are subcentimetre-level GNSS solutions from multi-constellation and correctional services and very high resolutions from **hyperspectral** satellite imagery.

Unmanned aerial systems continue to deliver high-precision solutions as well, as do sensors installed to collect data – thus swelling the ever-growing **Big Data** pool made up of structured data as well as unstructured data from assorted sources, including **Citizen Science**. To continue pushing the boundaries of geospatial technology further are advances in computer processing power with amazing capabilities of quantum computing and artificial intelligence (AI), which make the processing of sophisticated and big data easier and faster.

With these rapid changes, data science and data engineering are gaining importance as a means to achieving the standards of findability, accessibility, interoperability, and reusability (FAIR) while effectively handling all the dimensions of big data: volume, velocity, variety, and veracity (4Vs). With the ongoing data and digital revolution, digital data volumes in future will be accounted for in the order of **yottabytes** and **brontobytes**.

3. Mass Haul Diagrams

A Mass Haul Diagram (MHD) is a graphical representation of the volumes of cut and fill along a linear project such as a road, railway, or canal. It helps engineers and project managers determine the most efficient and cost-effective way to move and distribute equipment and materials, especially during earthwork operations.

Basics of Mass Haul Diagrams:

i. Horizontal axis: Represents the length or distance along the project, graduated in chainage.

ii. Vertical axis: Represents the cumulative volume of material (both cut and fill). Areas the x-axis represent a cut and vice-versa.

iii. Above horizontal axis: Volumes of material that need to be cut or excavated.

iv. Below horizontal axis: Volumes of material that need to be filled or deposited.

Main Components:

i. Cut areas: These are sections where the natural ground level is above the design level. The material from these areas is typically used for fill areas.

ii. Fill areas: These are sections where the natural ground level is below the design level. These areas require material to raise them to the design level.

iii. Haul distance: The distance over which the excavated material is transported to the fill area.

iv. Free haul distance: The distance within which there is no cost associated with transporting the material.

v. Overhaul distance: The distance beyond the free haul distance. Over this distance, there is a cost associated with transporting the material.

vi. Balance point: A point where the volume of cut equals the volume of fill. This is also the optimal point for minimising earthwork costs.

Applications of Mass Haul Diagrams:

i. Optimising earthwork: MHDs allow for optimising the movement of excavated material. This helps in minimising the haul distances and associated costs.

ii. Cost estimation: By determining overhaul distances and associated costs, it's easier to estimate the total cost of the earthwork operation.

iii. Equipment planning: Based on the volume of cut and fill, project managers can plan the number and type of equipment required, e.g., trucks for longer distances beyond 1.5 km and scrapers or dozers for distances below 1.5 km.

iv. Time scheduling: Helps in scheduling the sequence of operations and estimating the time required for completion.

v. Environmental Impact Assessment (EIA): By minimising unnecessary movement of earth, the environmental impact can be reduced.

Creating a Mass Haul Diagram:

i. Profile analysis: First, analyse the project's profile to understand the cut and fill requirements.
ii. Plotting: On graph paper or using software, the cumulative volume of cut and fill is plotted against the project's length.
iii. Interpretation: Study the diagram to identify balance points, free haul, and overhaul distances.

Advantages:

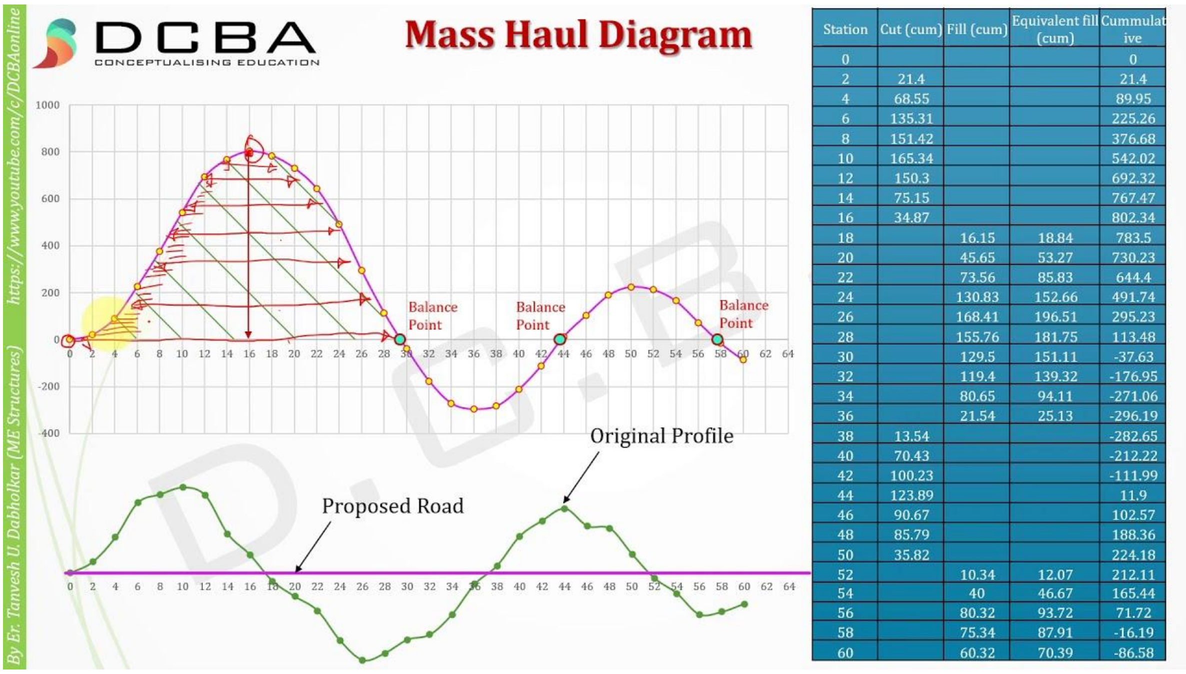
i. Visual representation of earthwork makes it easier to understand.
ii. Efficient distribution of materials
iii. Potential cost savings
iv. Helps in the decision-making process for material sourcing and disposal

Limitations:

i. As with any graphical method, accuracy depends on the scale and detail of the plotting
ii. Requires a thorough understanding to interpret correctly

In modern times, various civil engineering software tools offer functionalities to generate Mass Haul Diagrams automatically, making it easier for engineers to plan and manage earthwork operations.

Refer to the example below:



Station	Cut (cum)	Fill (cum)	Equivalent fill (cum)	Cummulative
0				0
2	21.4			21.4
4	68.55			89.95
6	135.31			225.26
8	151.42			376.68
10	165.34			542.02
12	150.3			692.32
14	75.15			767.47
16	34.87			802.34
18		16.15	18.84	783.5
20		45.65	53.27	730.23
22		73.56	85.83	644.4
24		130.83	152.66	491.74
26		168.41	196.51	295.23
28		155.76	181.75	113.48
30		129.5	151.11	-37.63
32		119.4	139.32	-176.95
34		80.65	94.11	-271.06
36		21.54	25.13	-296.19
38	13.54			-282.65
40	70.43			-212.22
42	100.23			-111.99
44	123.89			11.9
46	90.67			102.57
48	85.79			188.36
50	35.82			224.18
52		10.34	12.07	212.11
54		40	46.67	165.44
56		80.32	93.72	71.72
58		75.34	87.91	-16.19
60		60.32	70.39	-86.58

FIGURE 3.1

An example of Mass Haul Diagram. Source: DCBA online

4. Underground Surveying

Underground surveying is a subsurface surveying technique that involves using optical surveying, magnetic surveys that produce subsurface images from measurements of the Earth’s magnetic field, laser measurements – especially 3D laser scanning solutions, such as SLAM technology for 3D mapping and volumetric analysis in busy and restricted or GNSS-deprived environments , seismic surveys that use seismography to generate subsurface images from reflected shock waves, ground penetrating radar (GPR), measuring and mapping subsurface features, transfer of both horizontal and vertical controls from the surface to the underground environment, and alignment of underground structures, including mines, tunnels, and caves, among others.

4.1 Practical Application of Underground Surveying

Practical application areas of underground surveying include:

i. **Vertical and horizontal alignment** of tunnelling works for bridges, subways, transportation tunnels, sewers, utility lines for power, fuels or communication, water tunnels, etc.
ii. **Subsurface maps and models** to support exploration, engineering and construction of underground structures
iii. **Locating mineral deposits**
iv. **Locating geohazards**: sinkholes, landslides, etc. Geohazards in mining environments refer to the potential risks and hazards that can occur due to geological factors, such as unstable ground conditions, rockfalls, landslides, or subsidence. These hazards can pose significant threats to the safety of workers, infrastructure, and the environment
v. **Guiding the orientation** of shafting works and adits
vi. **Mine safety applications** by monitoring stability/deformation and risk profiles including subsidence
vii. **Estimating earthwork volumes**, including underbreaks and overbreaks
viii. **Environmental application** in detecting underground contamination and monitoring remediation efforts
ix. **Archaeological mapping** and reconstruction for various documentations of ancient sites
x. **Studying subsurface geology** and mineral deposits as well as subsurface hydrology
xi. **Petroleum exploration** for mapping subsurface reservoirs of oil and natural gas

4.2 Transferring Survey Controls

As a general rule, the surveyor should test the instruments to be used to ensure their accuracy, based on points of known (X, Y) coordinates and elevations (H). Optical solutions, GNSS, and lasers are commonly applied to transfer survey controls or reference points from one location to another. This step is necessary so that survey projects can be extended and executed within a controlled and location-specific framework of (X, Y) coordinates and elevations (H or Z). The tolerances vary, from relaxed decimetre or centimetre levels at the preliminary stage to stringent millimetre levels at the final construction stages. The process of increasing the density of control points or reference points in an area is also known as *densification.*

As a satellite-based solution, GNSS has made it easier to create (X, Y) control points without running long traverses from primary control points in a country, which used to be the case before the invention and commercial availability of GNSS services. Static positioning techniques are commonly applied to densify control points for construction. Differential Real Time Kinematic (RTK) GNSS as well as software-based post-processing methods are also common, depending on the surveyor’s choice.

Augmented GNSS services such as satellite-based augmentation system (SBAS) have helped to enhance the accuracy of GNSS positioning primarily by providing additional data or corrections to the signals received from GNSS satellites. It typically works like this:

i. Error Correction: One of the main sources of inaccuracies in GNSS measurements is errors introduced as signals travel through the Earth's atmosphere. Augmented GNSS systems use ground-based stations to monitor these errors and provide corrections to the GNSS receivers. These corrections can include data about ionospheric delays, atmospheric conditions, satellite clock errors, and other sources of signal distortion.

ii. Increased Satellite Visibility: Augmented GNSS systems may augment the constellation of GNSS satellites with additional satellites or ground-based transmitters. This increases the number of available signals and improves the overall visibility of satellites, especially in urban areas or regions with obstructed views of the sky. More visible satellites mean better triangulation and improved accuracy.

iii. Real-Time Monitoring: Augmented GNSS systems often involve real-time monitoring of GNSS performance. This allows for continuous assessment of system integrity and the ability to quickly identify and correct any anomalies or inaccuracies.

iv. Differential Corrections: Another technique used in augmented GNSS is differential corrections. This involves comparing the position calculated by a reference receiver with the known true position at that location. The difference between the calculated and true positions is then used to adjust the measurements obtained by other receivers in the area, improving their accuracy.

v. Redundancy and Resilience: Augmented GNSS systems often incorporate redundant systems and measures to enhance reliability and resilience. This includes redundant ground stations, multiple communication links, and robust error detection and correction mechanisms.

By combining these techniques, augmented GNSS systems significantly enhance the accuracy and reliability of standard GNSS measurements, making them suitable for applications where precise positioning is critical, such as aviation, maritime navigation, surveying, and precision agriculture.

Continuously Operating Reference Stations (CORS) are part of the solutions that have been advanced to increase the accuracy of GNSS positioning in many countries, through a network of permanently installed ground stations. These stations continuously track signals from GNSS satellites, allowing for the collection of highly accurate positional data. CORS achieve improved accuracy in a similar manner to other augmented GNSS systems, but with some specific methods as follows:

i. Reference Stations: CORS consists of a network of reference stations that are precisely positioned and equipped with high-quality GNSS receivers. These stations continuously track signals from GNSS satellites, allowing for the collection of highly accurate positional data.

ii. Real-Time Data Transmission: CORS stations transmit the GNSS data they collect in real-time to a central processing facility. This facility collects data from multiple stations in the CORS network and performs differential corrections and other processing techniques to improve accuracy.

iii. Differential Corrections: One of the primary methods used by CORS to enhance GNSS accuracy is through the application of differential corrections. By comparing the precise measurements obtained from reference stations with the less accurate measurements obtained from GNSS receivers in the field, CORS can calculate correction factors for atmospheric delays, satellite clock errors, and other sources of error. These corrections are then broadcast to users in real-time or made available for post-processing.

iv. Wide Coverage: CORS networks typically cover large geographic areas, providing users with access to correction data across a wide range of locations. This wide coverage improves the availability and accuracy of corrections, even in remote or challenging environments.

v. Open Access: Many CORS networks provide open access to their correction data, allowing users to access real-time or archived correction data free of charge or for a nominal fee. This open access facilitates widespread adoption of CORS technology across various industries and applications.

The stations continuously track signals from GNSS satellites, allowing for the collection of highly accurate positional data. Overall, CORS enhances GNSS accuracy by providing real-time differential corrections and precise positional data obtained from a network of reference stations. This approach significantly improves the accuracy and reliability of GNSS measurements, making CORS an essential tool for applications that require precise positioning, such as surveying, construction, and geographic information systems (GIS).

There is a promising future of GNSS and its prospects for application in obstructed and confined environments, such as urban canyons, because of inventions such as multi-constellation satellite service capabilities and the renowned Z-Blade GNSScentric technology.

Shafting and **plumblines** are a common means of vertical alignment for tunnelling works. The plumb line is simply a weighted line that is used to establish a vertical reference, and the laser plummet projects a beam of light onto a target, providing a more precise vertical reference. **Benches** assist surveyors in transferring controls from the surface to underground, using a series of instrument stations. When using benches, traversing and levelling are the key procedures surveyors undertake to transfer horizontal and vertical control, respectively. Pegs are used for demarcating formation levels, marking them off with conspicuous spray paint. Other tools such as tape measure and strings are also useful and mostly applicable at the preliminary stages, for example, when guiding the course of excavation where a road should pass through.

4.2.1 Trigonometric techniques of intersection and resection

The two **trigonometric** point determination techniques of **intersection** and **resection** come in handy to engineering and mining surveyors in various contexts. It is important to know their main **features** and **differences**. The following summary distinguishes them under the given contexts.

i. **Intersection:** This technique involves determining the location of an unknown point by using measurements taken from two known points. This is typically used in topographic surveys to establish new control points.

ii. **Resection**: This technique involves determining the location of the instrument (and hence the location of an unknown point) by taking measurements to known points. It can be of two types: angular resection (using angles) and distance resection (using distances). It is especially useful in situations where the exact location of the instrument setup needs to be known, or when there's an obstruction that prevents setup at a known control point.

For practical purposes, the choice between these techniques often depends on the specific constraints of the surveying situation, the equipment available, and the precision required. In Table 3-1 is a summary comparing the two techniques.

Table 4-1: *Comparison of intersection and resection control techniques*

Feature/Context	**Intersection**	**Resection**
Instrument Setups	The instrument stations used are two known points	The unknown point is the instrument station
Observations	Observe horizontal angles from the two known points to the unknown point.	For angular resection, observe horizontal angles from the unknown point to three known points. For distance resection, observe horizontal distances from the unknown point to reflectors placed on two known points or use the free stationing program in a total station
Applications	Used to establish new (temporary) control points for construction activities where it is not possible to set up the instruments at the points of interest because of obstructions caused by ongoing activities	Similar application, especially useful when the exact location of the instrument setup needs to be determined or when there are obstructions to setting up at a known control point

4.2.2 Free stationing and radial traversing

In Table 3-2 table gives a high-level overview of the instruments, procedures, and quality assurance methods used in each technique. When selecting a method, surveyors consider the specific requirements of their project, the environment, and the equipment available.

Table 4-2: *Comparison of free stationing and radial traversing*

Feature/Aspect	Free Stationing	Radial Traversing
Instruments	Total Station set to the free stationing mode	Total Station or Theodolite with EDM
Instrument setup	Set up at an unknown position (free station) and oriented without necessarily being over a known point	Set up over a known control point (traverse station) and oriented to take measurements to other points in its visible range
Procedures	Orientation using angle to a known point	From the traverse station, sight directly to other points or features whose positions you wish to determine
	Measure distances to multiple known points. Typically, two known points are used, but more can be used for better accuracy	Measure horizontal angles from a reference line (backsight) to various other sighted points (foresights) Measure distances to sighted points so as to complete the polar coordinate (r,θ) system
	Calculate the free station's coordinates using the known coordinates of the reference points and the measured distances (and angles, if necessary)	Apply trigonometry to determine the sighted points' coordinates. This is executed by polar to rectangular conversion/computation to determine dE and dN and hence the coordinates E,N of the unknown points

Quality Assurance	Check measurements with multiple known points for redundancy and to cross-check results Backsight check - After the free station's position is computed, take a backsight to a previously observed point to ensure consistency. Repetitive measurements - Measure angles and distances multiple times and take their mean to minimise errors	Repetitive measurements - measure angles and distances multiple times to get an average and reduce errors Closed traverse (ending at another known point). Quality assurance mainly involves checking the computed distances for accuracy Cross-check with other known points - Measure distances to other nearby known points to cross-check the results and ensure the quality of the survey

In both techniques, the key to ensuring accuracy and quality is redundancy. By measuring distances and angles multiple times, and by cross-checking against known data points, potential errors can be identified and corrected.

4.3 Tunnel Surveys

Lasers are the main precision instruments used for alignment in tunnels. They present the advantage of generating a sharp, precise, visible line of reference under the poorly lit underground environment characterising tunnelling and underground mining activities. Against this line of reference, surveyors can direct the vertical and horizontal alignments for excavations and estimates of quantities for "**underbreaks**" and "**overbreaks**", as shown in the example of a tunnel being excavated (Fig. 4.1).

As will be shown later in the practice exercises using a real-world example drawn from the Sondu-Miriu Hyropower tunnel, Kenya, engineering surveyors must apply coordinate geometry to solve for **precise laser offsets** with respect to the designed centreline of the tunnel. This is a necessary undertaking, a prerequisite for accurately setting out the tunnel and meeting the increasing demand on accuracy and precision towards the final works, such as the final lining of the tunnel with concrete.

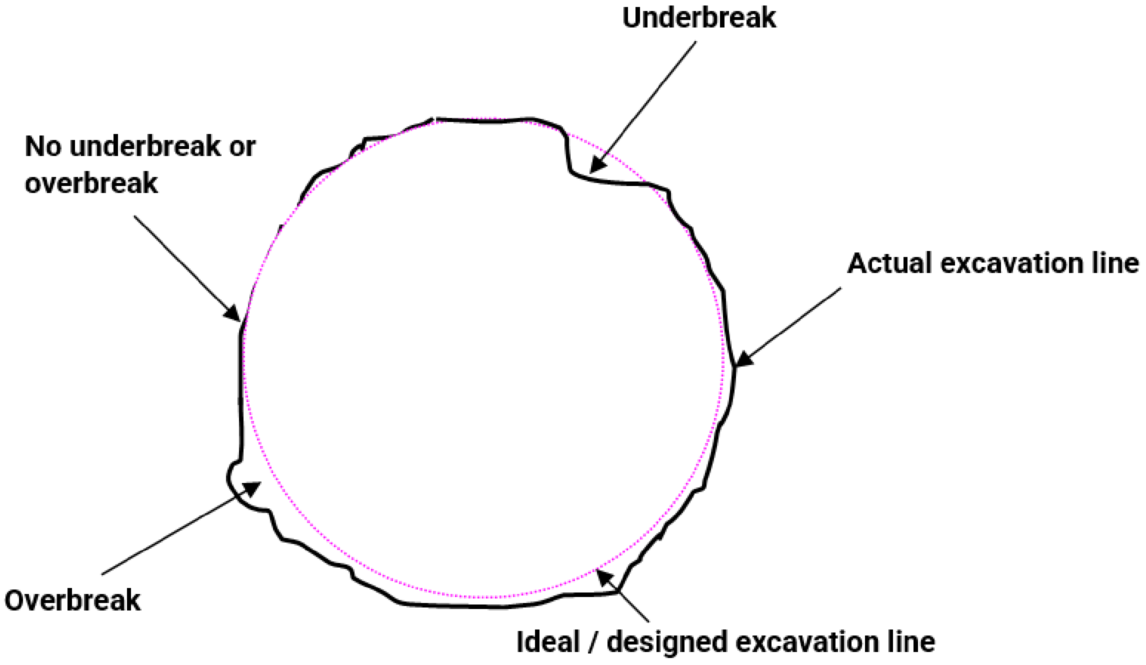


FIGURE 4.1
Cross-section of an excavated tunnel showing overbreaks and underbreaks.

Laser technology has been applied over time to align tunnels horizontally and vertically in an underground mining environment. The laser is typically mounted on a tripod or other stable platform and projects a beam of light that can be used as a reference line.

To align tunnels horizontally, the laser is set up at a control point and the beam of light is projected along the tunnel. Workers can then use this beam of light as a reference line to ensure that the tunnel is being excavated in the correct direction and at the correct elevation.

To align tunnels vertically, the laser can be set up at a known elevation and the beam of light projected onto the walls of the tunnel. Workers can then use this reference line to ensure that the tunnel is being excavated at the correct elevation.

Overall, the use of lasers can greatly improve the efficiency and accuracy of tunnel excavation, as well as reduce the likelihood of errors and rework.

A case study on tunnelling has been selected to exemplify the rigour and granularity of engineering and mining surveys. Long tunnels may require teams to work from both ends and meet up midway, hence the stringent accuracy requirements to avoid gross errors or minimise the systematic errors that can result in the teams veering off horizontally and/or vertically - never to meet up at all with massive losses of investment. Surveyors must consider the differences in coordinate and reference systems for transboundary tunnels to ensure that mathematical calculations and error-minimisation techniques are harmonised.

Tunnels may serve the needs of mining, railway transport, road transport, non-motorised transport, water transport, hydropower production, among others. Notable tunnels and amazing products of engineering surveys in the world include, for example:

i. **The Delaware Aqueduct** in the New York City water supply system (built 1939-1945) – the world's longest tunnel at 13.5 feet (4.1 m) wide and 85 miles (137 km) long.
ii. **Gotthard Base Tunnel** from Zurich to Milan – the world's longest rail tunnel (57.09 km) as of June 2016 (built from 1996), at the cost of US$10.3 billion.
iii. **Seikan Tunnel** connecting the Honshu and Hokkaido islands in Japan (53.9 km, 23.3 km under seabed), completed in 1988, at the cost of US$3.6 billion.
iv. **Channel Tunnel** (50.5 km, 37.9 km under the sea), constructed from 1987-1994 at the cost of £4.65 billion.

Due to their execution in restricted underground environments with neither natural lighting nor physical landmarks for approximate positioning, tunnel surveys qualify as one of the strictest types of engineering surveys. Air must be pumped along long tunnels for the safety of workers, who should be in full safety gear. Underground water is a common challenge in tunnelling, hence the use of electric power to pump water out of the tunnels to facilitate survey procedures, such as fixing reference points along the designed centreline and temporary benchmarks, usually using concrete nails. Measures must be taken to avoid cases of electrocution due to faulty wires that may be exposed to the water. Blasting of rocks for easier tunnel excavation is common practice. For safety, geological investigations are required to determine rock type, structure and composition and hence the right reinforcement needed, which may vary from shotcrete to iron bars or iron plates.

Surveying plays a vital role in the management of coastal zones, mineral exploration, and tourism. In coastal zone management, surveying is used to monitor the changing coastline, to identify potential hazards and to help plan and develop coastal areas. In mineral exploration, surveying is used to map geological features, to identify potential mineral resources, and to determine the best locations for mining operations. In tourism, surveying is used to create maps of attractions, to locate areas of natural beauty, and to plan and develop tourist sites.

An example of how laser beams are used to guide the excavation of a straight section of a tunnel with an excavation radius of 2.2 metres is shown (Fig. 4.2). This example is drawn from a practical application case of constructing a headrace tunnel for hydropower production in Kenya, the Sondu-Miriu Hydropower Project, for which the final radius after lining with concrete was designed to be 2.1 metres. More radial allowance is necessary during excavation to give room for sufficient thickness of concrete lining and for the movement of people, vehicles, machinery, and tools such as formwork of shutters and reinforcing bars.

Using traversing and levelling, targets are surveyed to be positioned at the correct (X,Y) locations and elevations (H) such that the laser beams are parallel and also tracing the correct slope according to the designed downstream/upstream slope of the tunnel section, **1 in 1000** in this practical case. The second pair of targets coinciding with the chainage of H' provides a necessary check. Measurements from the reference laser beam, both diametrically and vertically, aid in setting out the measurements needed not only for accurate excavation and construction so as to replicate the designed properties, but also for volumetric estimates of earthworks. It can be appreciated from this example that both horizontal control and vertical control are critical and must be accurate to achieve such an amazing engineering feat.

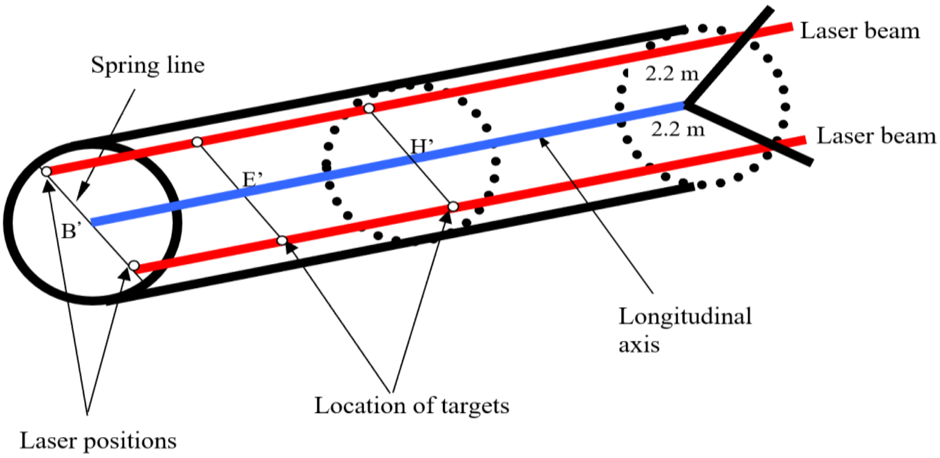


FIGURE 4.2

Straight section of Sondu-Miriu Hydropower Tunnel, Kenya. Drawn on site from surveying experience during civil works. Credit: Nashon Adero.

A laser beam was used to set out the curved section of the tunnel (Fig. 4.3). The exercise becomes more demanding because the designed curve geometry must be taken into account. As shown, the curve radius, R, is 200 metres, using the centreline as the reference as per the standard practice of setting out curves. The surveyor's challenge is to determine the offset AY, which gives the measurement from the laser beam to the point on the designed centreline. The surveyor needs to know the designed bearing of the straight/tangent to the curve at the point EC (known coordinates and chainage) and the chainage of A. As will be shown in the section for exercises, the mathematical equations for a straight line in rectangular coordinates (plane surveying), curve length, and chord length are routinely applied to arrive at the solution for the offset AY. These underground application examples suffice for underground mining surveys as well since tunnelling is a necessary undertaking in such projects.

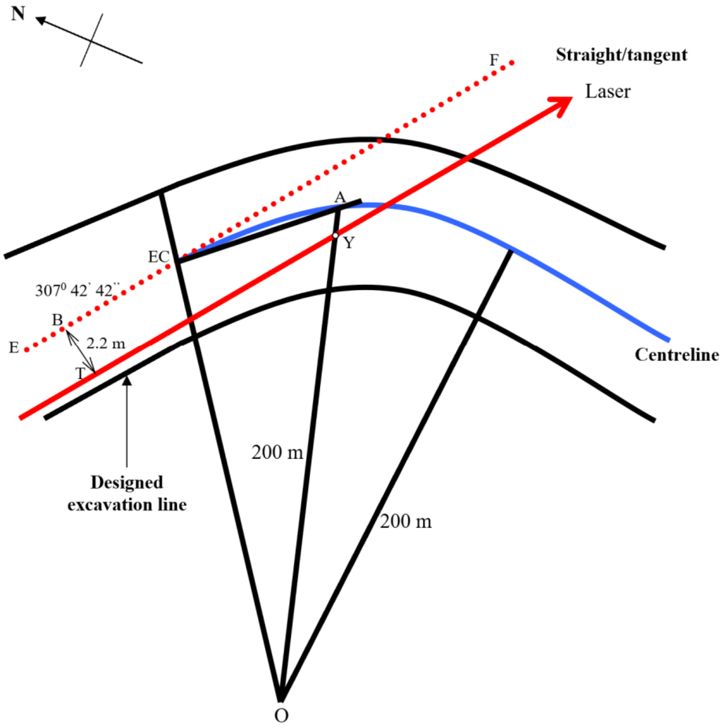


FIGURE 4.3

Curved section of Sondu-Miriu Hydropower Tunnel, Kenya. Drawn on site from surveying experience during civil works near the intake weir. Credit: Nashon Adero.

5. Aspects of Setting Out and Deformation Monitoring

Setting out of engineering structures relies on a network of control points and **offsets** calculated in reference to specific points on reference lines. Offsets are linear distance measurements perpendicular to the reference line at a point. The designed centreline of a structure such as a road or a tunnel is used as the reference line by default. Vertical control is also necessary to set out the right elevations and slopes.

5.1 Slope Planning and Horizontal Alignment

On design documents, slope may be expressed as **1 in X**, **1/X**, or in **degrees** (Ø). In any case, slope = tan (Ø) = dy/dx (vertical difference divided by horizontal equivalent), which is 1/X in this example, also equal to the tangent of the slope angle. The slope can also be expressed as a percentage, which is the same as 100 tan (Ø).

Transport and logistics for mining activities rely on infrastructure, which may not be existing in remote areas and have to be surveyed and constructed. Railways demand a very gentle slope, normally less than a degree, because of the low friction between the steel wheel and the steel rail. Roads can manage a higher gradient or grade. A surveyor must take such factors into account during setting out.

A typical underground project that strictly requires the application of accurate surveying techniques is the tunnel section shown, extracted from the case of Sondu-Miriu Hydropower Project, Kenya (Fig. 5.1). It should be noted that this is a clean and renewable energy project, hence its relevance to greening operations in the normally energy-intensive large-scale mining industry.

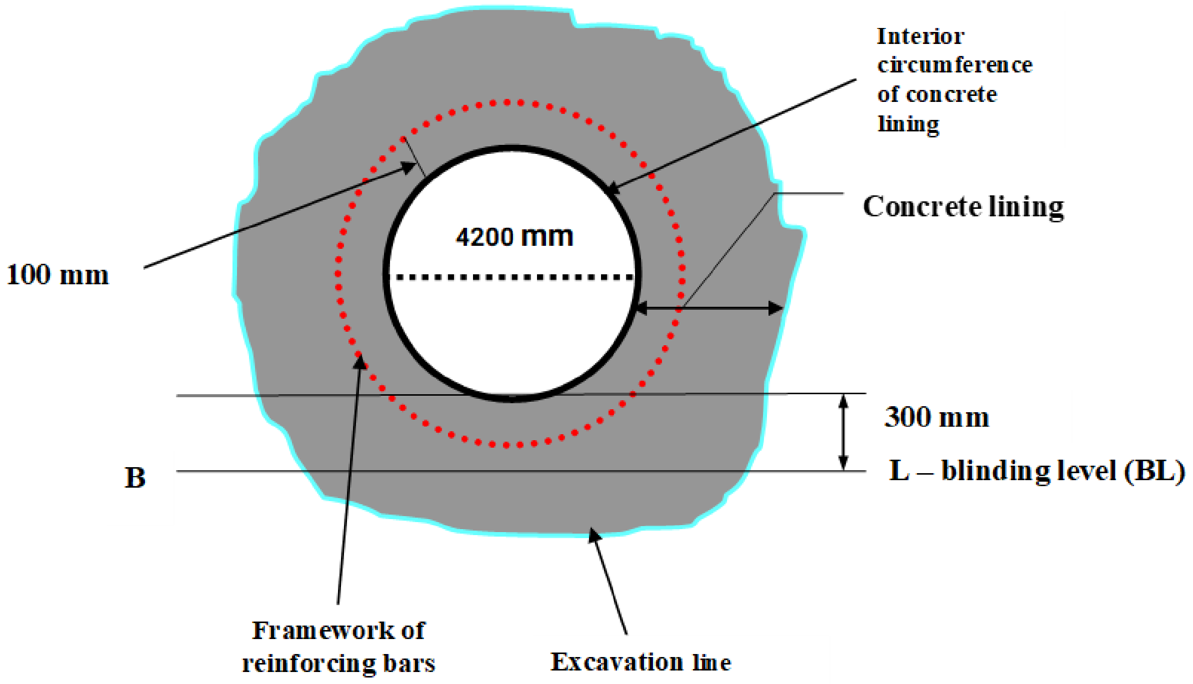


FIGURE 5.1

Reinforced concrete lining of a tunnel section with a design diameter of 4200 mm.

Horizontal and vertical alignment of the reinforcing iron bars inside the tunnel in Fig. 4.1 were accomplished using a total station and a level. Surveyors aligned an adjustable 15-metre-long formwork made of steel to assume the designed shape and orientation of the tunnel, after which the iron bars were laid on it to take on the shape and orientation of the formwork before the formwork could be collapsed and shifted to a new position. The aim was to end up with a tunnel of a circular shape once lined with reinforced concrete, as shown in Fig. 5.2.

FIGURE 5.2

Reinforced concrete lining of a tunnel section using optical solutions - a total station and a level. Photo credit: Nashon Adero.

5.2 Deformation Monitoring

Deformation monitoring involves carrying out systematic, precise, and periodic measurements on a structure in order to detect (usually small and gradual) displacements as a function of time in the structure away from the originally established positions, shape or geometrical relationships – normally due to induced stresses. Deformation monitoring is key to preventive maintenance. With technological advances, big data, Machine Learning and Artificial Intelligence, **predictive maintenance** is becoming a reality as well.

Examples of structures to be monitored include bridges, dams, buildings, tunnels, road and rail infrastructure, fuel storage tanks, and pipelines. Precise survey measurements help detect lateral and/or vertical shifts/movements/subsidence. The measurement techniques employed can be as simple as measurements of radials in a tunnel using a levelling staff, such as within an excavated tunnel, to complex ones yielding sub-centimetre (millimetre) measurements using precision instruments and photogrammetry techniques. The survey methods applied to monitor structural deformations make use of traversing, levelling, laser surveys, photogrammetry/drone- and LiDAR-assisted generation of **point clouds**, or satellite-based positioning and imaging methods (GNSS/GPS/satellite images).

In summary, a surveyor needs to consider the following instrumentation and procedures for a complete deformation monitoring schedule:

i. **Instrumentation**: Optical instruments, GPS/GNSS, imagery/photogrammetric set ups
ii. **Reference points** are accurately determined
iii. **Monitoring points** are placed on the structure with receptors, e.g., calibrated reflectors
iv. **Monumenting** of the control points as a cautionary measure against the displacement of reference points
v. **Taking periodic measurements from the control points**, used as reference stations, and taking readings to the monitoring points on the structure to obtain data on any changing geometries
vi. **Deformation analysis based on well-grounded theory** to reflect on the ideal condition, against the observed conditions at different epochs/times
vii. **Reporting of the results and recommendations** for necessary preventive interventions

6. Mining Applications

6.1 Minerals and the Future of Civilisation

In terms of increasing demand for the advanced materials, today’s Silicon Age has far exceeded the all the preceding ages: Stone Age, Bronze Age, and Iron Age. Minerals are driving the future of industrialisation and human civilisation, making materials science and engineering research critical to modern living (see Fig. 5-1).

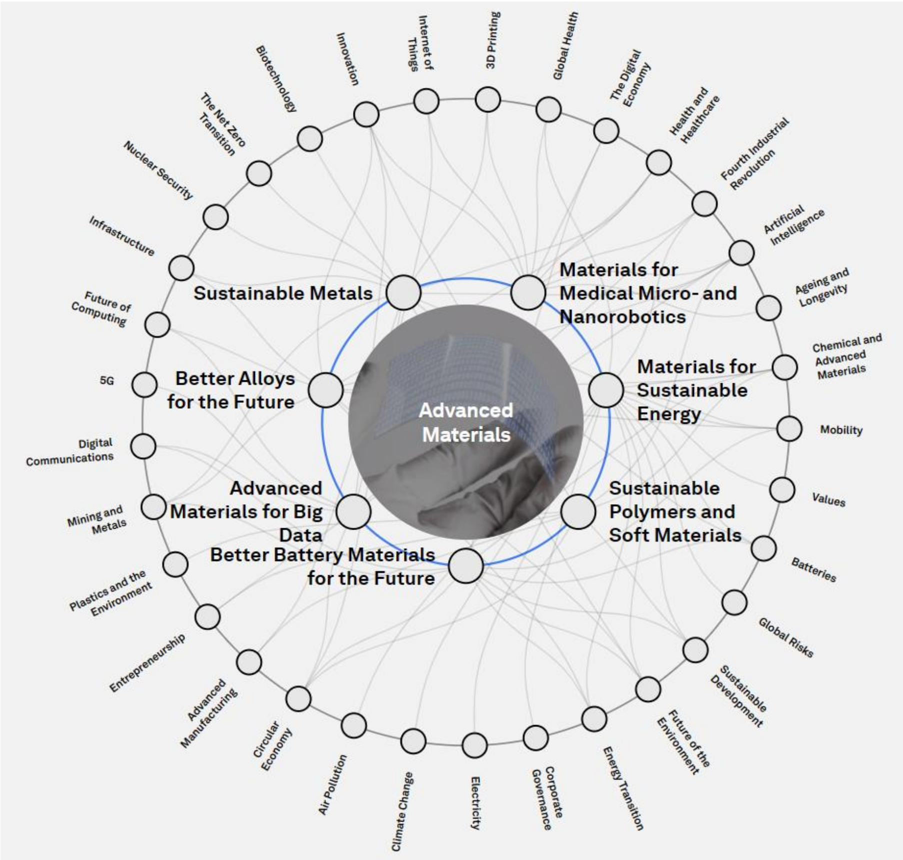


FIGURE 6.1

Advanced materials shaping the future with minerals and metals.
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Battery and fuel technologies (hence Battery Electric Vehicles – BEVs), for example, are gaining policy relevance in a world experiencing a growing uptake of sophisticated consumer electronics and electric vehicles. Lithium (white gold), nickel, cobalt, graphite, copper, aluminium, manganese, tantalum, platinum, palladium, and rare earth minerals, such as neodymium, are among the minerals considered critical to this future. Renewable energy integration into the mining sector is gaining policy momentum and relevance as an effective way of achieving decarbonisation targets, hence importance of surveying and mapping for geothermal, hydropower, solar, wind, and wave-energy projects.

The global mining industry is categorised as a heavy industry due to its energy-intensive demands for large-scale operations. McKinsey & Company estimated that mining was contributing 4-7% of the global greenhouse gas (GHG) emissions by 2020. Environmental responsibility in the mining sector is a key global issue in the pursuit of the UN Sustainable Development Goals (especially Goal 7, Goal 13, and Goal 15). Decarbonisation and meeting net-zero emission targets in the face of climate change are compelling policy goals. Green steel production using hydrogen (deep decarbonisation) is a key example of the innovative attempts at greening the mining industry.

Informed by recent global developments, mining scholars have rightfully argued that, in terms of importance to society, mining should be accorded a weight that is no less than the weight of farming, fisheries, and forestry. Mining surveys, as a result, are gaining prominence. Issues of job losses aside, automation is gaining importance in the global mining industry since it is key to safety enhancement.

Critical minerals are so referred because their demand outpaces supply with advances in socioeconomic development and technology. **Strategic minerals** are critical to national security/defence, industrialisation and economic development, geopolitical significance, and technological advances, hence facing potential global supply chain vulnerabilities. Tin, for example, is considered a strategic mineral due to its essential roles in industrial applications, electronics, defence technologies, and its potential vulnerability in global supply chains. Tin's strategic importance is underscored by its contributions to economic development, technological advancement, and national security. Similarly, tungsten, coltan, and chromium are also classified as strategic minerals.

The mineral raw materials included in the **World Mining Data Report** series are categorised into five groups, which exclude precious stones. An expanded list of minerals by clustered categories is presented Table 6-1, alloys included.

Table 6-1: *Categorisation of common mineral resources*

Category	Examples
Iron and Ferro-Alloy Metals	Iron, Chromium, Cobalt, Manganese, Molybdenum, Nickel, Niobium, Tantalum, Titanium, Tungsten, Vanadium, Cobalt, Steel
Non-Ferrous Metals	Aluminum, Antimony, Arsenic, Bauxite, Beryllium, Bismuth, Cadmium, Copper, Gallium, Germanium, Indium, Lead, Lithium, Mercury, Rare Earth Minerals,

	Rhenium, Selenium, Tellurium, Tin, Zinc, Base Metals (e.g., Aluminum, Copper, Zinc, Brass, Bronze)
Precious Metals	Gold, Platinum-Group Metals (platinum (Pt), palladium (Pd), rhodium (Rh), ruthenium (Ru), iridium (Ir), and osmium (Os)), Silver
Precious Stones	Diamonds, Emeralds, Rubies, Sapphires, Tsavorite, Tanzanite
Industrial and Construction Minerals	Asbestos, Baryte, Bentonite, Boron Minerals, Diatomite, Feldspar, Fluorspar, Graphite, Gypsum and Anhydrite, Kaolin (China-Clay), Magnesite, Perlite, Phosphate Rock (incl. Guano), Potash, Salt, Sulfur, Talc (incl. Steatite and Pyrophyllite), Vermiculite, Zircon, Wollastonite, Soda Ash, Limestone, Fluorite, Silica Sand, Construction Aggregates (e.g., Sand, Gravel), Clays (e.g., Ball Clay, Fire Clay)
Mineral Fuels	Steam Coal (incl. Anthracite and Sub-Bituminous Coal), Coking Coal, Lignite, Natural Gas, Petroleum (incl. Natural Gas Liquids), Oil Sands, Oil Shales, Uranium, Coal Bed Methane
Energy Transition Minerals	Lithium, Cobalt, Graphite, Rare Earth Elements (e.g., Neodymium, Dysprosium), Silicon, Vanadium
Strategic Minerals	Coltan (Columbite-Tantalite), Tin, Tungsten. Rare Earth Elements, Tantalum, Tungsten, Cobalt, Uranium, Chromium
Critical Minerals	Antimony, Bismuth, Gallium, Germanium, Indium, Rhenium, Tin, Titanium, Tungsten, Fluorspar/Fluorite, Niobium

Mine surveying is key to the blue economy in the following ways:

i. **Exploration and development of underwater mineral resources:** Mine surveying techniques can be adapted to map and explore underwater mineral resources, which can contribute to the development of the blue economy.

ii. **Environmental monitoring:** Mine surveying can be used to monitor the impact of mining activities on the marine environment, and to design and implement mitigation measures to minimise this impact.

iii. **Marine infrastructure development:** Mine surveying is essential for the design, construction, and maintenance of marine infrastructure such as ports, harbours, and offshore wind farms, which are key components of the blue economy.

The high instrumental value of minerals has invoked the application of advanced ICT-enable technologies, especially **blockchain technology**, to address the following areas of application.

i. **Supply chain management:** Blockchain can be used to create a secure and transparent supply chain for minerals, from extraction to processing to sale. This can help to prevent the use of conflict minerals and promote ethical and sustainable mining practices.
ii. **Asset tracking:** Blockchain can be used to track the ownership and transfer of mining assets, such as mining rights and equipment, in a secure and transparent way.
iii. **Payment processing:** Blockchain can be used to facilitate secure and efficient payment processing in the mining sector, reducing the risk of fraud and errors.

With advances in big data and computer-aided processes, blockchain technology as a secure, immutable ledger system promises to enhance end-to-end transparency, efficiency, and security in the mining sector, while promoting sustainable and ethical mining practices.

6.2 Classical and Emerging Features of Mining Surveys

Mining surveys involve the applied precision science and engineering that generates the geospatial metrics required to guide mineral exploration and mining activities while utilising the principles of surveying, geodesy, mining, and geology. Mining surveys may be considered as a special subclass of engineering surveys applied in mining environments. As such, mine or mining surveys deal with the accurate geospatial measurements required to plan, design, implement, assess, and monitor mining activities including their environmental impacts while ensuring safe practice and post-mining environmental responsibilities.

The life cycle of any mining enterprise, from exploration to post-closure activities, presents many phases in which the role of surveying and geospatial techniques and technologies remains critical. Spatial metrics are key to policy decision support, safety monitoring, mineral resource exploration, mine planning, mine design, determining land-related mining rights with exactitude, quantitative estimates of earthworks or materials on site, and post-mining rehabilitation or landscape restoration.

Deposit processing involves the exploration, evaluation, and determination of the reserves of a deposit and supports a mining plan in regard to optimal use of the reserves. **Approval procedures** are a precondition when exploring and extracting mineral resources. They are the basis for the acquisition of a mining permit or license and access to the land where mining takes place.

Traversing and levelling are the classical methods that continue to find application in mining fields, respectively for the horizontal and vertical alignment of both surface and underground mining activities. Theodolites, total stations, and levels are the commonly optical instruments used, complemented by laser precision instruments.

6.3 Evolution in Instrumentation and Methods for Mining Surveys

Mining surveys require adequate instrumentation to effectively address both surface and underground assignments.

Advances in geospatial positioning technologies continue to enhance mining operations and automation in the mining sector in through the following main pathways:

i. Providing accurately determined positions/locations for equipment location, machine guidance, tracking, and monitoring purposes
ii. Providing accurate and precise measurements for vehicle routing and tracking/fleet management and related safety monitoring
iii. Accurate determination of volumes, e.g., using LiDAR scans
iv. Providing accurate spatial parameters for early warning/ environmental monitoring
v. Providing accurate spatial parameters for drill and blast optimisation
vi. Guiding automated rigs
vii. Optimising material handling using preferred surveyed routes
viii. Optimising exploration sampling efforts through accurate surveying and mapping for minerals

A *gyrotheodolite* is used for orientation in underground environments. Laser surveys (including airborne laser scanning) and the common optical solutions in engineering surveys are applied to deliver mining-related solutions as well.

Slope planning, pegging, setting out, deformation monitoring, and determining rights and legal liability as per mining blocks are common survey assignments in the mining sector. Since land and mining are strongly interconnected, cadastral surveys are critical to determining mining rights on land. Countries are advancing towards digital 3D cadastre so that mining rights can be better managed, including the effects of underground mining on the structures owned by neighbouring communities.

Airborne solutions continue to transform mining operations and exploration. **Airborne geophysical surveys** produce geophysical maps and are commonly conducted to map out the mineral potential of a territory. Control points are established to ensure that the final map can be georeferenced, hence enriching the final products with actionable location-based intelligence. Aerial photogrammetry combined with LiDAR aboard UAVs has been highly useful as a safer means of pit mapping and measuring the volume of stockpiles while conducting 3D modelling and monitoring. The photogrammetrically generated data is usually processed using automated software-assisted processes to create digital terrain models (DTM), digital elevation models (DEM), imagery that is both orthorectified and georeferenced, and topographic maps.

Spaceborne solutions rely on the global coverage of geolocation information (GNSS) and imagery data from space satellites for safe and cost-effective results for the mining industry. Mining and geological applications benefit from the data obtained from satellite image processing, georeferencing, orthorectification, feature extraction, and mosaicking.

Material detection is made possible using the short-wave infrared (SWIR) wavelength bands, obtainable from SPOT 4 and SPOT 5 satellite remote sensing as well as DigitalGlobe’s high-resolution SWIR imagery. A **borehole camera** is part of the highly useful equipment in mining surveys. The 3D spatial coordinates of borehole data are analysed using GIS techniques and artificial neural networks (ANN) to reveal characteristics that are key to detecting geohazards.

A **borehole camera** is used generally for geological mapping, geotechnical evaluation, structural analysis, orebody delineation, and hydrogeological assessment, with specific key functions as follows:

i. ascertaining groundwater conditions and hydrogeological characterisation in a mining area – detects water inflows, aquifers, and permeable zones; shows location, colour, consistency, and the amount of precipitates. These key applications aid in environmental impact assessment, designing dewatering systems, and water resource management

ii. viewing subsurface conditions for geological information on rock types, faults, fractures – hence supporting fracture logging by direct observations and measurement or using imaging functions and acoustic televiewers
iii. viewing bedding planes, and recording the stratigraphy and lithology of the accessed units
iv. documenting cracks or holes and leaking joints
v. observing hole offsets and blockages
vi. assessing rock quality and age – geotechnical investigations
vii. provides images for identifying mineralisation zones and estimating the size and grade of the ore body, which supports mine planning

Remote sensing and GIS are together potent tools for assessing, quantifying, and monitoring the effects of mining on land and environment. They are important sources of the data and information that is increasingly required for sound decision support and policy development for sustainable mining practices in the broader mining-environment-society nexus. Advances in the resolution of satellite imagery are delivering more resourceful data for land use and land cover assessments across mining areas. Initiatives such as Digital Earth Africa and Digital Earth Australia are providing analysis-ready data (ARD) and decision-ready data (DRD) from processed satellite imagery, making it even easier to generate spatial models that support decisions and policies on sustainable mining and reclamation of closed mining sites. Sentinel (10 m), PlanetScope (3 m), Pleiades (0.5 m), WorldView-3 (0.3 m), and hyperspectral images of sub-metre spatial resolutions demonstrate the innovations pushing the boundaries of satellite-based imagery solutions for the mining sector.

LiDAR technology has been a big boon to mining surveys, especially SLAM LiDAR technology because it is not dependent on GNSS signals and can quickly and efficiently generate 3D models of the terrain and tunnels in areas deprived of GNSS signals. It offers significant advantages in mine planning and development stages by providing accurate, real-time 3D mapping and localisation capabilities in underground environments. Its applications span across various aspects of mine engineering, safety, and operations, contributing to more efficient and sustainable mining practices. Here is a list of the key application areas of SLAM LiDAR in mining.

i. Precise volumetric analysis of 3D features, e.g., stockpiles, and for excavation and haulage planning, etc.
ii. Laser-based linear measurements of distances and clearance levels
iii. Rendering 3D models for better visual impression and planning
iv. Digital twins for planning, design and maintenance purposes
v. Exploration and Surveying: SLAM LiDAR can be used for underground exploration and surveying to map the geological structures, identify mineral deposits, and assess the terrain's topography. This information is crucial for understanding the layout and characteristics of the mine site
vi. Infrastructure Planning: During the planning stages of a mine, SLAM LiDAR can aid in designing underground infrastructure such as tunnels, shafts, and access routes. The precise 3D maps generated by SLAM LiDAR help engineers plan the optimal layout for these structures, considering factors like geology, safety, and operational efficiency.
vii. Stope and Drift Design: SLAM LiDAR technology assists in designing stopes and drifts within the mine. By providing accurate measurements of the underground environment, including rock mass characteristics and structural features, SLAM LiDAR helps engineers determine the most efficient and safe locations for excavations
viii. Ventilation and Airflow Analysis: Proper ventilation is critical for maintaining air quality and ensuring the safety of miners underground. SLAM LiDAR can be used to analyse airflow patterns and assess the effectiveness of ventilation systems. By identifying areas of poor airflow or ventilation obstructions, mine operators can optimise ventilation designs to enhance safety and efficiency
ix. Monitoring Ground Stability: SLAM LiDAR enables continuous monitoring of ground stability within the mine. By detecting changes in the underground environment, such as rock movements, subsidence, or deformations, SLAM LiDAR helps identify potential safety hazards and allows for timely intervention to mitigate risks
x. Asset Management: SLAM LiDAR technology can be utilised for asset management within the mine, including tracking the location and condition of equipment,

infrastructure, and geological features. This information aids in maintenance planning, resource allocation, and optimising the utilisation of mine assets

xi. Emergency Preparedness: In the event of emergencies such as cave-ins or gas leaks, SLAM LiDAR-generated maps provide valuable real-time information for emergency response teams. By visualising the underground environment and locating trapped miners or assessing hazards, SLAM LiDAR supports effective emergency preparedness and response efforts

On mining sites are key structures such as storage tanks and dams, which do need regular deformation monitoring to ensure safety. Blasting and other highly vibratory activities on mining sites due to heavy machinery make subsidence monitoring a crucial undertaking. **Land subsidence** is a key safety risk that should be monitored keenly on mining sites. **Interferometry** is a technique whereby multiple repeat satellite radar images taken over a scene are integrated to detect small shifts, such as small ground movements that could well be in the order of a millimetre per year. The European Union's Copernicus Sentinel-1 satellites, for example, have been providing this important service that can generate industry-optimised analytics for actionable insights in aid of monitoring changes in landscapes affected by mining and quarrying activities. *Differential radar interferometry* or *Differential Interferometric Synthetic Aperture Radar (DInSAR)* has been a powerful means of monitoring small changes that lead to land subsidence in mining areas. This method, based on **active remote sensing**, is more effective and economical over large areas than the less effective point-by-point measurements obtained using classical optical solutions.

Airborne Ground Penetrating Radar (GPR) facilitates remote data collection in hard-to-reach and hazardous areas, typical of most mining areas. These radar-based technological advances are a great boost to **subsidence engineering**. GPR sends electromagnetic pulses into the ground and by measuring the time it takes for the signals to bounce back, it can map subsurface structures, revealing geological characteristics and potential weaknesses, which aid in identifying and mitigating the risks associated with subsidence. As such, GPR avails risk assessment information about subsurface anomalies by identifying changes in subsurface materials, such as voids, fractures, or changes in soil composition, which point to potential areas of subsidence. Potential triggers of land subsidence include mining and groundwater extraction. For safety monitoring, GPR also tracks subsidence progression and the effectiveness of mitigation measures through repeated surveys.

Augmented GNSS as an advanced spaceborne positioning solution delivers centimetre-level accuracy for **automation** and **machine guidance** in mining. This solution is also applicable to route planning and fleet management, which are key to enhancing productivity in busy mining operations.

With offshore prospects in deep-sea exploration for minerals, surveys of the seafloor morphology or bathymetry make use of **multibeam acoustic and airborne laser systems** for full bottom coverage, nautical charts, and echo sounders for depth measurements. Multibeam acoustic surveys employ sonar systems to generate detailed three-dimensional maps of the seafloor, allowing for precise identification of geological formations and potential hazards.

The use of **green laser** is transforming outcomes in airborne laser bathymetry (ALB) for clear waters. GNSS still finds application in navigation for safety and for transport of cargo during such exploration missions. **Backscatter** results from echo sounders help in identifying the geological constitution of the seafloor and the objects on it e.g., hard materials and rocks tend to reflect more sound than a softer material, such as mud.

Technological innovation is enhancing offshore mineral exploration prospects using **autonomous underwater vehicles**. For sea-floor exploration, navigation and sampling use **autonomous robotic systems** that can work under high pressure, low temperature, and total darkness. Intelligent response to sound frequencies that trigger the dropping of weights used during immersion enables the return of the vehicles to the surface, relying on their buoyancy. Several case studies of these efforts exist with the GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany, acting as a key example in deep-sea exploration for minerals.

Software developments continue to boost model development for planning and design related to mining. Block models can nowadays be readily generated using specialised commercial software, such as **Surpac** and **MineSight 3D**. Automated cartographic solutions for mapping and planning at scale add to the long array of benefits of software development.

Automation of operations in the mining sector including **machine guidance** requires accurate geospatial positioning techniques. Research on the bleeding edge also promises deep-sea mining as the next frontier of mining, making mining surveys even more critical in future and a key technical aspect of the blue economy. **Extended reality or immersive technologies**, such as virtual reality (VR), augmented reality (AR) and mixed reality (MR), are among the new avenues that geodata-driven technologies have opened up for the mining industry to reap immense benefits of enhanced productivity, safety, and cost-effectiveness.

6.4 Mineral Resource Mapping Fundamentals

6.4.1 Evolution from traditional methods

- Historically, resource mapping relied on **ground surveys** and **in-situ** sampling, which could be time-consuming and limited to relatively small areas.
- Advances in technology now enable **fast, efficient methods** covering large regions such as districts and entire countries, often leveraging **remote sensing** and **aerial/spaceborne platforms**.

6.4.2 Recent technological developments

- **Remote sensing (sensor) technologies** include **spaceborne** (satellites), **airborne** (aircraft, UAVs/drones), **radar**, **LiDAR**, and **magnetic sensors**.
- These innovations deliver broader coverage with adequate resolution, offering improved **data integrity** and more comprehensive **spatial analysis** capabilities.

6.4.3 Surveying and mapping approaches

- **Geophysical surveys**: Use magnetic, gravity, electromagnetic, seismic, and radiometric measurements. These surveys help detect variations in the subsurface, revealing potential mineral targets.
- **Geological mapping**: Focuses on surface and near-surface features (e.g. faults, folds, and shear zones). Identifying these structures can pinpoint areas of likely mineralisation.
- **Geochemical sampling**: Analyses chemical properties of soil, rock, and water to detect **anomalies** indicative of underlying mineral deposits.

- **Core drilling and logging**: Involves extracting subsurface samples for direct observation. Logging techniques record rock types, textures, and other properties to confirm mineral presence and guide further exploration.

6.4.4 Role of GIS in resource mapping

- Modern **GIS (Geographical Information Systems)** platforms integrate data from geophysical, geological, and geochemical surveys alongside field observations and remote sensing.
- A **GIS-based approach** allows for comprehensive **data layering, visualisation,** and **analysis**, aiding in target prioritisation and reducing exploration risk.

6.4.5 Key insights and best practices

- **Multi-disciplinary integration**: Combining different survey techniques often provides the most reliable mapping results.
- **Scalability**: Remote and automated sensing methods can scale from small sites to regional or national projects.
- **Ongoing innovation**: Improvements in sensor technology, UAV autonomy, and computational capacity (e.g. AI-driven analysis) continue to enhance the speed and accuracy of resource mapping.
- **Sustainability and safety**: Modern surveys reduce on-site human intervention, minimising environmental impact and improving safety, while still delivering robust datasets.

By leveraging geophysical, geological, and geochemical methods—supported by remote sensing and GIS—today's resource mapping can identify and evaluate mineral prospects more **efficiently** and **accurately** than ever before.

6.5 Sensors and their Suitability for Mineral Surveys and Mapping

6.5.1 Magnetic measurements

What they measure: Variations in the Earth's magnetic field caused by the magnetic susceptibility and remanence of subsurface rocks. Up to several kilometres (airborne surveys).

Minerals or deposits typically identified:

- **Iron-rich minerals**: Magnetite, pyrrhotite, and other ferromagnetic minerals.
- **Iron ore (Banded Iron Formations)**: Large-scale concentrations of magnetite can strongly distort local magnetic fields.
- **Nickel or chromium deposits**: These often have associated magnetic minerals, particularly in mafic-ultramafic complexes.
- **Skarn deposits**: Can contain significant amounts of magnetite.

Because the magnetic method is sensitive to even small quantities of magnetite or other ferromagnetic minerals, it can be used for mapping geologic structures (faults, dikes, and contacts between different rock types) that may host mineralisation.

6.5.2 Gravity measurements

What they measure: Changes in the Earth's gravitational field caused by density contrasts between subsurface materials. Up to several kilometres (resolution decreases with depth).

Minerals or deposits typically identified:

- **Dense sulfide ores**: Massive sulfide deposits (such as VMS—volcanogenic massive sulfides or SEDEX—sedimentary exhalative deposits) can create noticeable gravity highs due to higher densities.
- **Iron ore deposits**: Iron formations can stand out because of their high density.
- **Barite**: Barite (barium sulfate) is also relatively dense and can be detected via gravity anomalies.
- **Salt domes (evaporites)**: Although salt (halite) is less dense than surrounding rock, the resulting contrast can also be mapped by gravity surveys (this is more common in petroleum exploration but can reveal certain mineral settings).

Gravity surveys are especially useful in identifying large-scale structures or bodies with distinct density contrasts. However, smaller or lower-density contrast deposits may be harder to detect.

6.5.3 Electromagnetic (EM) measurements

What they measure: The conductivity (or resistivity) and induced polarisation (in some survey types) of subsurface materials. Shallow to moderate depths (depends on frequency and system).

Minerals or deposits typically identified:

- **Sulfide ores** (e.g., copper, nickel, zinc, lead): These minerals often have high electrical conductivities. Massive sulfide deposits in particular can give strong EM anomalies.
- **Graphite**: Graphitic horizons are highly conductive.

- **Gold deposits**: While gold itself is conductive, it usually occurs in sulfide-rich host rock or mineralised shear zones that can be conductive or chargeable.
- **Minerals in fault/shear zones**: Hydrothermal alteration along structures can change conductivity contrasts.

EM methods (such as Time-Domain EM, Frequency-Domain EM, or Induced Polarisation) can detect subtle variations in conductivity and chargeability, making them key tools in exploring for sulfides and related mineralisation.

6.5.4 Seismic measurements

What they measure: Reflection and refraction of seismic (sound) waves based on differences in acoustic impedance (the product of density and seismic velocity). From near-surface to several kilometres (reflection seismic).

Minerals or deposits typically identified:

- **Layered mineral deposits**: Potash and salt layers, or layered mafic intrusions, can have velocity or impedance contrasts.
- **Massive sulfides**: While not always the primary tool for sulfides, large, dense sulfide bodies may cause distinct reflections if they form coherent layers or lenses.
- **Structural features**: Seismic is more commonly used in petroleum exploration, but it can be used to map faults, folds, or stratigraphic traps that might be associated with mineral deposits.

Seismic surveys are often more expensive and logistically intensive than some other geophysical methods but are invaluable for detailed mapping of subsurface structures and stratigraphy, which can indirectly guide mineral exploration.

6.5.5 Radiometric (Gamma-Ray) measurements

What they measure: The natural gamma radiation primarily from the decay of potassium (K), uranium (U), and thorium (Th). Airborne or ground-based gamma-ray spectrometry is commonly used. Very shallow (commonly <1 m penetration).

Minerals or deposits typically identified:

- **Uranium deposits**: Elevated radioactivity from U-bearing minerals (e.g., uraninite, autunite).
- **Thorium-rich minerals**: Monazite, thorite.
- **Potassium alteration zones**: Many hydrothermal systems associated with porphyry copper-gold deposits or other intrusive-related deposits have potassic alteration that increases K levels.
- **Rare Earth Element (REE) deposits**: Often associated with Th- or U-bearing minerals.

Radiometric surveys are excellent for large-scale mapping of surface geology, alteration zones, and deposits with radioactive elements. However, they typically do not penetrate deeply and are more useful for near-surface investigations.

6.5.6 Combining methods for more effective exploration

In practice, exploration programmes often combine multiple geophysical methods to reduce uncertainty. For example:

- **Magnetic + EM**: Commonly used together in searching for massive sulfide deposits where the target may be both magnetically susceptible and electrically conductive.
- **Gravity + Magnetic**: Often run concurrently in the search for iron ore or dense sulfide deposits.
- **Seismic + Radiometric**: May be used in certain terrains, particularly if uranium or potassic alteration is suspected in layered or structurally complex settings.

By correlating anomalies from different geophysical surveys and integrating them with geological and geochemical data, exploration teams can more confidently pinpoint drill targets and define mineralised zones.

6.5.7 Summary of measurement techniques

1. **Magnetic** surveys highlight magnetically susceptible minerals (e.g., magnetite) and reveal structural features. **Pros:** Rapid and cost-effective for large-scale surveys; excellent at detecting faults, dykes, and other structural features. **Cons:** Weakly or non-magnetic targets (e.g., pure limestone) often go undetected; remanent magnetism can complicate data interpretation. **Often Paired With: Electromagnetic (EM)** or **Gravity** surveys for deeper insights, alongside **geological mapping** to confirm structural contexts.

2. **Gravity** surveys detect density contrasts to locate dense (or less dense) rock bodies, including massive sulfides and iron ore. **Pros:** Effective at detecting dense ore bodies and broad-scale lithological variations; helpful in delineating major structures. **Cons:** Smaller or low-density contrast targets may be overlooked; requires accurate terrain, topographic, and elevation corrections. **Often Paired With: Magnetic** surveys for structural correlation, and **Seismic** for detailed 3D stratigraphic imaging.

3. **Electromagnetic** surveys are especially sensitive to conductive minerals such as sulfides and can delineate mineralised shear zones. **Pros:** Excellent for identifying conductive mineralisation, such as sulphide ores; can delineate fault and alteration zones. **Cons:** Conductive overburden or saline groundwater can mask target anomalies; effective depth penetration varies with frequency and terrain conditions. **Often Paired With: Magnetic** for structural mapping, and **Induced Polarisation (IP)** for assessing chargeability related to mineralisation.

4. **Seismic** surveys map rock layering and structural traps through reflections/refractions, helpful for both hydrocarbon and some mineral exploration. **Pros:** Provides high-resolution imaging of subsurface layering and structures in both 2D and 3D; beneficial for pinpointing stratigraphic boundaries and deposit geometry. **Cons:** Relatively expensive and logistically demanding; not all deposits yield strong reflections. **Often Paired With: Gravity** and **Magnetic** for initial reconnaissance, and **borehole logging** to calibrate seismic velocities.

5. **Radiometric** surveys measure surface gamma radiation to identify radioactive elements (U, Th) and potassic alteration zones. **Pros:** Rapid mapping of surface lithological changes; identifies uranium-, thorium-, or potassium-rich zones associated with certain minerals and alteration types. **Cons:** Very limited depth of investigation; subject to environmental and regulatory considerations for radioactive surveys. **Often Paired With: Surface geochemistry** for validation of radioactive anomalies, and **geological mapping** to confirm near-surface rock types.

Each technique has a particular niche based on the physical properties of the minerals or rocks in question. The optimal exploration strategy often involves selecting (and combining) the methods that best exploit the expected deposit's physical and chemical properties.

6.6 Quantitative Estimates in Mining Surveys

Ore reserve estimates are a critical assignment of mining surveyors all over the world. The assignment integrates engineering surveying, mapping, and GIS to achieve accurate and reliable ore reserve estimates, providing essential support for mining decision-making. As a rule of procedures, the following steps and techniques apply:

6.6.1 Geological Mapping:

- Conduct detailed geological mapping of the deposit area to understand the distribution of ore bodies and geological features. Engineering surveying plays a key role in accurately locating these features within the broader mining landscape.
- Identify and delineate ore zones based on rock types, structures, and

mineralisation patterns, utilising GIS to integrate spatial data and create detailed geological maps.

6.6.2 Topographic Surveying:

- Perform topographic surveys using **Total Station, GPS/GNSS, UAVs/drones,** or **LiDAR** to generate accurate surface maps. Engineering surveyors ensure precision in capturing elevation data and terrain features.
- Create Digital Terrain Models (DTMs) that represent the physical features and elevation of the mining area, which are essential for guiding volumetric calculations. GIS is used to manage, analyse, and visualise these digital topographic datasets.

6.6.3 Drilling and Sampling:

- Plan and execute drilling programmes (core, RC, or blast hole drilling) to extract samples from various depths within the ore body. Engineering surveyors accurately mark drill locations and verify their coordinates for consistency.
- Collect representative ore samples for laboratory testing to determine grade, density, and mineral content. GIS can be used to link assay data with spatial locations.

6.6.4 Geological and Engineering Modelling:

- Use data from geological mapping, topographic surveys, and drilling to create a 3D geological model of the ore body. Engineering surveying ensures that spatial accuracy is maintained, while GIS integrates various layers of data (e.g., geological structures, ore zones, and topography).
- Define ore zones, boundaries, and variations in **grade** and **thickness** using both geological interpretation and advanced modelling techniques.

6.6.5 *Volume Estimation:*

- Apply survey data to calculate the volume of the ore body using cross-sectional or block modelling. Engineering surveying ensures accurate measurements, while GIS and 3D modelling software (e.g., SURPAC, MineSight) enable precise volume estimation.
- The integration of GIS allows for better spatial analysis of the ore body, improving the accuracy of reserve estimates.

6.6.6 *Grade Estimation:*

- Analyse assay data from ore samples to calculate the **average grade**. GIS can be used to map variations in grade across the deposit.
- Employ geostatistical methods, such as **kriging** or **inverse distance weighting**, to interpolate ore grades within the deposit, ensuring spatial continuity in grade distribution.

6.6.7 *Resource Classification:*

- Classify the ore into different categories (**measured, indicated, inferred**) based on confidence levels in data quality, geological continuity, and sample spacing. Engineering surveying ensures precision in spatial measurements, while GIS provides a platform to manage and classify resources spatially.
- GIS helps visualise the spatial distribution of these resource categories across the deposit.

6.6.8 *Cut-off Grade Determination:*

- Calculate the cut-off grade, which is the minimum grade required for the ore to be economically viable. This process involves considering market conditions, processing costs, and mining costs.

- GIS allows for spatial analysis of areas above and below the cut-off grade, enabling informed decisions on the economic viability of different zones.

6.6.9 Ore Reserve Calculation:

- Apply the cut-off grade to the estimated ore volume and grade to determine the tonnage of ore reserves. Adjustments are made for dilution (waste material mixed with ore) and recovery rates (the amount of ore that can be extracted and processed). Engineering survey data helps refine these calculations.
- GIS assists in managing and visualising the spatial distribution of reserves, enabling more effective planning.

6.6.10 Reporting and Validation:

- Document and validate the ore reserve estimate in accordance with international reporting standards such as JORC or NI 43-101.
- Engineering surveying ensures that all spatial data is accurate and verifiable, while GIS aids in producing maps and visual representations for reporting. Validation checks, including peer reviews, ensure the accuracy and reliability of the reserve estimate.

6.6.11 Volume Calculation (for Simple Geometry)

- **Rectangular Block Volume:**

  $V = L \times W \times H$

  - V = Volume (m^3)
  - L = Length of the ore body (m)
  - W = Width of the ore body (m)

  - H = Height or thickness of the ore body (m)

- **Triangular Prism Volume:**

  $V = 1/2 \times b \times h \times L$

  - V = Volume (m³)
  - b = Base width of the triangle (m)
  - h = Height of the triangle (m)
  - L = Length of the ore body (m)

- **Cylindrical Shape Volume:**

  $V = \pi \times r^2 \times h$

  - V = Volume (m³)
  - r = Radius of the base (m)
  - h = Height or thickness of the ore body (m)

6.6.12 Tonnage Calculation

- **General Formula:** Tonnage = V×Density
  - Tonnage = Ore mass (tonnes)
  - V = Volume of the ore body (m³)
  - Density = Density of the ore (tonnes/m³)

6.6.13 Grade Calculation

- **Average Grade Calculation (Weighted Average):**

  Average Grade = ∑(gi×wi)∑wi

  - gi = Grade of the sample i (% or g/tonne)

  - wi = Weight of the sample i (tonnes)

- **Grade of Ore Block (Simple Average):**

  G = ∑gin

  - G = Average grade (% or g/tonne)
  - Gi = Grade of sample i (% or g/tonne)
  - n = Number of samples

6.6.14 Ore Reserve Calculation

- **Ore Reserve (Using Cut-off Grade):**

  Ore Reserve = Tonnage × Recovery Factor

  - Ore Reserve = Economically extractable ore (tonnes)
  - Tonnage = Total ore mass above the cut-off grade (tonnes)
  - Recovery Factor = Percentage of ore that can be extracted (%)

6.6.15 Metal Content Estimation

- **Contained Metal:**

  Contained Metal = Tonnage × Grade

  - Contained Metal = Amount of metal within the ore body (tonnes or kilograms)
  - Grade = Average grade of the ore (e.g., % or g/tonne)

6.6.16 Dilution and Recovery Adjustments

- **Diluted Ore Tonnage:**

Diluted Tonnage = Tonnage × (1+Dilution Factor)

  - Diluted Tonnage = Adjusted ore tonnage considering dilution (tonnes)

  - Dilution Factor = Fraction of waste included in the ore (e.g., 0.1 for 10%)

- **Recoverable Ore:**

Recoverable Ore = Diluted Tonnage × Recovery Factor

  - Recovery Factor = Share of ore that can be recovered during processing (%)

These equations form the basis for estimating the quantity and quality of ore in a mining project, supporting decisions on its economic feasibility.

6.7 Maps and GIS Application in Mining Surveys

For a comprehensive description, map is redefined in this module as a selective abstraction of real objects over a given time period on a chosen surface to scale using a standard mathematical reference model of the Earth which, for the Earth's portion being represented, best preserves the key features of interest: size, shape, direction, or distance.

The emergence of automated cartography and Geographic Information Systems (GIS) has significantly enhanced and streamlined the process of creating digital maps. Despite the ongoing geospatial data-driven digital revolution, adherence to cartographic standards remains crucial and indispensable. Maps designed to inform mining decisions must comply with the fundamental standards, including:

i. Title – It is advisable to concisely convey the overarching message of a map through an appropriate title.
ii. Scale – Consistently indicate the map scale, ideally in the form of a scale bar, to maintain proportionality across varying display and print sizes.
iii. Coordinate system – Provide information about the coordinate referencing system employed, whether geographic (spherical coordinates) or projected (linear/Cartesian or rectangular coordinates – more amenable to Euclidean geometry, algebra, and calculus).

iv. Map projection – When the Earth's curved surface is projected onto a plane, cylinder, or cone, specify the map projection used, such as the Universal Transverse Mercator (UTM) and its corresponding zone.

v. Orientation – Indicate the North direction by selecting a suitable North arrow from the GIS software's gallery.

vi. Legend – This crucial component serves as a guide to the map's elements, represented by various lines, symbols, and shades, among other features.

6.7.1 Key types of maps used in mining surveys

Geological maps and **geophysical maps** are two main types of maps used to study subsurface features. Geological maps and geophysical maps both provide essential information about the Earth's subsurface, but they differ in their objectives, data sources, and presentation.

Geological maps are used for a variety of applications in mining and natural resource management. While geological maps provide information about the composition, structure, and age of rock and sediment layers, geophysical maps are used to measure and map variations in the physical properties of rocks and sediment layers. Geological maps provide information about the location and type of ore and mineral deposits, geological structures, and fault lines. Geological maps are also used for geological hazard mapping and for planning underground construction projects.

Geophysical maps are used to identify subsurface features and to infer the composition and structure of the subsurface. They are used in the oil and gas industry to identify potential drilling sites and in mineral exploration to identify potential ore and mineral deposits. Geophysical maps are also used in environmental studies to identify possible sources of groundwater contamination and in engineering studies to identify potential sites for underground construction projects.

In summary, in Table 5-2 is a tabular comparison between the two types of maps.

Table 6-2: *Comparison of geological and geophysical maps*

Aspect	**Geological Maps**	**Geophysical Maps**
Purpose	Display rock types, structures, geological history, and identify resources, hazards, and features	Investigate subsurface properties and structures, identify mineral, energy and groundwater resources, and aid in environmental assessment and hazard mitigation
Data Sources	Field observations, rock sampling, drilling, laboratory analysis (texture, mineralogy, age), aerial photography	Airborne or ground-based surveys (magnetometry, gravity, seismic, electromagnetic induction, ground-penetrating radar)
Representation	Colours, symbols, lines, and annotations	Contours, colour gradients, or grid values
Scale	Various scales, from outcrop to basin or regional scales	Various scales, from regional to national or global scales
Types	Bedrock, surficial, structural, stratigraphic, tectonic, thematic maps, cross-sections, diagrams	Magnetic, gravity, seismic, electromagnetic, radar maps, and other physical parameters (resistivity, conductivity, density)
Key Features	Rock units, contacts, faults, folds, stratigraphy	Anomalies, interfaces, structures, isopachs, isochrons

Interpretation	Geological knowledge, field experience, lab data analysis: Requires interpretation of field and laboratory data to infer the geologic history and processes that have shaped the landscape, which can be affected by factors such as age, deformation, erosion, and deposition	Geophysical knowledge, data processing techniques, and integration of multiple datasets: Requires integration and modelling of multiple datasets to infer subsurface features and properties, which can be affected by factors such as depth, resolution, noise, and geologic complexity
Applications	Mineral exploration, civil engineering, land use planning, groundwater resources, education, research	Oil and gas exploration, mineral exploration, earthquake studies, archaeology, groundwater management, geohazard mitigation
Primary Users	Geologists, engineers, urban planners	Geophysicists, geologists, engineers

6.7.2 GIS application in mining

A GIS application is an automated process that generates a spatially oriented product or result needed by a user. GIS applications may include map update or map production, data query and display, spatial analysis, or other processes that use GIS software and geographic data (Ogaja, Adero, & Koome, 2023, p. 149).

There is a significant role of GIS in the mining industry, through offering valuable insights and tools for informed decision-making, resource management, and environmental protection. GIS technology is central to multicriteria analysis, hence to the implementation of modern multicriteria spatial decision support systems (MCDSS). The key areas of GIS application in mining can be summarised as follows:

i. **Mineral exploration:** Identifying and mapping mineral resources using geological and geophysical data to guide exploration activities and target potential deposits.

ii. **Geological mapping:** Integrating and visualising geological information, such as rock types, structures, and geological history, to better understand the geology of a mining area.

iii. **Geophysical mapping:** Analysing and displaying geophysical data to reveal subsurface properties and structures, such as anomalies, interfaces, and potential resource deposits.

iv. **Spatial analysis:** Conducting spatial analyses to determine the relationships between geological, geophysical, and other spatial data for informed decision-making. Proximity of mines to critical ecosystems, which need to be protected, is easily carried out using GIS. Area calculations are executed with ease using GIS, based on a projected coordinate system, such as UTM.

v. **Resource estimation:** Estimating the size, quality, and distribution of mineral resources in a mining area using spatial data and statistical modelling techniques.

vi. **Environmental assessment:** Evaluating the potential environmental impacts of mining activities by analysing spatial data related to land use, hydrology, and ecosystems.

vii. **Geohazard mitigation:** Identifying and monitoring geological hazards, such as landslides, subsidence, and seismic activity, to minimise risks to mining operations and surrounding areas.

viii. **Mine planning and design:** Using GIS tools to design and optimise mining operations, considering factors such as access, infrastructure, waste disposal, and resource extraction.

ix. **Infrastructure and logistics management:** Planning and monitoring the transportation, storage, and processing of extracted resources using spatial data and GIS tools.

x. **Reclamation and closure:** Evaluating and planning the reclamation and closure of mining sites, ensuring the restoration of the environment and land use compatibility.

6.7.3 GIS-based optimisation methods

It is common during construction projects to encounter practical cases that call for geospatially leveraged optimisation techniques. Spatial coordinates, which can be obtained accurately using optical surveying techniques or GNSS surveys, underpin the mathematical models applied to achieve such optimisation goals. In these practical cases, the optimisation calculus takes the form of linear and/or polynomial equations. First derivatives equated to zero give an indication of the optimal metrics that can lead to maximum cost savings.

A relevant illustration on optimisation can be drawn from the reference book for this module, co-authored by Ogaja, C., Adero, N., & Koome. D. (2023): *Project Design for Geomatics Engineers and Surveyors*, 2nd edition. UK: Taylor & Francis Group, CRC Press. Students should refer to pages 20-21 of the book. In this example, cost savings of about USD 10,000 can be realised by applying optimisation calculus based on a rectangular model of the excavation area using a local rectangular coordinate system.

Hint: From the book, the general cost optimisation function with a determination of the variable distance on dry ground, x, is $\mathbf{f(x)=2.7x+4.7((14000-x)^2+9000^2)^{1/2}}$**.** Chain Rule is applied to obtain the first derivative of this equation which, if equated to zero, gives the value of x for which the cost is minimum.

6.8 Post-Mining Responsibility

After mine closure, mining surveys find application in mine rehabilitation, restoration, or reclamation in diverse ways. Each approach may overlap depending on specific project goals, environmental policies, and the end-use vision for the site (Table 6.3).

Table 6-3: *Comparison of geological and geophysical maps*

Term	Definition	Primary Focus	Goals	Key Actions	Nuances and Blends
Mine Rehabilitation	The process of returning a disturbed mining site to a stable, usable state	Stability and safety	Achieve a safe, non-polluting, and stable landscape that minimises further environmental harm	Soil stabilisation, erosion control, recontouring, planting vegetation	Blends with reclamation when aiming for productive post-mining use; may or may not aim to restore the site to its original state
Mine Restoration	The process of restoring the site to its original ecological condition or close to it	Biodiversity and ecosystem restoration	Re-establish natural ecosystems, biodiversity, and native species	Reintroduction of native plants and animals, water quality improvements, habitat restoration	Emphasises ecological integrity; may blend with rehabilitation if it includes stabilising actions; differs from reclamation as it aims for ecological authenticity
Mine Reclamation	The act of repurposing a mined site for other beneficial uses, such as agriculture, recreation, or development	Productive land use and community benefits	Convert the site to a usable state that serves alternative purposes, enhancing local economy or community benefits	Conversion for agricultural, recreational, or commercial use, recontouring, establishing land cover, sometimes soil amendments	Overlaps with rehabilitation when stabilising the site; may overlap with restoration if intended to mimic natural ecosystems, though it primarily focuses on utility

- **Rehabilitation and Reclamation**: Both aim to **stabilise and repurpose** the land, though reclamation specifically seeks **productive** uses while **rehabilitation focuses on stability and safety**.

- **Rehabilitation and Restoration**: Share some actions (e.g., vegetation planting) but diverge in purpose; restoration aims for **ecological authenticity**, whereas rehabilitation prioritises **stability**.
- **Reclamation and Restoration**: Occasionally blend when the reclaimed land is restored to its original ecosystem; however, reclamation usually prioritises **utility over ecological authenticity**.

6.9 Policy, Legal and Regulatory Aspects in Mining Surveys

Mining rights are tightly linked to sensitive issues and questions around land tenure and the physical environment, hence to land and environmental rights as well. Many studies across the world have established extensive violations of human rights in the mining sector, a key example being the case of Taita Taveta, Kenya, as confirmed in 2016 through a public inquiry led by the Kenya National Commission on Human Rights (KNCHR) and facilitated by researchers and experts from Taita Taveta University (TTU). The inquiry found that the violations were widespread, from land rights, environmental rights, gender rights, children rights, to labour rights. Key to gaining a shared understanding of the extent of such violations of rights and resolving them is the geospatial exactitude obtainable from accurate mining surveys and mapping.

Conducive policies, laws, and regulations are needed to resolve and manage conflicts in the mining sector. Mining surveys provide the spatially explicit metrics and parameters required to accurately allocate, enforce, and monitor land-related mining rights. Maps are generated using GIS techniques based on data from various sources e.g., aerial photogrammetry, laser scanning – both terrestrial laser scanning (TLS) and airborne laser scanning (ALS), satellite imagery, topographical surveys, and cadastral surveys. The maps are used together with the datasets and information needed for sound decision support when administering such crucial matters of land and mining rights, all the way to minimising the negative environmental effects of mining and ensuring adequate rehabilitation after mine closure.

The evolution of mining legislation has realised significant milestones, not least in Africa. Kenya, an East African economic giant, introduced in 2016 a modern mining law that has been referred to as Africa's most progressive mining law. The Mining Act of 2016 specifies how mining rights should be administered based on a digital mining cadastre and units of blocks defined by graticules spaced 15" apart. This Kenyan example confirms the important role of mining surveys and mapping in managing and administering mining activities and mining rights.

The following illustration of a mining block serves as a suitable example on how to translate legal and policy aspects into practice when issuing mining rights or licenses attached to land parcels (Fig. 6.2). ABCD is the **pseudoquadrilateral** representing a mining block. In the Kenya Mining Act of 2016, for example, such a block is bounded by meridians spaced 15 arc seconds apart and parallels spaced 15 arc seconds apart. As shown based on a spherical Earth model, R is the radius of the Earth, estimated to be 6371 km.

Generally:

- **Arc length for AB or CD = (longitude difference, i.e., $\lambda_2 - \lambda_1$ in degrees/360) * $2\pi(R\cos\Phi)$**, where Φ is the latitude (in degrees) of the circle of latitude, along which the longitude difference is measured. Near the equator (OE), RcosΦ is almost equal to unity.

- **Arc length for AD or BC = (latitude difference, i.e., $\varphi_2 - \varphi_1$ in degrees/360) * 2πR**, since all meridians are great circles such that R is the Earth radius always.

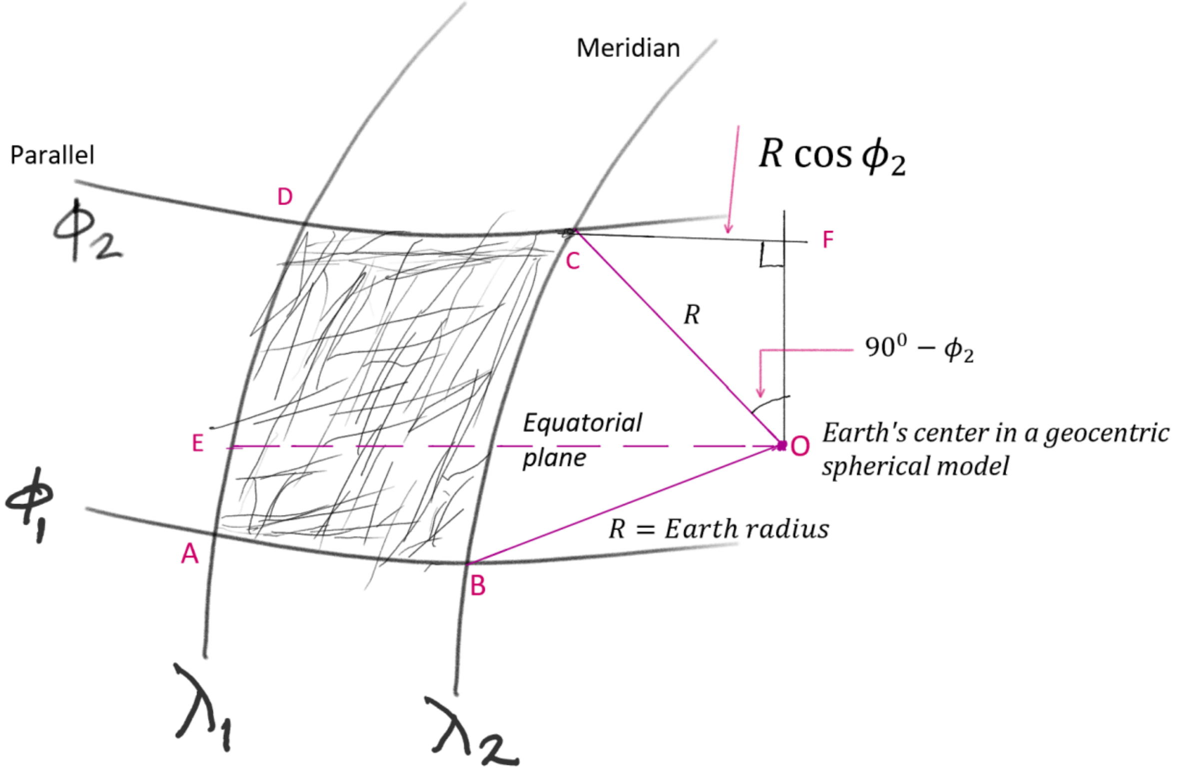

FIGURE 6.2

A pseudoquadrilateral ABCD representing a mining block based on a geocentric spherical model of the Earth

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8. Practice Exercises from Real-World Cases

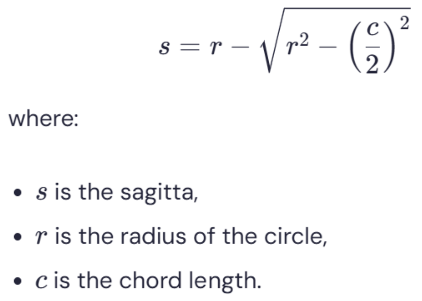
Course participants should attempt the following practice-oriented questions then refer to the recommended solutions later.

8.1 GIS Application Exercise

1. Use GIS software of your choice to make a digital map of the Counties in Kenya to recommended cartographic standards. From a spreadsheet of population data for each county ranging from 1999 to 2019, show a mapped trend in population sizes and population density for any two counties of your choice over that period. Present the mapped data as a layout to be shared as a pdf file. Detail the procedures followed.

2. Zoom in to Taita Taveta University, Kenya, from any digital map service e.g., Google Earth. Sketch a mining block around it bound by 15 arc seconds, as provided for in the Kenya Mining Act of 2016. Prove that the linear dimensions of the sides of the block measure about 460 m. Based on this, deduce the number of mining blocks obtainable from an area of 800 ha.

3. The **sagitta relation** refers to the formula that relates the sagitta (the height of the arc) to the radius of the circle and the chord length. It can be expressed as:



$$s = r - \sqrt{r^2 - \left(\frac{c}{2}\right)^2}$$

where:

- s is the sagitta,
- r is the radius of the circle,
- c is the chord length.

The chord length, c, can be simplified as 2rsin(Θ/2), where Θ is the angle at the centre of the circle.

Construct in GIS software these relations and measure the sagitta to confirm that it matches the expectations of the mathematical formula.
N/B: If c = diameter, then Θ = 180^{o}. Show that s = r in this case.

8.2 Engineering Application Exercise

4. A straight segment of a railway has a design gradient of **0.5 degrees**. You are required to survey from the downstream end at chainage **295 + 125** to the upstream end at chainage **295 + 140**. The upstream level should have a reduced level of **597.000** metres.

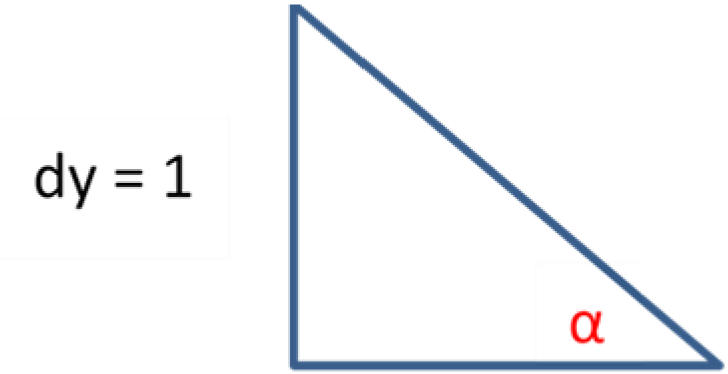
(a) Find **X** if the plan drawing expresses the railway gradient as **1 in X**.

(b) Calculate the correct staff reading at the downstream end if a backsight reading of **3.025** metres has been taken on a TBM whose reduced level is **594.945** metres.

(c) List the survey **instruments, tools** and **accessories** that would be suitable for this exercise, grouping them by functions under horizontal control and vertical control.

Solution

(a)



Making dy equal to UNITY, gradient (slope) = dy/dx = 1/X = tan α, where α = 0.5^0

X = 1/tan 0.5^0 = **114.59** or **115**

Expressed as **1 in 115**

(b) **dx** is calculated as the difference between the chainages = **15 m**

dy = gradient as a (decimal) fraction*dx = tanα*dx = **0.131m**

Downstream level = upstream level – dy = 597.000 – 0.131 = **596.869 m**

Height of Collimation (HI) = RL of X(BM) + staff reading at X(BM) = 594.945 + 3.025 = **597.970 m**

Staff reading downstream = HI – RL downstream = 597.970 – 596.869 = **1.101 m**

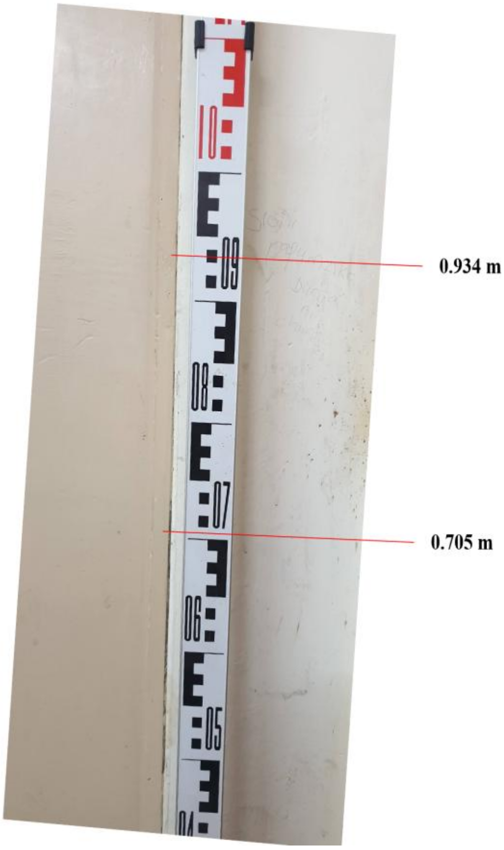
Check: Staff reading upstream = 597.970 – 597.00 = 0.970 m (hence higher than downstream by 1.101 – 0.970 = **0.131 m**…proved).

(c) **Horizontal control**: Instruments can be theodolite, tachymeter/total station, or geodetic GPS. Tools can be a tape measure, ranging rod/pole, or a string. Accessories include a tripod, reflector/prism, or any other visible target.

Vertical control: The most suitable instrument is a level. Tools may include a plumb bob, spirit bubble, tape measure and strings. Accessories include a levelling staff.

5. Make a simplified illustration on how to take readings off a levelling staff. A typical solution is shown below.

Note that a levelling staff is used together with a **level**. It is held vertically on the target point whose height is being measured. There are major graduations of 100 mm, minor graduations of 10 mm forming small blocks, and some of the 50 mm blocks out of the major 100 mm block are joined to form (inverted) **E** patterns.



Levelling staff

(Photo credit: Nashon Adero, Taita Taveta University Survey Lab, 17-09-2022)

6. A surveyor uses a Total Station whose accuracy is specified in the operator's manual as **10 mm + 10 ppm**. The instrument measures a chord length to be 150.030 m where the intersection angle is 60^0 for a curved tunnel of radius, R = 150 m.

   Based on the information above:

   (i) Determine if this Total Station is fit for use on the site

   (ii) Advise the engineers on the action to take based on this finding

Solution

Suitability of the Total Station

(i) Proof

δ = half of intersection angle (**IA**) = 30^0

Theoretical chord length = 2Rsin δ

2(150 m) $\sin 30^0$ = 150.000 m

Standard Deviation, SD, for theoretical chord length = 10 mm + 10*(150.000/1000) mm = 11.500 mm

Rule:

The measurement is acceptable **if:** Observed difference ≤ 2SD

Observed difference = 150.030 m – 150.000 m = 0.030 m = **30 mm**

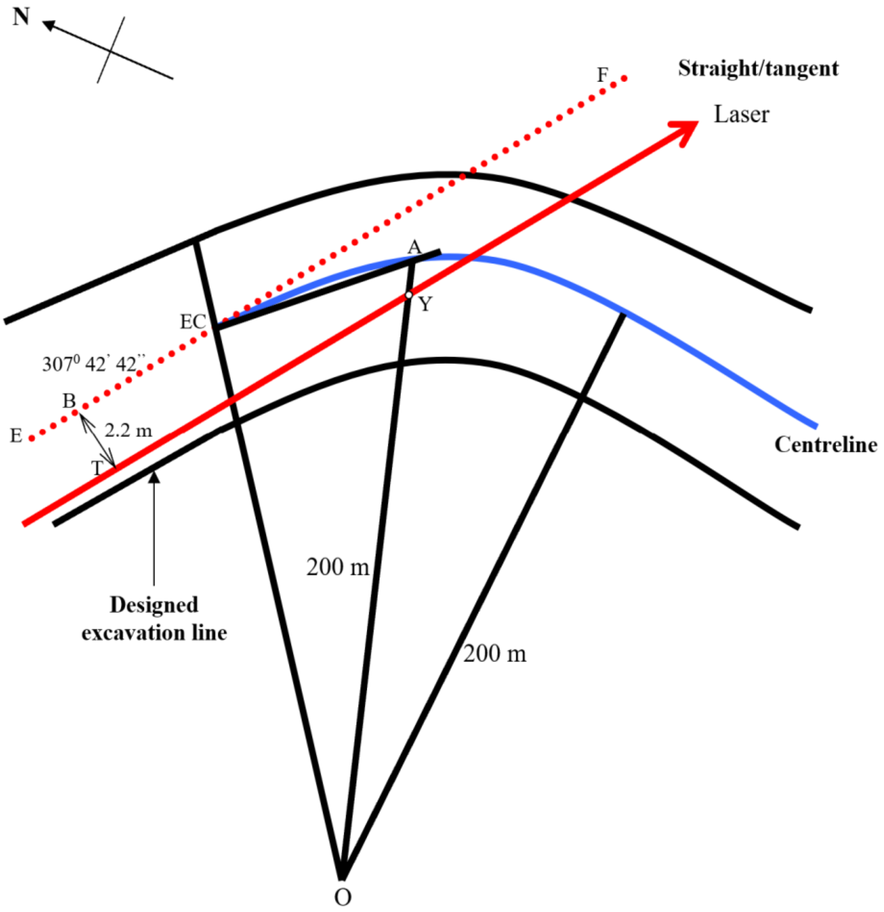
2SD = **23.000 mm**

Observed difference >2SD, hence not acceptable!

(ii) Advice: Replace the instrument or use the instrument after calibration and further verification of accuracy against a known distance.

7. Refer to the diagram below showing the geometry of one curved upstream section of a water tunnel. It is based on the Sondu-Miriu Hydropower project in Kenya. In the curved section of R = 200 m, the engineering surveyors used formwork spans measuring only 3 metres in length, a choice that can be mathematically proven given R = 200 m, because the curve length and chord length for such a short span do not vary significantly, but over several spans the errors can accumulate significantly if not checked. The coordinates of EC are given as (709 390.152 mE, 9 956 751.906 mN) and its chainage is 0+108.442 m. The chainage of point A, on the curve, is 0+109.482 m. Solve for the offset distance AY to the designed

centreline. (**Hint**: To obtain accurate results, the intermediate answers obtained should not be rounded off).



Solution

EF is the straight tangential to the curve at EC. This straight is also the centreline of the adjoining straight section. The laser beam is parallel to the straight EF at a separation distance of 2.2 metres. The centreline of the curved section is as shown.

Task: To determine the offset from the laser beam to the centre of the tunnel at chainage 0+109.482 m, i.e., point A.

Distance from EC to A = chainage of A – chainage of EC = 109.482 – 108.442 = 1.040 m (curve length)

Bearing of A from EC = $307^0\ 42'\ 42'' - 180^0 + \delta$

δ is the tangential angle = (90 x curve length)/(∏R) degrees = (90 x 1.04)/200∏ degrees

∴ Bearing EC $\longrightarrow$ A = $127^0\ 51'\ 38''.2$

Chord length = 2RSinδ = 1.040 m

Coordinates of A

By polar to rectangular computation ($s = 1.040$ m; $\alpha = 127^0\ 51'\ 38''.2$)

$\Delta N = -0.638$ m $\Delta E = +0.821$ m

$N_A = 9\ 956\ 751.268$ m $E_A = 709\ 390.973$ m

Coordinates of O (centre of curve)

EC $\longrightarrow$ O

By polar to rectangular computation ($s = 200$m; $\alpha = 217^0\ 42'\ 42''$)

$\Delta N = -158.220$ m $\Delta E = -122.338$ m

$N_O = 9\ 956\ 593.686$ m $E_O = 709\ 267.814$ m

Determining equation of the radius A $\longrightarrow$ O

Using coordinates of A and O

Gradient (m) = $\Delta E/\Delta N = 0.782$

$E = mN + c$ (equation of a straight line in rectangular coordinates)

$\therefore\ c = E - mN = -7\ 072\ 363.763$

$E = 0.782N - 7\ 072\ 363.763$---------------------------(i)

Determining equation of the laser beam

m = gradient of the tangent EF (parallel to the beam)

Taking any other point on the line EF, say B at 100 m from EC, so that

$s = 100$ m and $\alpha = 307^0\ 42'\ 42''$

By polar to rectangular computation ($s = 100$ m and $\alpha = 307^0\ 42'\ 42''$)

$\Delta N = +61.169$ m $\Delta E = -79.110$ m

$m = \Delta E/\Delta N = -1.293$

Coordinates of T (2.2 m perpendicular to B)

By polar to rectangular computation ($s = 2.2$m; $\alpha = 217^0\ 42'\ 42''$)

$\Delta N = -1.740$ m $\Delta E = -1.346$ m

$N_T = N_{EC} + 61.169 - 1.740 = 9\ 956\ 811.334$ m

$E_T = E_{EC} - 79.110 - 1.346 = 709\ 309.696$ m

$c = E - mN = 13\ 586\ 498.196$

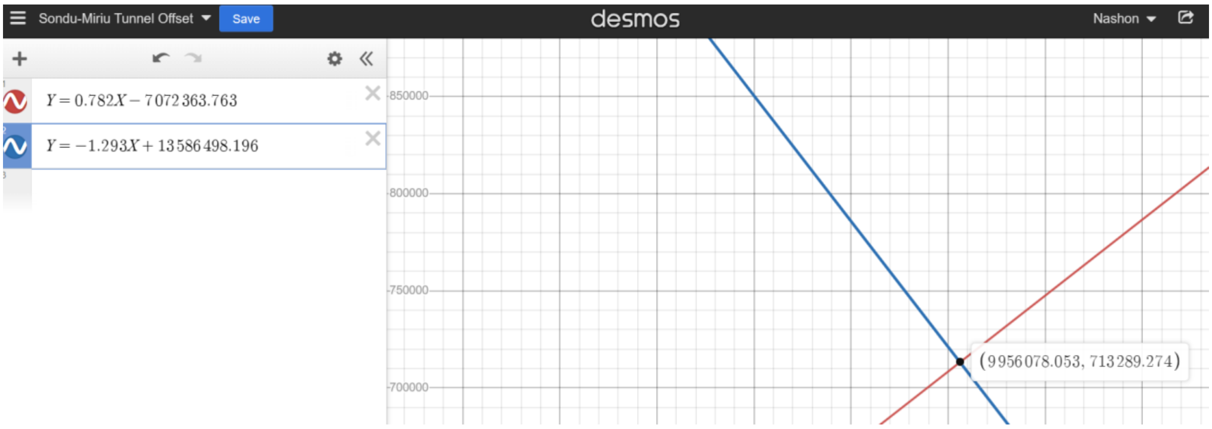
$E = -1.293N + 13\ 586\ 498.196$------------------------(ii)

Solving the two equations (i) and (ii) simultaneously, coordinates of the intersection point Y are obtained as:

N_Y = 9 956 078.053 m

E_Y = 713 289.274 m

The graphical solution using Desmos open and advanced graphical calculator gives the solution much faster and conveniently at the intersection of the two lines as shown below.



$Y = 0.782X - 7\,072\,363.763$

$Y = -1.293X + 13\,586\,498.196$

$(9\,956\,078.053,\ 713\,289.274)$

Using A and Y coordinates and rectangular to polar computation, Y → A becomes $37^0\ 59'\ 46''$ @ 2.197 m.

∴ Offset YA = 2.197sin (α laser beam - α YA) = 2.197 m

N/B: Because the figures presented have been rounded off, some of them look the same though they are different. The surveyor must take this fact seriously and use the figures as computed and stored in a calculator or computer so as to avoid the accumulation of systematic errors in such sensitive tunnel surveys. Regular checks after several metres are necessary during construction in order to contain such errors.

8. When assessing the relationship between angular and linear precisions of optical survey instruments, the sighting distance is critical. Illustrate mathematically how the angular and linear dimensions relate. Hence, show how the following

relationships between the angular precision of an instrument and the linear tolerance come about.

(**Hint**: Consider how the arc length of a circle (linear tolerance) is mathematically related to the angle it subtends at the centre for a given radius, **r**).

i. 20” is equivalent to 10 mm at a sighting distance of 100 m

ii. 10” is equivalent to 5 mm at a sighting distance of 100 m

iii. 5” is equivalent to 2.5 mm at a sighting distance of 100 m

iv. 1” is equivalent to 0.5 mm at a sighting distance of 100 m

Also show that if 5 mm tolerance has been specified for site work up to a distance of 100 m, a 10” theodolite (or total station) would be suitable. By simple proportion, show that if 5 mm tolerance has been specified but the maximum distance to be set out is 50 m, a 20” instrument is sufficient.

9. For a straight 60-metre-long section of the Northern Collector Tunnel from Murang’a to Thika in Kenya, a design gradient of 1 in 55 has been specified. The downstream chainage is 0+095 and the chainage values are increasing upstream.

   a) Determine the chainage for the upstream end of this section

   b) If a surveyor has observed a backsight of **1.509 m** at the Benchmark whose Reduced Level is **1,799.162 m** and given that the Benchmark is **0.582 m** higher than the invert level at the downstream end of this section, determine:
      i. The invert level of the upstream end
      ii. The staff reading at the upstream end from the same instrument station

   c) If the tunnel is to be concrete-lined using a **15-metre**-long formwork/shutter beginning from the chainage **0+095**, calculate the chainage and the correct staff reading from the same instrument station expected at the downstream invert level of the third (3rd) formwork/shutter from this chainage.

Solution

a) 60 m + 95 m = 155 m, hence **0+155**

b) (i) Reduced Level of downstream end = 1799.162m – 0.582m = **1798.580 m**

dy/dx = 1/55, but dx = 60m for upstream end

dy = 60 m/55 = 1.091m (height difference from downstream)

Upstream level = 1.091 m +1798.580 m = 1799.671 m

(ii) Height of Collimation = RL at BM + BS = 1799.162 + 1.509 = 1800.671 m

Staff reading upstream = Height of Collimation – RL upstream Height of Collimation = 1800.671 m – 1799.671 m = **1.000 m**

c) Due to continuity, the downstream position of the 3rd shutter = upstream position of the 2nd shutter **= 30 m slope distance** from the starting point. Horizontal Equivalent (dx) = 30 cos((tan^{-1}(1/55)) = **29.995 m**.

Chainage = 0+ 095 +29.995 m = 0+124.995 (rounded off to **0+125**)

dy = 30 sin(tan^{-1}(1/55) = **0.545 m**

Staff reading downstream of 3rd shutter = Staff reading at chainage 0+095, i.e., (1800.671 - 1798.580) – 0.545 = **1.546 m**

10. A tunnel section of the Sondu-Miriu Hydropower Project has a designed slope of 1 in 300.5. The chainage 0+000m is reckoned to be at the junction of Adit 1 and the main tunnel leading from intake facilities to the power station. Blinding levels are to be indicated at 2 m intervals upstream from chainage 0+100 m to 0+110 m. The designed invert level of the final concrete lining at chainage 0+000 is 1386.208 m, and the level of blinding is designed to be 300 mm below the invert level. Using this information, compute the data for setting out the levels. Assume that a level has been set up so that the backsight to a TBM whose reduced level (RL) is1387.200 m reads 0.301 m.

Solution

Height of collimation (HI) = 1387.200 + 0.301 = 1387.501 m
Blinding level at 0+000 = 1386.208 – 0.300 = 1385.908 m
dy = slope x distance
∴ blinding level at 0+100 m = 1385.908 + 100/300.5
= 1386.241m

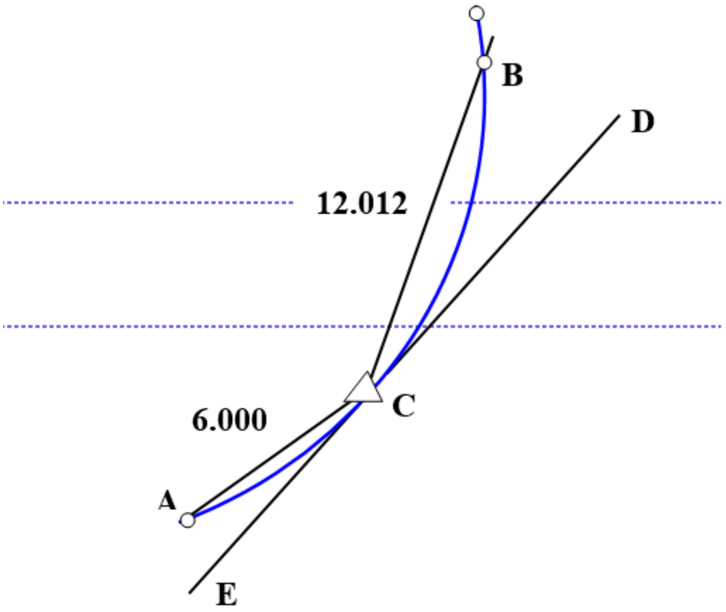
Grade staff reading at 0+100 m = HI – 1386.241 = 1.260 m

Calculating the rest similarly gives the following setting out data for blinding levels:

Chainage (m)	Blinding level (m)	HI (m)	Grade staff reading (m)
0+000	1385.908	1387.501	
0+100	1386.241		1.260
0+102	1386.247		1.254
0+104	1386.254		1.247
0+106	1386.261		1.240
0+108	1386.267		1.234
0+110	1386.274		1.227

11. A curved tunnel section is to be constructed to have a gradient of 1 in 300.5 and interior diameter of 4.200 m. The radius of the curve is 200 m. Concrete lining is to be placed at 3 m intervals with the help of a lining shutter of length 3 m. The shutter is positioned so that its downstream end is at the beginning of the curve, A, chainage 0+260 m. The spring level at chainage 0+000 m in the adjoining straight section is designed to be 1377.769 m. A total station is set up at 12.012 m from the upstream end, B, of the shutter and 6.000 m from point A along the centreline. A level machine has been set up to attain a height of collimation (HI) = 1376.833 m. As the surveyor in charge of this construction, you are required to perform all the essential measurements to set out the vertical alignment using readings off an inverted tape and related horizontal alignment too. Show your work.

Solution



As shown in the sketch above, the upstream end of the shutter is at point B. ED is tangential to the curve at the instrument station, C. The curve defines the centreline of the curved tunnel.

Vertical alignment

Chainage of upstream end is 0+263 m (curve length practically equal to chord length for 3 m interval given R = 200 m)

dy = 1/300.5 x 263 m

Spring level at 0+263m = 1377.769 + dy
= 1378.644 m

Zenith level upstream = 1378.644 + 2.1 = 1380.744 m.

Similarly, zenith level downstream = 1/300.5 x 260 + 1377.769 + 2.1
= 1380.734 m

After balancing the sides, the tape readings for setting out the correct zenith/summit levels upstream and downstream are:

Downstream: 1376.833 – 1380.734 = **- 3.901m**

Upstream: 1376.833 – 1380.744 = **- 3.911m**

Using adjustment screws, the zenith levels downstream and upstream are adjusted until the inverted tape readings above are obtained. The diameter of 4.200 m is then set out along the vertical axis and horizontal axis to achieve a perfect circular shape.

Horizontal alignment

Calculating the tangential angles ACE and BCD,

Angle ACE = $\sin^{-1}$ (chord length/2R) = $\sin^{-1}$ (6.000/2R) = $00^0\ 51'\ 34''$

Angle BCD = $\sin^{-1}$ (chord length/2R) = $\sin^{-1}$ (12.012/2R) = $01^0\ 43'\ 15''$

Angle ACB (Obtuse) = **$177^0\ 25'\ 10''$**

If the horizontal angle reading to A is set to $00^0\ 00'\ 00''$, then the horizontal angle reading to be set when aligning the upstream end is **$177^0\ 25'\ 10''$**. The lining shutter is then adjusted sideways until the tip of a plumb bob hung from its zenith at this end coincides with the cross hairs at this reading.

Curve length CB = **δ∏R/90** = 12.014 m.

Now, considering that a chord length of 3 m equals to a curve length of 3 m to the millimetre accuracy required in this case with R = 200 m, the curve length from C to the required position of downstream end of the 3-metre-long shutter is 15.014 m.

Given curve length = 15.014m

Then corresponding chord length = 2Rsinδ

$$= 400\sin[(90 \text{ x}15.014)/\Pi R\,] = 15.010\text{m}$$

Thus, the reading for aligning the downstream end becomes:

$180^0 - \sin^{-1}(6.000/400) - \sin^{-1}(15.010/400) = \mathbf{176^0\,59'\,24''}$

12. The reduced level (RL) for a point on the roof of a tunnel is supposed to be 900.000 metres. A surveyor takes a backsight reading of 1.100 metres to a temporary benchmark in the tunnel whose elevation is 897.000 metres. From the same instrument station, determine the correct staff reading you expect at the tunnel roof.

Solution

Using the Height of Collimation (HI) Method and let any unknown staff reading be X:

HI = BS + RL of the Benchmark = 1.100 m + 897.000 m = 898.100 m

- Subtract any other staff readings from the HI for the same instrument station to obtain the levels of the other points
- 898.100 m – X = 900.000 m
- X = - 1.900 m (the negative sign here means the staff is inverted)

The instrument station **above** is changed to a new location **Y,** and a new backsight reading of **–1.800** metres taken on the staff held onto the same monitoring point. Determine the new staff reading the surveyor should expect at a point **Z** on the tunnel floor which is designed to have a reduced level of **896.000** metres.

Get a new HI because the instrument has been moved to a new point, following a Change Point (CP).

- HI = BS + RL = -1.800 m + 900.000 m = 898.200 m
- 898.200 m – X = 896.000 m

X = 2.200 m (note this positive value means the staff is held vertically upwards onto the point on the floor in a normal aspect, not inverted).