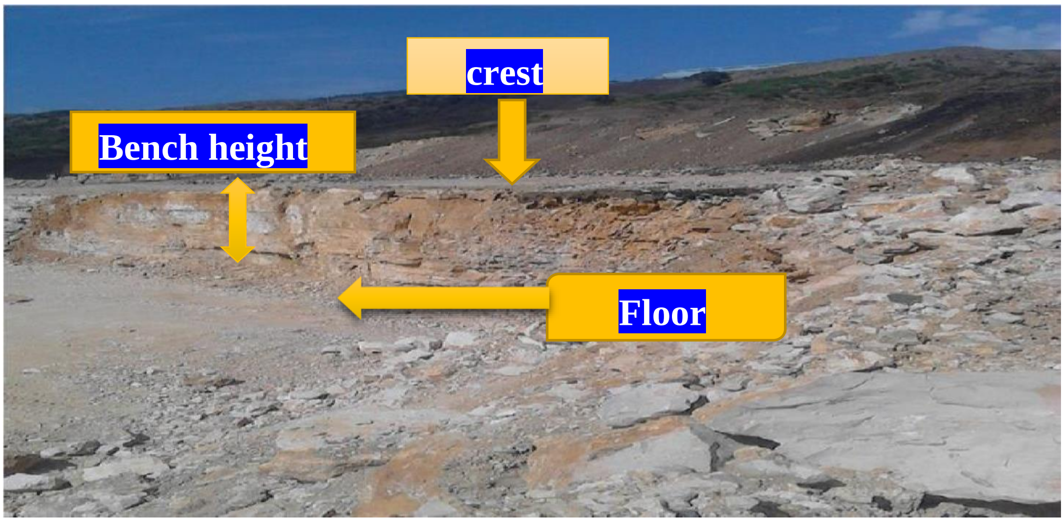
ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

EVALUATION OF LIMESTONE QUARRY QUALITY, PLANNING AND SLOPE DESIGN IN DANGOTE LIMETONE QUARRY, MUGHER AREA



A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN MINING GEOLOGY

BY: BELAY AMBERBER

ADVISOR: DR. WORASH GETANEH

CO ADVISOR: DR. TARUN K. RAGHUVANSHI

Jun, 2018

Addis Ababa, Ethiopia

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

EVALUATION OF LIMESTONE QUARRY QUALITY, PLANNING AND SLOPE DESIGN IN DANGOTE LIMETONE QUARRY, MUGHER AREA

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN MINING GEOLOGY

By: BELAY AMBERBER

ADVISOR: DR. WORASH GETANEH

CO- ADVISOR: DR. TARUN K. RAGHUVANSHI

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

EVALUATION OF LIMESTONE QUARRY QUALITY, PLANNING AND SLOPE DESIGN IN DANGOTE LIMETONE QUARRY, MUGHEER AREA

By: BELAY AMBERBER

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF EART SCIENCE

APPROVED BY BOARD OF EXAMINER

Name	Signature
DR. TIRUFAT WOLDEMARIAM	----------------------------
Chairman:	
DR. WORASH GETANEH	---------------------------
Advisor	
DR. TARUN K. RAGHUVANSHI	--------------------------
Co – Advisor:	
DR. TIRUFAT WOLDEMARIAM	----------------------------
Internal Examiner:	
DR. DANIEL	-------------------------------
External Examiner:	

DECLARATION

I the undersigned declare that this thesis is my original work and has not been presented for any degree in any university, and all the sources of materials used for the thesis have been duly acknowledged.

Name: Belay Amberber

Signature: ______________________

This Thesis has been submitted for examination with my approval as university advisor and co-advisor

Name	Signature
Dr. Worash Getaneh (Advisor)	____________________
Dr. Tarun K. Raghuvanshi (co-advisor)	____________________

Date and place of submission:

JUN, 2018

Addis Ababa University

ABSTRACT

The study area is found in western Ethiopia in Oromia Region State Mugher area. It is covered by mostly sedimentary and few volcanic rocks. In open pit mining method most of the time the excavation process is mostly so random that it has its own impact on the quality and excavation time. Because of the random excavation process the limestone is mixed with quaternary basalt and large amount of overburden. And also some large limestone boulders affect the working area of logistics. Such problems can be solved by designing the slope stability of the site. Apart from this problem the quality of the limestone is one of the important factor to be considered. It's based on these classification the possible industrial usage of the limestone is made.

Thus the main objective of the research is to evaluate limestone quarry planning and slope design. Moreover, the research aims to make safe cut slope design and determine quality of rocks for different field of application. To achieve the research objectives, collecting samples of rocks, RMR data, were done based on lithology, color, and structure and area coverage of each exposed section collected from the mining places for slope design and quality evaluation. The data were treated with the help of Rocscience.RocPlane.v2.029 software for determine possible mode failure. Furthermore the slope design of the quarry site was done based on Datamine studio 3.21 software.

The average result of RMR determination the result lays under fair rock mass classification (50 – 60%). According to the field data, it's possible to conclude that all the joint sets could not affect the stability of the Dangote limestone quarry excavation. The simulation result shows that there is no possible mode of failure in every critical slope sections. Since the large amount of ore body is indicated from the northwest direction, the sequential direction of excavation have to start along northwest direction for the long term quarry planning and cost effectiveness.

The average value of each major oxide mineral of rock from XRF results are: CaO $<$ 47.6wt. %, MgO $>$ 3wt. %, SiO_2 $>$ 2wt. %, Fe_2O_3 $>$ 1wt%. Hence, according to BGS standard classification it lies under impurity limestone. Therefore, it used for Mineral wool and natural cements on (subject to the silica/clay mineral ratio).

Keyword: Slope design, RMR, Limestone quarry, Kinematic analysis, XRF, Open Pit

ACKNOWLEDGEMENT

I am extremely grateful to my advisors Dr. Worash Getaneh and Dr. Tarun K. Raghuvanshi for their relentless, genuine and constructive comments and advice which was played a pivotal role for the success of this study. And also, I would like to thanks Woldia University for giving me this chance without their sponsor I will not been here.

I would like to thanks the various institutions that provided me all the necessary data when I'm in need. These institutions include: Addis Ababa University, Ministry of Mines Petroleum, Natural gas, Dangote Cement industries.

My deepest gratitude goes to my friends, Engineer Tesfaye Meseret, Tilahun W/Mariam and Biruk Mitiku for their unreserved encouragement and support in editing the research work. My deepest gratitude also goes to W/o Meseret Belayehun and her family for printing this research paper and for her moral support. Last but not least, the greatest thanks also goes to my mother W/o Wonzie Tarekegn, my father Amberber Degefu, and my sisters Sara, Ababa and Almaze Amberber for their unreserved encouragement and patience, follow up which enabled me to accomplish this work.

Table of Contents

List of Tables

List of Figures

List of Appendix

List of Acronyms

BGS	British Geological Survey
EIGS	Ethiopian Institute of Geological Survey
ERDAS	Earth Resources Data Analysis System
ESAP	Ethiopian Society of Animal Production
GPS	Global Positioning System
GSE	Geological Survey of Ethiopia
ISRM	International Society of Rock Mechanics
MME	Ministry Mines of Ethiopia
OPC	Ordinary Portland Cement
PPC	Portland Pozzolana Cement
RMR	Rock Mass Rating
RQD	Rock Quality Designation
UCS	Uniaxial Compression Stress
XRF	X-Ray Florescent

1. INTRODUCTION

1.1 Background

Mugher valley is part of Blue Nile Basin situated in the Northwestern Ethiopian Plateau. The E and SE part of the area is bounded by the tectonic escarpment of the uplifted western flank of the Main Ethiopian Rift. It is also bounded by the Axum–Adigrat and Ambo-Nekemte lineaments to N and S directions respectively. The Blue Nile Basin contains about 1400m thick section of Mesozoic sedimentary rocks that un-conformably overlying Neo-Proterozoic basement rocks and un-conformably overlain by Early-Late Oligocene and Quaternary volcanic rocks (Gani et.al, 2008).

There are Over 100,000 square kilometer of carbonate rocks are exposed in Ethiopia but very little is known about the active mining site within the deposit. In Ethiopia extensive limestone beds are exposed in three regions: the Mekelle outlier in the North (Tigray), the Blue Nile Basin in Northwestern Ethiopia, and the Ogaden Basin (Asfawossen Asrat, 2015).

According to Gumerov and Aklilu Asefa (1981) and Tibebu Mengiste et al.,(1993) as cited in Solomon Tadesse et al., (2003) the limestone deposits vary from pure limestone through magnesium limestone to dolomites. Enormous, un-estimated quantities of limestone are available in Ethiopia. In Ethiopia reserves of limestone is well-explored for production of cement in the Mugher valley and Dire Dawa are estimated to be over 100 and 4.6 million tones, respectively (EIGS, 1989).

1.2 Location and Accessibility

The area is bounded by geographical coordinate latitude 9˚15’00”N to 9˚30’00” N and 38˚20’00”E to 38˚30’00”E, in the Northwestern Ethiopian Plateau. The area falls within topographic sheet covering the northern portion of “Inchini” and southern portion of “Minare” sub-sheet. The project area is accessible by asphalt road leading to Mugher cement enterprise, via Mugher town, about 90 Km west from Addis Ababa. Mugher town is the nearest town situated approximately 5 Km south of the Mugher enterprise. From the factory about 7 Km all-weather road, constructed by the enterprise, leads to the northern part of the area and to the quarry site.

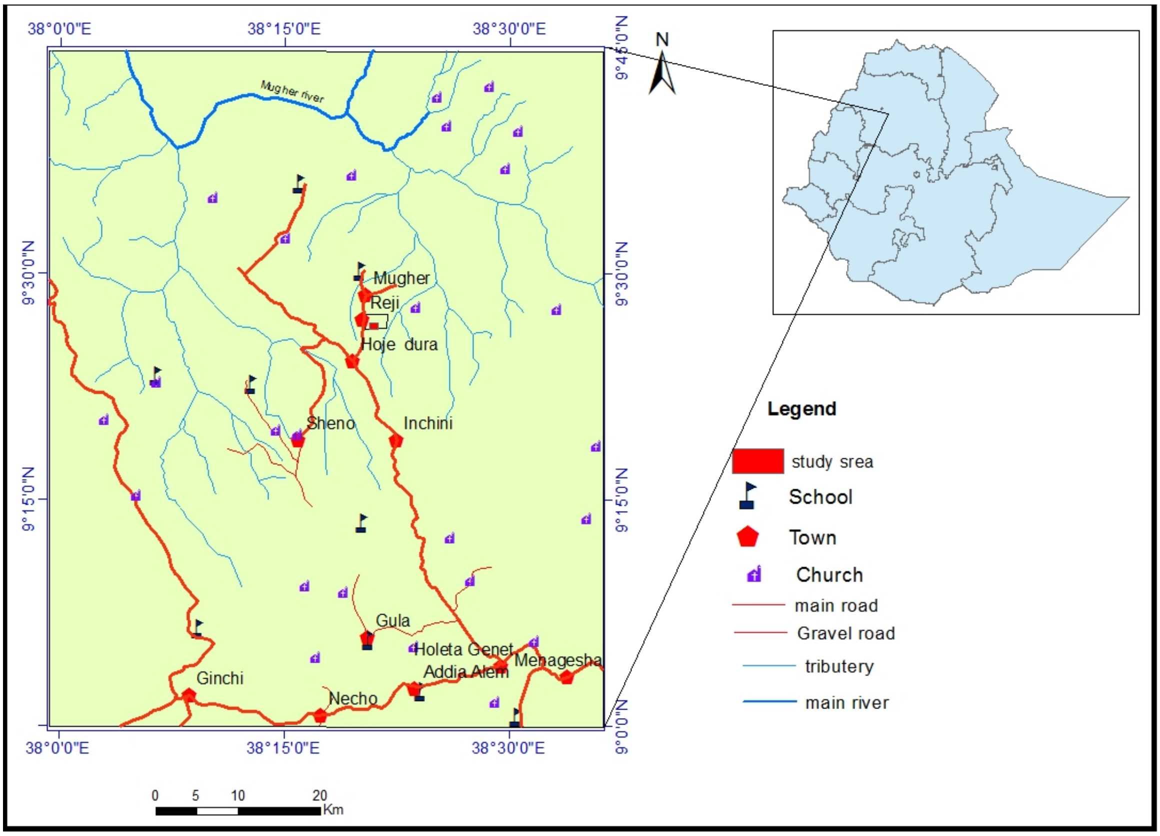


Figure 1-1: location map of the study area

1.3 Climate

Study area falls under sub-tropical climatic zone with the highest rainfall occur between June and September (ESAP, 2007). Another smaller rainy season is also known between February and May, however, in the study area rainfall amount is generally low. Two rainy seasons are known in the area those are summer and winter.

Table 1-1: The mean annual rainfall of the surrounding area

Month	Jan	Feb	Mar	Apr	May	Jun	July		Aug	Sept	Oct	Nov	Dec
Addis Ababa	15.5	38	66.8	89.4	83.0	130.7	259.5		276.5	170.9	36.5	7.9	9.5
Chancho	28.5	24	61.6	61.0	61.0	133	133.2		321.8	125.3	38.1	13.3	13.5
Derba	14.2	31	62.2	64.1	122	119.8	307.9		320.1	159.0	27.8	9.5	16.2
Holeta	23	57	74	95	76	162	287		332	206	22	14	12

Mean annual rainfall around the study area is 100.2mm (Table 1.1) and the maximum and minimum temperature ranges from 17°C to 9°C (Table 1.2), respectively ESAP (2007).

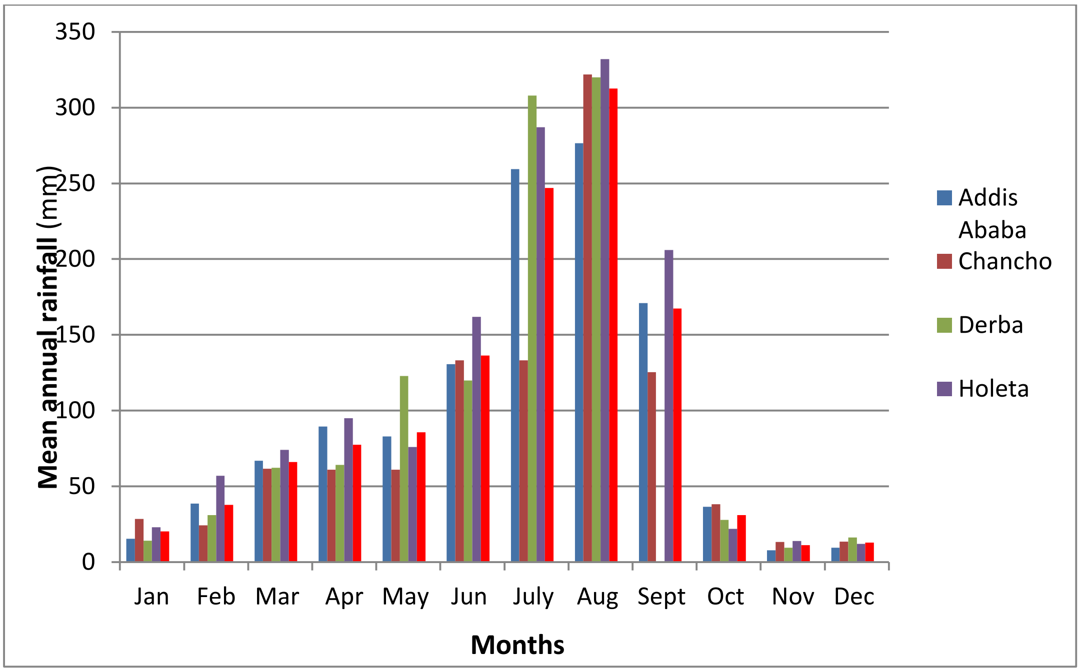


Figure 1-2: Mean annual rainfall around the study area

Table 1-2: Mean annual Temperature of surrounding the study area

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Fitche	3.54	14.39	15.10	15.24	15.09	15.08	13.7	13.08	13.50	12.74	12.67	13.21
Holeta	16.0	16.7	17.5	17.6	17.7	16.5	15.9	15.3	15.0	14.7	16.2	14.9

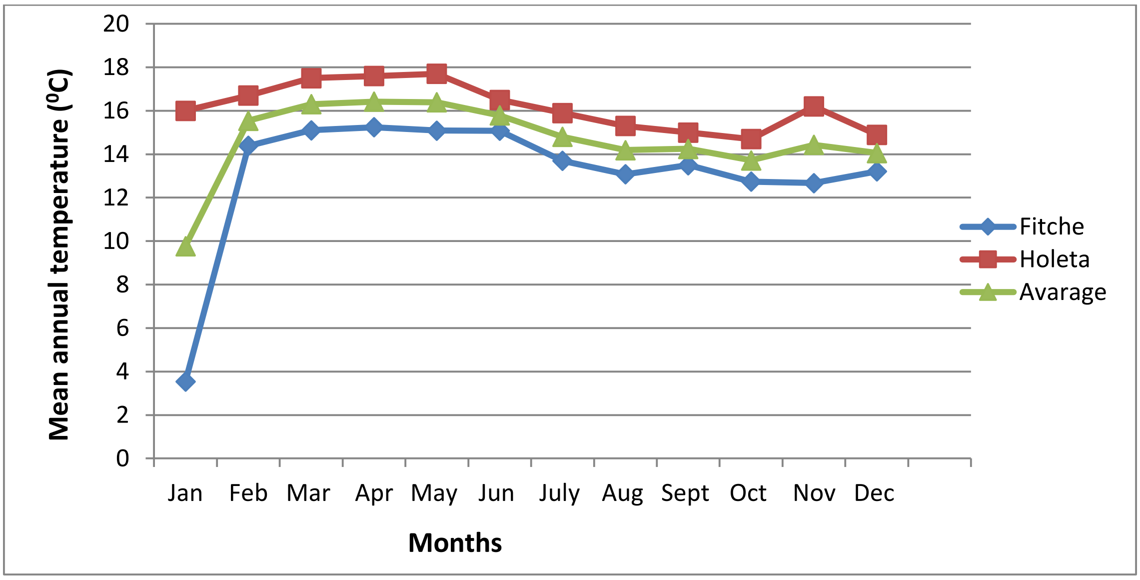


Figure 1-3: Mean annual temperature around the study area

1.4 Physiography

Study area varies in altitudes, from 1300 m in the North at the river bed of Sodoble to 2900 m in the South. Morphologically, the terrain is linear steep ridge to gently and moderately rugged topography. Abrupt changes in elevation are related to lithology and geological structure. The area is part of the Northwestern highlands in the western part of the Blue Nile Basin, characterized by gorges and deeply cut valleys. Sharp escarpments of the Tertiary basalt are typical throughout the study area particularly towards the limestone contact. The study area is drained by few perennial streams, which are collectively flowing to Sodoble River. Mainly the drainage pattern within the volcanic rock is dominated by dendritic pattern whereas the sedimentary section is dominated by parallel pattern.

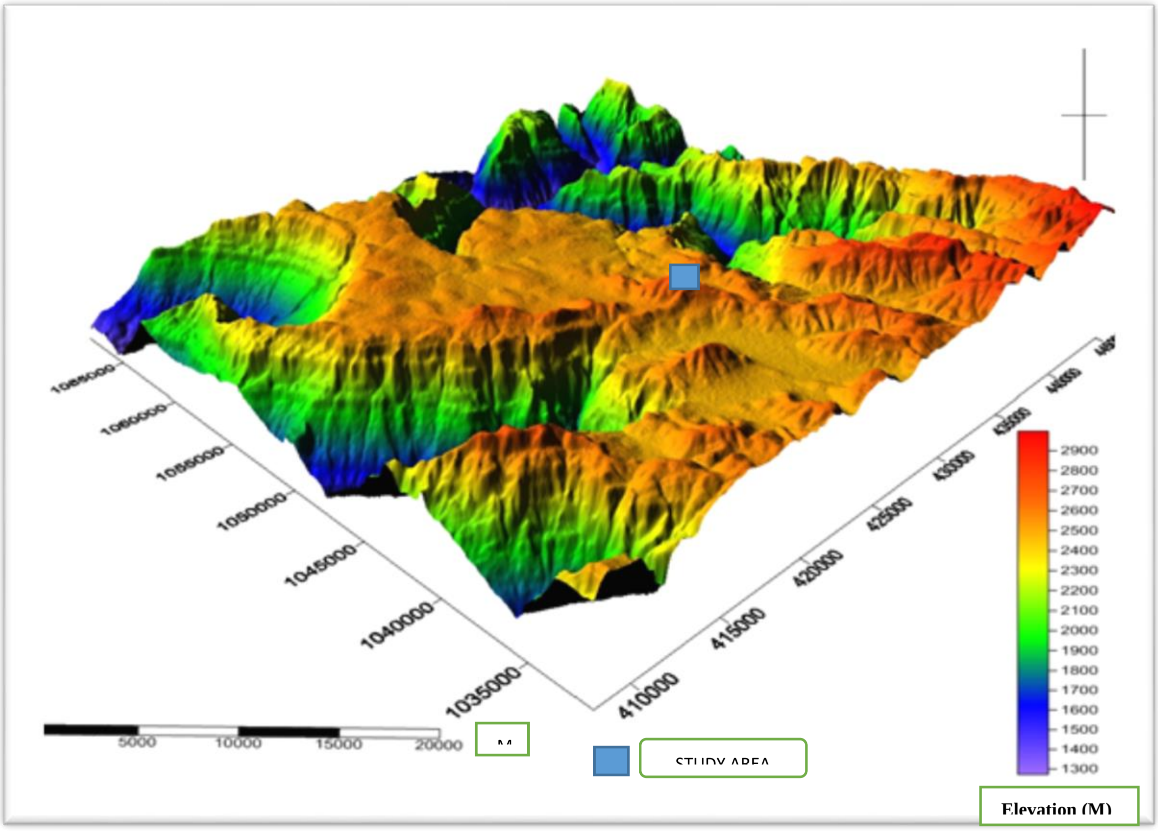


Figure 1-4: Physiographic map of the study area

1.5 Seismicity of the study area

Ethiopia is controlled and influence by seismicity because Ethiopia is present in the rift system which divides the country in to two along the NE-SW direction (Tilahun Mamo, 2005). Areas present in the afar triangle and main Ethiopian rift system are more susceptible for earthquakes but along rift margins low magnitude earthquakes are recorded. In the rift boarder fault. Seismicity is less common in the south due to the difference stage of rift evolution (Kier et al., 2003).

Ethiopia is divided in to five seismic zone depending on intensity and magnitude of seismic activity in the area which is the function of distance from the rift valley and seismic amplification of the formation of the area. Seismic amplification depends on the thickness of the soil, moisture content and degree of compactions (Tilahun Mamo, 2005).

The study area located in the boarder of active seismic zone of Ethiopia and has low to high impact on building and slope stability so it requires much consideration and study systematically to know the exact intensity and magnitude of the earthquake for further structural design if the large structures is built in the study area. The study area mainly situated under the Ethiopian seismic code 7 between 8 MM scale.

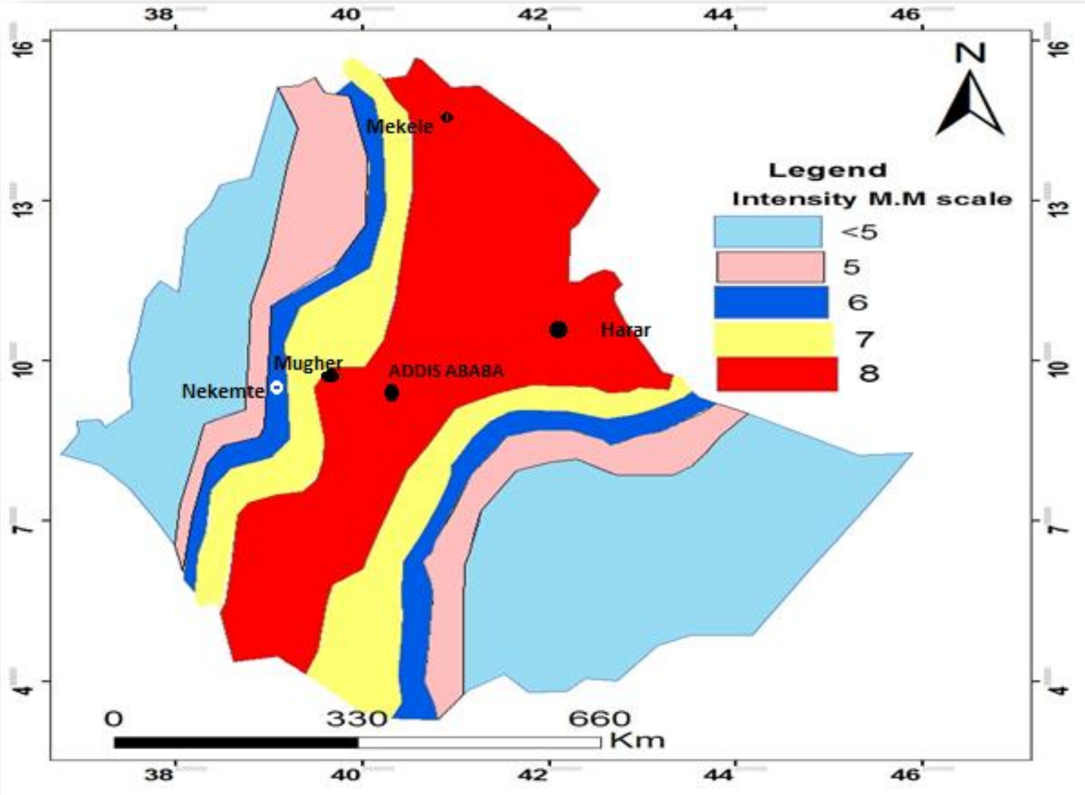


Figure 1-5: Seismic zoning of Ethiopia (modified after World Health Organization, 2010)

1.6 Statement of problem

Ethiopia is one of the countries which have bulk industrial minerals compared to some countries in the world. Industrial minerals like limestone, phosphate, kaolin, potash, are commonly occurring minerals and rocks that are widely used in industry, sometimes undergoing very little processing. Industrial minerals are highly utilized in the construction industries and now a days their demands are booming (rising).

Among the industrial minerals mentioned above, limestone is one of the important and main inputs for the production of cement. The mining method for limestone is called open pit (quarry). In this mining method most of the time the excavation process is mostly so random that it has its own impact on the quality and excavation time. Because of the random excavation process the limestone is mixed with basalt and large amount of overburden. And also some large limestone boulders affect the working area of logistics and its time consuming to remove them. Such problems can be solved by studying and/or designing of the slope stability of the site.

Apart from this problem the quality of the limestone is one of the important factor to be considered. And the quality of the limestone is classified into very high, high, medium, low and impure limestone based on the $CaCO_3$ percentage. It's based on these classification the possible industrial usage of the limestone is made. For example medium purity level is needed for the production of paper, but not for the production of cement. For the production of cement high purity level is needed.

However, it's possible to say that there is no paper that can describes properly the purity of Ethiopian limestone used for the production of steel, rubber, plastic and paint i.e very high calcium carbonate ($CaCO_3$) percentage level. Even the cement industry in the country they only make sure of the quality for the production of cement only. Therefore, if purity of rock is placed in the system, an unmarketable product will exist.
Therefore, it is required to evaluate slope stability design and quality of the limestone in Dangota limestone quarry site.

1.7 Objectives

1.7.1 General Objectives

- The general objective of this research is to evaluate the limestone quarry quality, planning and slope design.

1.7.2 Specific Objectives

- To assess the slope instability of the open pits mine.
- To workout safe cut slope design for the quarry.
- To examine Mugher valley limestone quality (specified area)
- Based on research findings to recommend optimum long-term quarry planning

1.8 General Approach and Methodology

In order to meet out the objectives of the present study the following systematic methodology was adopted;

- ✓ A thorough literature review was undertaken to have a general background on the subject matter and to develop a conceptual framework within which the present methodological composition was evolved. For this published, unpublished papers and technical reports related to geology, mining data and geomorphology of the Mugher area was reviewed.
- ✓ Systematic primary data from the field has been collected on geology, geological structures, strength of the rock, Rock mass rating classification.
- ✓ Determine mineralogy of some rocks in the study area, laboratory analysis
- ✓ Petrographic analysis of the rock for identification of mineralogy
- ✓ XRF was used for analyses of major oxide element
- ✓ Collected actual field data to fill the gap between available and required data. The Field investigation has been concentrated data on RMR, structural data, in-situ measurement and testing.
- ✓ Compiling all information collected during pre-field, field and post-field works systematically for the input of ArcGIS software, and other computer software program.
- ✓ Finally, conclusion and recommendation based on the result was made.

1.8.1 Methodology

I. Pre field work

The following activities were conducted before the field work:

- ✓ Reviewing of published and unpublished papers and technical reports related to the present study
- ✓ Exploring about the research project title and proposal
- ✓ Writing and presenting research proposal
- ✓ Acquiring information on the climate, peoples culture and possible destination
- ✓ Collecting topo maps, geological maps, aerial photos, Google earth and satellite images to get an idea on the geology of the study area.
- ✓ Delineating the project area from topo-maps
- ✓ Preparing all the materials useful during the field work

II. During field work

The field work in the area has been carried out in two rounds.

- ➢ The first round was conducted during September 2016 and took one week for observation and understand the general overview of the area and mining activity of limestone quarry.
- ➢ The second round field work was also conducted in the area in order to collect the necessary field data. To collect these data it took three weeks and was carried out during April, 2016.

A. Materials and Methods for Field Work

In order to accomplish the field work, the following materials were used.

- ➢ Topographic map (1: 10,000 scale),
- ➢ regional geological map (1:250,000 scale),
- ➢ GPS, compass, tape meter, hammer are the main equipment that are used during the field work.

Geomechanical properties of rock mass exposed in the study area were investigated by field observations and in-situ measurements. In the field limestone section were selected for collecting the proper data. The selection of the section were carried out based on some factors including degree of exposure that represents pure carbonate rock, availability of

Geomechanical data and accessibility to work. The collection of rock samples, measuring and collecting structural and Geomechanical data were also done based on lithology, color, and structure and area coverage of each exposed section.

During the field work, about 30 representative samples were collected for both hand specimen description and laboratory studies from Dangote limestone quarries. Random sampling technique was used for the collection of the samples in quarries. And mainly focused at the bottom and top part of the thick bed and bench of the quarry. This is because, there is no clear variations observed among the sections.

For evaluation of slope stability geomechanical data were also collected in the systematically way within 100m spacing. The collected data were grouped into five slope section based on geomechanical (RMR) parameter. The Geomechanical (RMR) data including uniaxial compressional strength, rock quality designation, spacing of discontinuity, condition of discontinuity (surface roughness, persistence, thickness and degree of weathering), groundwater condition and orientation of discontinuity, slope height, slope angle, upper slope angle, structural discontinuities data were collected during the field work.

III. Post field work

After collecting field data, stability of the rock was determined by empirical methods. Both Hoek and Brown (2002) and modified Sharma failure criteria were used to analyze the collected data. Kinematic analysis were done to determine the possible mode of failure. The collected discontinuity orientation data were analyzed by using stereographic projection software, DIPS 5.0 (Rocplane, 1999) and Datamines software for slope design.

In the field, the study and description of carbonate rocks, like other sedimentary rocks are very limited and is not enough to make a conclusion of this study. Hence, investigations of the rock using thin-sections and X-Ray Florescent (XRF) analysis result are required to intensify the field study. Laboratory done in geological survey of Ethiopian and Dangote cement industries laboratory respectively. From the collected samples the most representative 23 samples were selected for both petrographic study (thin section) and chemical analysis (XRF) from Dangote limestone quarries. Of these total selected samples, 4 samples are used for petrographic study and the rest 19 samples are used for the chemical analysis. The petrographic study is performed to determine the mineralogical compositions, textures (grain-size, degree of sorting, roundness), skeletal grains, fossil contents and matrix using petrographic microscope. The chemical analysis also helps to examine the rock quality of major oxides of the rocks using XRF. Here, British Geological Survey (BGS, 2011) is used as a standard specifications of major oxides in order to compare with the analyzed X-ray florescent (XRF) result.

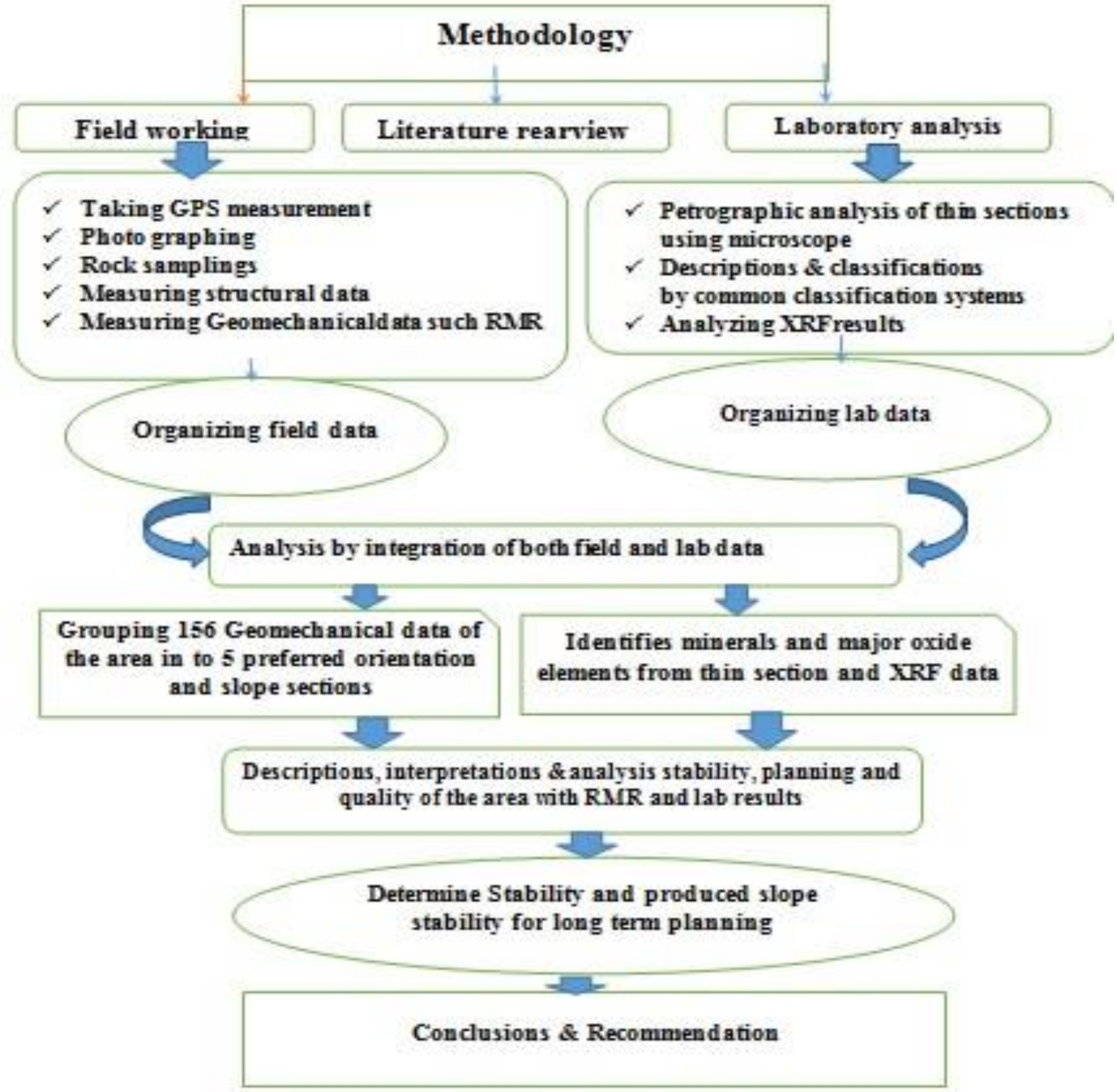


Figure 1-6: Conceptual flow chart for methodology

1.9 Scope and Limitation

The paper covers the safe cut slope design, assessing the slope instability of the quarry and its impact during production, and also characterization of limestone by purity level.

But the limitation is, in Ethiopia, there is scarcity of detailed documentation of industrial mineral in mining activity, geotechnical work related to slope design of the mine sites in broad sense and particularly in the western Ethiopia. With this limitation the study is to reduce this scarcity a little bit and to apply the quality and geotechnical work in the mining site.

1.10 Schemes of Presentation

Chapter one: introduce the present study generally its climate, physiography, seismicity, problems statement, objective, methodology followed in the study, scope of the study and limitations faced during the study.

Chapter two and three: briefly describe the study area in terms of its geological setup, geology of the study area, previous work related to exploration and description of local geology of the study area.

Chapter four: presents literature review and standards manual of some countries used in planning, stability and quality of rock.

Chapter five: present result and discussion.

Chapter six: presents the conclusion and recommendations.

2. LITERATURE REVIEW

2.1 Introduction

The open pit method is used to extract rocks from the ground. Open pit method is the process of mining any near surface deposit by means of a surface pit excavated using one or more horizontal benches. To sustain quarry development and its operation, the important aspects need to focus are planning and maintaining intact pit slopes in a quarry/mine pit. The purpose of the benches is to control the depth of the blast holes, the slope of the pit walls, and the dangers of high wall faces. It is a main concern in ensuring the constructed pit slopes and benches are stable and safe during quarrying operation activities as well as after permanent closure of a quarry pit. Slope management rather than one ensuring slope stability is followed; there is expectation of manageable slope instability at acceptable levels of risk rather than a design that focuses on achieving stable pits wall (slope and benches). The slope design is brought into the quarry pit design through proper quarry pit planning, which is usually an interactive process between the slope designer and the quarry planner. Stability of rock mainly influence by rock mass. Slope failure, if, become a threat to the workers and machineries (Fadel et al, 2015).

According to Varenfdorff (2003, as cited in Inthavongsa et al., 2016), mine planning is a difficult task. Even for small operations, it involves reasoning with complex variables and the practical difficulties of mining. It is also about predicting and planning the future in an unpredictable physical and economic environments. Planning affects everyone in the organization. Company executives demand more reliability and stability in cost and revenue forecasts from their operations. Management wants to explore ways of being more cost-effective. Miners and contractors need useful plans and realistic targets. Planners have to describe the method that will translate business into implementable plans. Extraction (more commonly referred to as quarrying) consists of removing blocks or pieces of stone from an identified and unearthed geologic deposit.

In quarry the stability is determine based on different techniques and field of applications that express in the particular quarrying techniques. Nevertheless, the process is relatively simple: locate or create (minimal) breaks in the stone, remove the stone using heavy machinery, secure the stone on a vehicle for transport, and move the material to storage (University of Tennessee Center for Clean Products, 2008).

2.2 Slope Stability

The slope stability analysis of rocks is vital for designing safe slopes in open–pit mines. Excavation as well slope design not only leads to improvements in slope stability and safety but also reduces costs, extends the life of mines and decreases the stripping ratio (waste/ore) (Bye and Bell, 2001, Naghadehi et al., 2011).

According to Hoek and bray (2004) open pit slope design has three main components. First, the overall pit slope angle from crest to toe incorporates all ramps and benches. This may be a composite slope with a flatter slope in weaker, surficial materials, and a steeper slope in more competent rock at depth. In addition, the slope angle may vary around the pit to accommodate both differing geology and the layout of the ramp. Second, the inter-ramp angle is the slope, or slopes, lying between each ramp that will depend on the number of ramps and their widths. Third, the face angle of individual benches depends on vertical spacing between benches, or combined multiple benches, and the width of the benches required to contain minor rock falls.

In slope design we use different methods for determination of stability of the quarries as well as open pit mines. The assessment of the stability worked or performed by using kinematic analysis by using dip software and rock mass classification system such as uniaxial compression strength , the SSPC (slope stability probability classification) system (Karaman, et al. 2013; Ulusay et al., 2001; Pantelidis, 2009; Alejano, 2011). Kinematic analysis is based on the motion of bodies without consideration of the forces that cause the motion (Kliche, 1999; Kulatilake et al., 2011). However, kinematic analysis does not consider the forces acting on a slope or important geotechnical parameters, such as cohesion and unit weight.

Slope stability investigation in mines is critical to the profitability of the mines in relation to slope failures. Kinematic analysis is one of the analytical methods used for the investigation (**O**laleye and Ajibade, 2016) that determined by the means of orientation of planar discontinuities, each structural domain is characterized by a single stereonet displaying the mean orientation of set.

2.3 Mode of Failure and Methods of Describing Stability

According (Hoek, 1973 as cited in Bromhead, 1999) in rock slopes, the discontinuities control the mode of failure. These discontinuities can include the bedding, but faulting, tectonically induced shearing and jointing in the rock mass each have a role to play in the development of failures. A mode of failure characteristic of rock slopes occurs where two intersecting discontinuities daylight in the slope face and the resulting discontinuity bounded wedge moves along the V-shaped notch formed by those discontinuities (Hoek, 1973). Where they are open joints, such sliding is assisted by joint-water pressures. Commonly, only the V-shaped notch is seen, as the material will have slipped out and unlike an earth or soil slide will have parted company with the rock face in so doing, necessitating the debris being cleared away. Another common type of failure occurs in steep rock faces where the discontinuities are near vertical. Rock falls and toppling failures then occur by collapse of individually joint-bounded blocks. Patterns of failure involving more than two discontinuities can occur, but failures involving two joints, or at most, two joint sets, are the commonest by far.

Plane Failure

Plane failure in rock slopes occurs when a geological discontinuity, such as bedding plane, strikes parallel to the slope face and dips into the excavation at an angle greater than the angle of friction and less than the inclination of the slope. The base area ‘A’ and the weight ‘w’ of the sliding mass are calculated from the geometry of the slope and the failure plane. A tension crack running parallel to the crest of the slope can also be included in the calculation.

Generally, a planar failure depends on joint continuity. Hoek and Bray (1977) proposed the general conditions for plane failure;

(a) The plane on which sliding occurs must strike parallel or nearly parallel (+ 20°) to the slope face.

(b) The failure plane may daylight in the slope face. Its dip must be smaller than the dip of the slope face, i.e. $\Psi f > \Psi p$

(c) The dip of the failure plane must be greater than the angle of friction of this plane, i.e. $\Psi p > \phi$

(d) Release surface which provides negligible resistance to sliding must be present in the rock mass to define the lateral boundaries of the slide.

The modified technique (Sharma et al, 1995) the effect of inclined upper slope surface and tension crack has been considered and accordingly the equation to calculate, area, weight, water forces and factor of safety has been modified. For plane failure analysis the following general conditions of must be satisfied;

(i) The failure plan must strike parallel or nearly parallel (approx. + 20%) to the slope face.

(ii) The dip of the failure plane must be smaller than the dip of the slope face (αp<αf).

(iii) (iii) The angle of internal friction (ϕ) of the failure plane must be smaller than the dip of the failure plan (ϕ<αp).

(iv) The upper slope surface and tension crack must be inclined.

(v) The inclination of the upper slope must be smaller than the inclination of the failure plan (αp>αs).

(vi) The tension crack must be present on the upper slope surface.

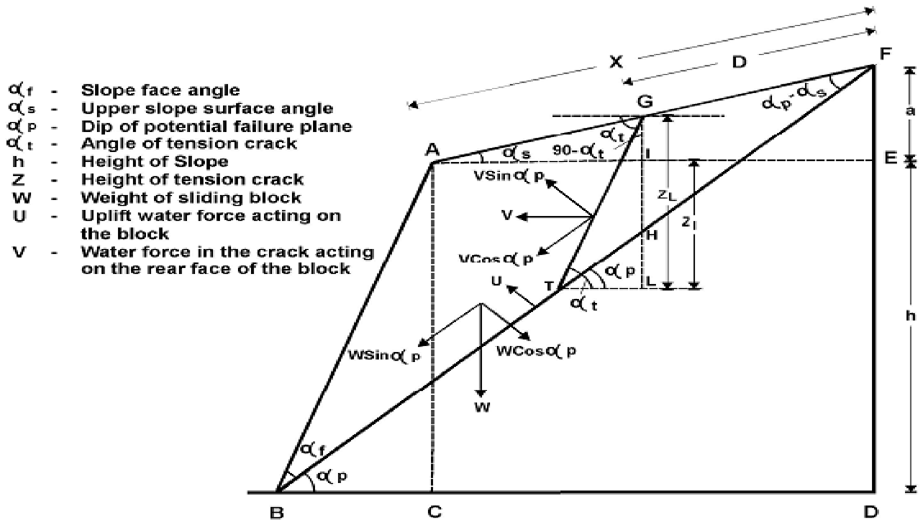


Figure 2-1: Geometry of the slope used in the analysis

Wedge Failure

When two discontinuities strikes obliquely across the slope face their line of intersection daylights in the slope face, the wedge of rock resting on these discontinuities will slide down the line of intersection, provided the plunge of line of intersection of the two wedge forming planes is greater than the angle of friction and is less than the inclination of the slope. The wedge failure depends on joints attitude and conditions and is more frequent than planar failures (Hoek and Bray, 1981).

A wedge mode of failure occur when two structural discontinuity planes strike obliquely and their line of intersection daylights on the slope face. The sliding of rock mass will be on these two intersecting planes in the direction in which the line of intersection plunge. For the wedge failure to occur the kinematic condition defined as $\alpha f > \alpha i > \phi$ has to be satisfied. Where; αf, is the inclination of the slope face; α_i, is the plunge of the line of intersection of the two wedge forming planes. Where, ϕ is the angle of friction (Hoek and Bray, 1981).

Toppling failure

Not all modes of slope failure can be analyzed using simple sliding theories, and probably the main other area which is amenable to analysis is the onset of toppling modes of failure. These can be stimulated by a large horizontal water pressure thrust in an already open joint or crack behind the face of a steep slope causing a large overturning moment to be exerted. The depth of the joint and the narrowness of the block are both features which will contribute strongly to this mode of failure. However, it does accept that there is no outlet for the water at the bottom of the joint, so that winter conditions where seepages on the cliff face freeze and seal the outlets while unfrozen groundwater accumulates inside the joint will be especially conducive to the buildup of high water pressures. Comparatively small quantities of water are needed to fill nearly closed joints, but even a small opening leads to considerable drops in the total thrust as the water level falls, and when the joint is wide open further filling with water is improbable. Water thrusts of this sort are not therefore a good mechanism to account for all toppling failures (Bromhead, 1986).

For a toppling failure to occur, the dip direction of the discontinuities dipping into the face must be within about 10◦ of the dip direction of the face so that a series of slabs are formed parallel to the face. Also, the dip of the planes must be steep enough for interlayer slip to occur. If the faces of the layers have a friction angle φj, then slip will only occur if the direction of the applied compressive stress is at angle greater than φj with the normal to the layers. The direction of the major principal stress in the cut is parallel to the face of the cut (dip angle ψf), so interlayer slip and toppling failure will occur on planes with dip ψp when the following conditions are met (Goodman and Bray, 1976): $(90^\circ - \psi f) + \varphi j < \psi p$). These conditions on the dip and dip direction of planes that can develop toppling failures.

Evans (1981) and Dunbaven (1983) consider toppling mode of failure. It is obviously progressive, since the initiation of the toppling movement transfers load to the front of the toppling block, increasing the settlement and accelerating the toppling. Furthermore, the deterioration in stiffness of the underlying incompetent stratum will be encouraged by the rise in stress close to its unsupported face. Other modes of toppling failure can be induced by undercutting (stream erosion, seepage erosion, or marine attack) or by thrusts or drags from associated slide movements. Many of these modes of failure defy simple analysis, or require specific techniques unrelated to the limit equilibrium models of this section (Goodman and Bray, 1976).

Generally toppling failure in rock slope occurs when the discontinuities are very steep and the following condition occurs: $\Psi > \phi$ and $b/h < \tan\Psi$ - toppling and sliding and if $\Psi < \phi$ and $b/h < \tan\Psi$ - only toppling will occur. Where 'Ψ' is the dip of the plane, ϕ is the angle of friction, 'h' is the height of the rock block and 'b' is the width.

Circular Failure

When the material is very weak, as in a soil slope, or when the rock mass is heavily jointed or broken, the failure will be along a circular path. Such types of failures are common in highly weathered shales. This failure occurs along a surface which develops only partially along joints, but mainly crosses them. These failures can only happen in heavily jointed rock masses with a very small block size and very weak or heavily weathered rock mass. It is essential that all the joints are oriented favorably so that planar and wedge failure are not possible (Bromhead, 1999).

Circular Failure Analysis based on Standard Circular Failure Charts. The following assumptions are made while deriving the standard circular failure charts:

(i) The material forming the slope is assumed to be homogeneous, i.e. its mechanical property does not vary with direction of loading.

(ii) (ii) The shear strength of the material is characterize by a cohesion 'C' and a friction angle 'ϕ' which are related by the equation $\tau = C + \sigma \tan\phi$.

(iii) Failure is assumed to occur on a circular failure surface which passes through the toe of the slope.

(iv) A vertical tension crack is assumed to occur in the upper surface or in the face of the slope.

(v) The locations of the tension crack and of the failure surface are such that the factor of safety of the slope is a minimum for the slope geometry and ground water conditions considered.

(vi) A range of ground water conditions, varying from a dry slope to a fully saturated slope under heavy recharge, are considered.

2.4 Factors Controlling Stability of Rock Slopes

Slope stability analysis is estimation of a factor of safety for the considered slope and slide mass. An intuitive formulation of a safety factor appropriate to translational sliding is the ratio of resisting to driving forces acting parallel to the direction (Pariseau, 2007).One of the early difficulties arose because many geotechnical problems, particularly slope stability issues, are more conveniently dealt with in terms of shear and normal stresses rather than the principal stress relationships of the original Hoek-Brown failure criterion.

The controlling factors of the stability are determined by different processes that can lead to reduction in the shear strengths of rock mass. Increased pore pressure, cracking, swelling, decomposition of clayey rock fills, creep under sustained loads, leaching, strain softening, weathering and cyclic loading are common factors that decrease the shear strength of rock mass. In contract to this the shear stress in rock mass may increase due to additional loads at the top of the slope and increase in water pressure in cracks at the top of the slope, increase in soil weight due to increased water content, excavation at the bottom of the slope and seismic effects. In addition to these reasons factor contributing in failure of slope are properties of rock mass, (slope geometry), state of stress, temperature and erosion. http://www.iitbhu.ac.in/faculty/min/rajeshrai/NMEICTSlope/Pdf/02%20Causes%20of%20slope%20failur

Important factors that controls the stability are geological discontinuities (fault, joint, bedding plane), water (ground water, drainage pattern, rainfall, permeability, aquifer), strength (shear strength, compressive strength, tensile strength), geotechnical parameters (gran size, moisture content, atterberg limit), method of construction (shovel, dumper, combination), dynamic forces (blasting, seismic activity), geometry of slope height and angle of slope, bench height and angle.

2.5 Safe Cut Slope Design

The decrease of shearing strength at very low strain rates is often of little importance and catered for in routine engineering design by the adoption of appropriate factors of safety. In the measurement of shear strength, the sample size can also have a major effect. The usual argument put forward to explain this is that a large specimen is more likely to contain joints or fissures than a small one (Bromhead, 1999).

Even after allowance for stress concentration at the toe of a surface mine slope, stress is unlikely to exceed strength of intact rock. For this reason, structural discontinuities that are generally present in rock masses, especially rock masses that host ore bodies, are important to rock slope stability. Faults, joints, bedding planes, fractures ("joints" for brevity), and contacts between different rock types, are essential considerations in stability analysis of rock slopes. Translational sliding along joints is the most common form of rock slope failure; slopes in soils tend to fail by rotation, although in densely jointed rock masses rotational failure is certainly possible. Mine waste dumps, tailings dams, earthen embankments, road fills, storage piles of broken rock, aggregate, and so forth, are soil-like in mechanical behavior, are usually much weaker than rock slopes, and also tend to fail by rotation. In any case, major determinants of slope stability are slope height and angle. Water is another factor of major importance to slope stability analyses. The factor of safety defined here is a global factor of safety in contrast to a local factor of safety (FS) that is defined as the ratio of strength to stress at a point. A local factor of safety less than one indicates the elastic limit may be exceeded, yielding, and failure ensue, at the considered point. A global safety factor less than one imply yielding and failure over an extended failure surface and is indicative of collapse (Pariseau, 2007).

Slope-stability analysis is often far from precise, regardless of the adequacy of the data available, and sometimes the provision for an absolutely safe slope is prohibitively costly.

2.6 Quality of rock

Any plant generally receives raw materials from a single captive quarry or from multiple quarries. While establishing a cement plant, the plant management needs to be satisfied that the quality and quantity of the limestone would be obtained from the limestone quarry. Therefore, a proper quarry planning is essential to maintain the quality and quantity of raw materials supplied to the cement plant. The long range planning is required to understand the amount of limestone can be supplied to the plant from the quarry i.e. the ultimate pit of the quarry. There has been much research done on computerized open-pit design in an attempt to find the ultimate pit limit that gives the maximum profit (Joshi et al., 2015). The quality of limestone plays an important role in the cost-effectiveness of cement production (Chatterjee et al., 2006).

According to Nayak and Mallik 2002, (as cited in Chatterjee et al., 2006) the kiln is more effective where the silica ratio is less than 2.3. Another important parameter that makes a cement plant cost effective is the lime saturation factor (LSF): a ratio of CaO and weighted sum of alumina, silica and ferric oxide. The LSF plays a vital role for cement production because it contains CaO; the primary constituent of cement in limestone quarry production planning for the consistent supply of raw material. The primary requirement for developing an acceptable raw mix for cement plant is calcium oxide (CaO). Secondary raw materials are required to achieve a balance of silica (SiO2), alumina (Al2O3), and iron (Fe2O3) (Josh et al., 2012). Lime saturation factor (LSF) is an index that helps in achieving the balance of main oxides which is mathematically expressed as;

$$LST = \frac{100*CaO}{2.8SiO_2+1.18Al_2O_3+0.65Fe_2O_3}$$

Where LST is limestone saturated factor

To maintain a consistent supply of suitable limestone grades to a cement plant, an ore grade model is generated, based on which a grade control plan can be produced to guide the excavation of the limestone. A good model aims to achieve reliable estimates of ore grades, representing the deposit as accurately as possible (Abdullah, 1990 as cited in Chatterjee et al., 2006).

3. REGIONAL GEOLOGY

3.1 Introduction

The Precambrian basement of Ethiopia contains a wide variety of sedimentary, volcanic and intrusive rocks, which have been metamorphosed to varying degrees (Kazmin, 1972; Getaneh Assefa, 1991). During period of the Upper Paleozoic the basement rock was peneplained in most parts of Ethiopia. It appears from previous studies that the sedimentary history of the Horn of Africa began probably between the Late Carboniferous - Ordovician and Early Triassic time (Getaneh Assefa, 1991) with the development of the NNE as well as NW trending grabens that were filled with continental sediments. Following these grabens marine sediments began to deposit and in Late Triassic early Jurassic time transgression of the sea advanced from the southeast and covered most of Ethiopia reaching up to the western and northern parts. Towards the end of Jurassic epeirogenic uplifting began causing withdrawal of the sea from the region by depositing regressive continental sediments (Bosellini et al, 1999).

Tectonic evolutions throughout NE Africa and sea level fluctuations through geologic time in general have the great roles for the formation of these basins and thick sedimentary deposits within them. The development of most of these basins is related to the extensional tectonic events that have taken place intermittently since the Late Palaeozoic and continued up to Tertiary (Mohr, 1962; Blanford, 1970). The Ogaden, Abay and Mekele Basins in Ethiopia are presumed to be intra-continental rift basins formed as a result of extensional stresses induced by the break-up of Gondwana land in upper Palaeozoic (Getaneh Assefa, 1991).

According to Asfawossen Asrat (2015) in geology, geomorphology, geodiversity and geoconservation of the Sof Omar cave system describe about the direction and time of sedimentary formation. Alternate sinking and uplifting of the landmass of the whole horn of Africa triggering transgression of the Indian Ocean from the southeast to the northwest characterized the early Mesozoic.

During the Early Cretaceous a general uplifting of the northern part of Ethiopia took place and regression began, meanwhile, subsidence of the Ogaden Basin continued depositing Gorrahei, Mustahil, Ferfer and BeltUne Formations. This regression is represented by clastic sediments (Amba Aradom Formation) in the Abay and Mekele Basins, but the lateral equivalent sediments in the Ogaden Basin are neritic carbonates and evaporate (Bosellini, 1989). The sedimentary successions in the Blue Nile Basin reach a maximum thickness of 3000m (Wolela Ahemed, 1997) at the central part of the basin (Dejen–Gohatsion area) and 200m at the extreme west (basin margin). The Amba Aradom Formation may once have extended and deposited further west than presently seen in the Abay Basin probably as far as Fincha area. It consists mainly of sandstone with beds of varies colored shales, siltstones and lenses of conglomerate. It thickens from zero meters in the west to 450 meters in the northeast near Gundo Meskel and 600 meters in the east near Lemi. It is regressive sediment unconformably underlain and overlain by Antalo Limestone and Tertiary volcanics, respectively. Alula (1992), however, interpreted that this formation is deposited conformably over Antalo Limestone, but angular unconformity separates the Amba Aradom Formation from the underlying Antalo Limestone in other parts of the basin (Elwerath, 1960; Serawit Amene and Tamrat Mojo, 1995 & 1996). Angular unconformity between Antalo Limestone and Amba Aradom Formation has been also recognized in the northern part of Ethiopia in Mekele Basin (Bosellini et al, 1997) that may indicate this unconformity is rather regional. Development of the East African Rift, in the Early Miocene, is associated with volcanism resulting in the outpouring of vast quantities of lava chiefly represented by basalt, masks the Mesozoic strata in most part of the country including the Abay Basin. Therefore, Mesozoic sediments in the Abay Basin are exposed only in deep valleys and in the Canyon of Abay River itself.

3.2 Limestone Formation in Ethiopia

Limestone is a sedimentary rock composed primarily of calcium carbonate with the occasional presence of magnesium. Most limestone is biochemical in origin meaning the calcium carbonate in the stone originated from shelled oceanic creatures. Limestone can also be chemical in origin as is the case with travertine. Chemical limestone forms when calcium and carbonate ions suspended in water chemically bond and precipitate from their aquatic sources. Because of its high calcium content, limestone is usually light in color, although many variations exist. Commercially, the term limestone includes dolomite, dolomitic limestone, oolitic limestone, and travertine (Dolley 2007), a porous calcitic rock that is commonly formed near hot springs (UTCCP, 2008).

According to Tibebu Mengistu and Hailemichael Fantaw (2003) the industrial mineral and rock resource potentials of Ethiopia limestones formation are mainly in the time of Jurassic to Quaternary. Calcitic and dolomitic limestone occurs in Ethiopia that is used for the cement and lime industries. So far, the limestone of Mosobo (Tibebu Mengistu, 1993), the Mugher valley and Dire Dawan (Gumerov, 1981) has been well explored for utilization in the cement production. Calcite limestone of dimensions stone quality is predominantly found within the Jurassic Antalo limestone and the Hamanlei series. The best exposure and most interesting deposited of the Antalo limestone are found in the central part of the Abay valley, and within the tributary of Abay River.

The Mugher valley is part of Abay sedimentary basin in Northwestern Ethiopian plateau and is bounded to the east and southeast by the tectonic escarpment of the uplifted western flank of the main Ethiopian rift and to the north and south by the Axum-Adigrat and Ambo lineaments, respectively. The basin contains about 1400m thick section of Mesozoic sedimentary rocks sandwiched between Neoproterozoic basement rocks and Early-Late Oligocene and Quaternary volcanic rocks (Gani et.al, 2008).

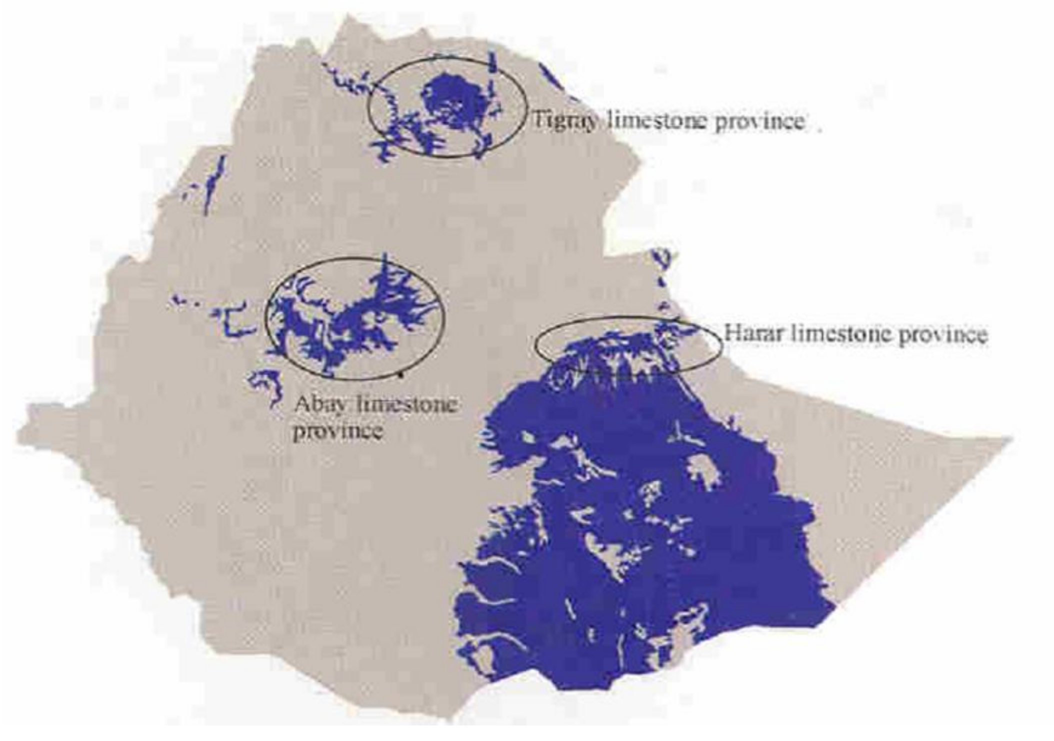


Figure 3-1: Locations of Mesozoic sediments of Ethiopia (Ethiopian Ministry of Mines, 2009)

The sedimentary rock cover in Ethiopia accounts for more than 40% of the surface area of the country (Figure 3.1). The Paleozoic and Mesozoic sedimentary successions in Ethiopia lie over a Precambrian crystalline basement of metamorphic plutonic complex (Assfawossen Asrat et al., 2009). The Mesozoic sediments are exposed in the North (in

Tigrai and the Danakil Alps), in central Ethiopia (within the Abay gorge and its major tributaries), and in Southeastern Ethiopia (Harrarghe, and the Ogaden plain) (Assfawossen Asrat, 2015).

According to Getaneh Assefa (1991) the Paleozoic era was characterized by classify the Mesozoic sedimentary succession of Abay Basin from bottom to top as; lower (Adigrat) Sandstone Unit, Gohatsion Formation Abay beds, Limestone unit (Antalo limestone), Muddy Sandstone (Muger Mudstone) and at the top upper Sandstone (Debre libanose Sandstone).

The characteristics of the formation of rock in the Mugher valley the lower sandstone, Triassic-Early Jurassic in age, unit is composed of pink to red, fine to coarse grained sandstone that are rarely inter-bedded with grey mudstone deposited in braided fluvial and deltaic environments . The Gohatsion Formation, Early-Middle Jurassic age, consists of a lower thinly bedded limestone interval and an upper interval of alternating limestone and gypsum beds. The gypsum beds are characterized by mottled texture, and are inter-bedded with glauconitic mudstone beds and rare thin sandstone beds. The alternation of gypsum and limestone indicates repetitive drying and flooding of an evaporate basin. The limestone unit comprises thinly bedded to massive limestone of Middle-Late Jurassic age, is made up of fossiliferous limestone inter-bedded with marl shale and mudstones. Oolitic limestones with scattered small patches of corals and stromatoporoids occur at the base and the top of this unit. The remaining part is dominated by intercalations of limestone with very thin layers of marls and clays (Russo, et al 1994).

The Antalo Limestone Formation passes up vertically into a 30m thick transitional facies. The regression of the sea initiated the deposition of the transitional facies between the Antalo limestone formation and the Mugher mudstone unit. The transitional facies are dominated by alternating thin beds of limestone, claystone, gypsum, calcarenite and sandstone (Wolela Assef, 2008).

The Mugher Mudstone, Late Jurassic-Early Cretaceous age, at its lower part consists of thin (15m) alternating gypsum, dolomite and shale whereas the upper part is constituted of thick (240m) mudstone (Russo, et al 1994) (Table 2.1). The upper part consists of inter-bedded mudstone, siltstone and fine to medium grained sandstone. The mudstone shows massive bedding, thin lamina and ripple lamination while the sandstone is massive with no visible sedimentary structures. The Early Cretaceous Upper (Debrelibanos) Sandstone consists of sandstone, pebbly sandstone and local lenses of conglomerate and clay stone deposited in sandy braided rivers on a broad alluvial fan (Getaneh Assefa, 1991).

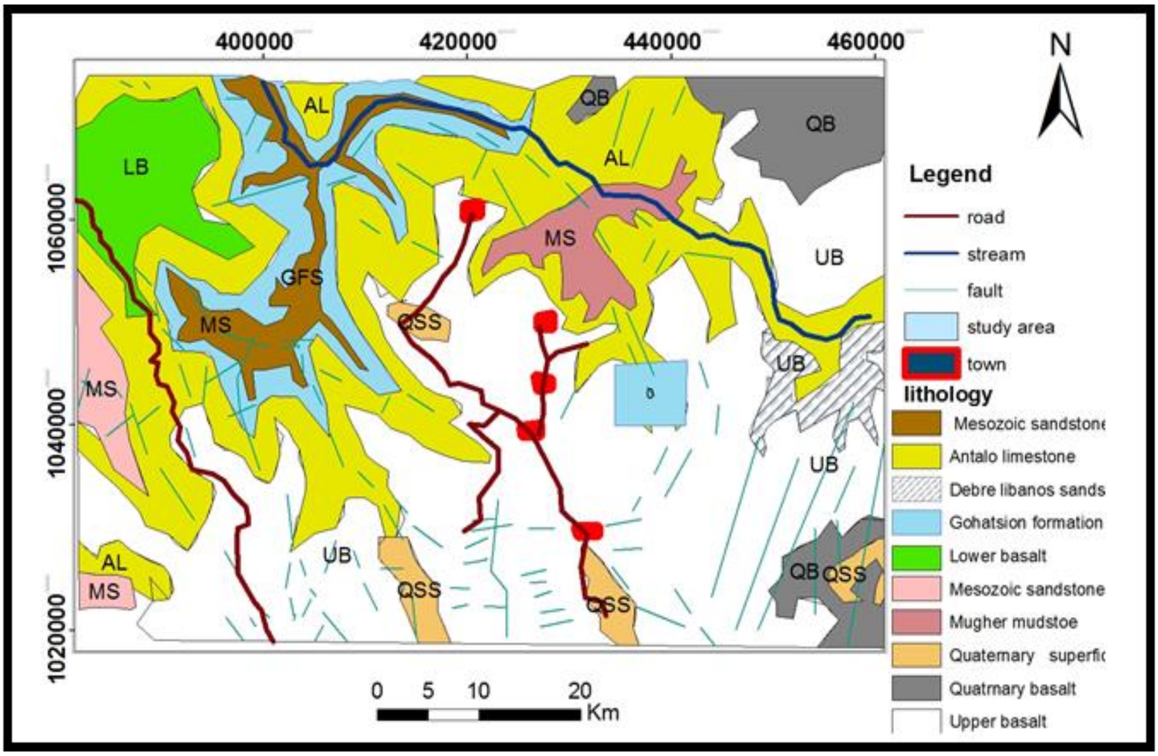


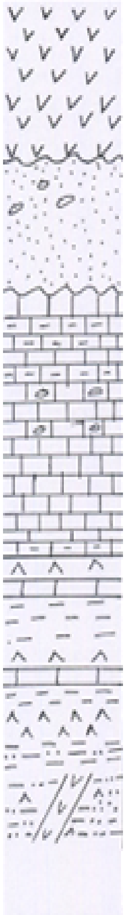
Figure 3-2: Regional geological map extracted from Geological Map of Addis Ababa Sheet, NC37-10 (Getahun Belay et al., 2011). The smaller rectangle on the map indicates the present study area.

The Mesozoic sedimentary succession of Abay Basin is caped unconformably by massive flood lavas, mainly basalt. These volcanic rocks are generally post-Oligocene and reach a maximum thickness of 5,500 m (Getaneh Assefa, 1991). The stratigraphy and history of sedimentation in the Abay Basin is elaborately by (Serawit Amene and Tamrat Mojo, 1999; Raaben et al., 1980; Mohr 1971). The area is characterized by the different lithology, structure and topographic variation. Among those lithological variations antalo limestone cover large portion of the deposit.

3.3 Geology of Mugher Valley

The northern and southern limit of the Abay Basin could not be defined due to an extensive coverage of Tertiary lava flows, however, towards north it can be assumed that the Triassic -Early Jurassic basin probably extend beneath the volcanics towards Mekele area as some sediments (Kazmin, 1972) are cropping-out in the Tekeze River, and to the south the basin limit is not known due to an extensive coverage of Tertiary volcanics.

Table 3-1: Stratigraphic succession of Mugher area non scale (MME, 1999)

Era	Period	Formation	Lithology	Thickness	Description
Cenozoic	Tertiary	Top series		300m	Jointed basalt forming step of cliff
Mesozoic	Cretaceous	Amba Arodom Debre-libanos sandstone		25m	White to yellowish, fine to medium grained, massive un-compacted sandstone
	Upper Jurassic	Antalo limestone		450m	Top part of fossiliferous limestone locally shale & silt stone alteration with interbeds of limestone marl and miner sandstone underlain by a reefal limestone. It is mainly crystalline limestone with interbeded shale fossiliferous & marly limestone beds with numerous bisturbated beds at the bottom part
	Middle Jurassic	Goha - tsion formation		300m	Upper part alternating gypsum, shale & limestone Middle part mainly gypsum with interbeded shale Lower part dominant mudstone with thin beds of limestone, dolomite, gypsum, crisscrossed numerous dyke

Although the continuation of the basin is not yet clear due to the wide coverage of Tertiary lava flows, the Eastern boundary is probably the great escarpment of the Ethiopian Rift, whereas to the West there is no precise limit because the sedimentary rock is partly eroded by the recent erosion, and the remnants are common as pockets north of Nekemte (Kazmin, 1972).

The sedimentary beds are nearly horizontal, but a general Southeast dip causes progressively older Mesozoic strata to disappear beneath the Tertiary volcanic lava flows in a westerly direction. The stratigraphy and history of sedimentation in the Abay Basin is elaborately discussed by Raaben et al. (1980) and Mohr (1971).

3.4 LOCAL GEOLOGY

3.4.1 Field Description of the study area

In the present area Mugher valley has exposed only limestone unit with inter bedded shale, marl and sandstone layers. Here, erosion resulted in the formation of step like features exposing cliffs of fossiliferous limestone some 60 m thick. Erosion seems taken place preferentially along thinner sandstone, shale and marl bands separating the two limestone cliffs. Thin sandstone/ shaly sandstone or muddy sandstone layer separates the overlying basalt from the limestone. This unit is exposed along the river in the tributaries of Kersa in the west and north western part of the area. On the bases of surface and sub-surface geology, the general stratigraphic sequence of the study area is listed from bottom to top below:

Limestone Unit

The quarry site is within limestone blocks. The unit is characterized by forming prominent cliffs underlying the sandstone. It is horizontally bedded dipping towards western direction 3 to 25 degrees. The limestone has a variety of bed thickness ranging from few centimeters to about 10 meter. Lithological the limestone is calcitic and fossiliferous on top with a cyclic sequence of marl and shale. Figure 3.3 shows that the beds are normally compact, fossiliferous and varying in color from creamy, light grey, creamy brown/ buff to beige. The bottom layer is generally, grey to light grey in color characterized by calcareous shale (shally limestone) with pronounced thickness of shale and marl. The unit is fractured and jointed with three sets of joints with joint spacing varying from few centimeters to 2m.

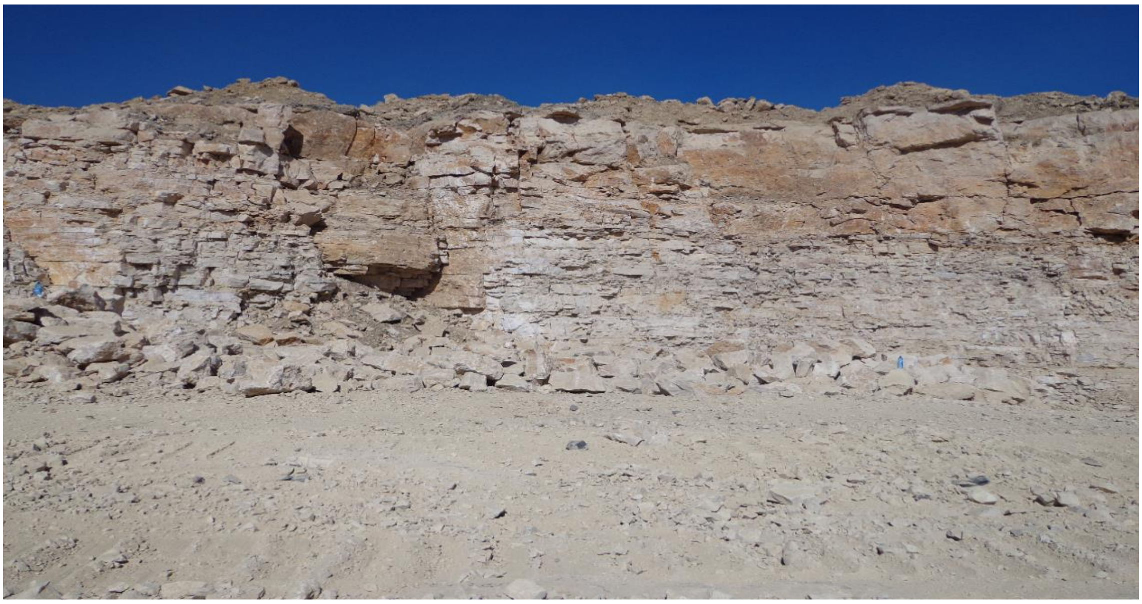


Figure 3-3: Top limestone horizon, yellowish cream limestone

Volcanic (Basaltic) unit

The volcanic unit is the upper most unit in the area which covers the southern part and western border of the Block. It occupies stratigraphically the highest topography characterized by forming big blocks and boulders. The unit is dark grey, predominantly Aphanitic, fresh to moderately weathered and jointed basalt. Short lived cyclic flows are frequent in the unit marked by paleosols along the contact of the successive flows.

Study area volcanic rock is characterized by the nearly vertical columnar basalt structures and exhibits spheroidal weathering. The contact with the underlying sandstone unit is not clearly defined due to thick scree/ slop deposit transported from the basalt.

Figure 3-4: Cliff forming columnar basalt

Structure

The rock units of both upper and lower bench are characterized by, local tilting, jointing and local fault. These geologic structures are common. Columnar basalt are the characteristic feature of Basaltic rocks. Joints are also observed on the sedimentary units especially in limestone. Local faults are shown with in little exposure especially in limestone.

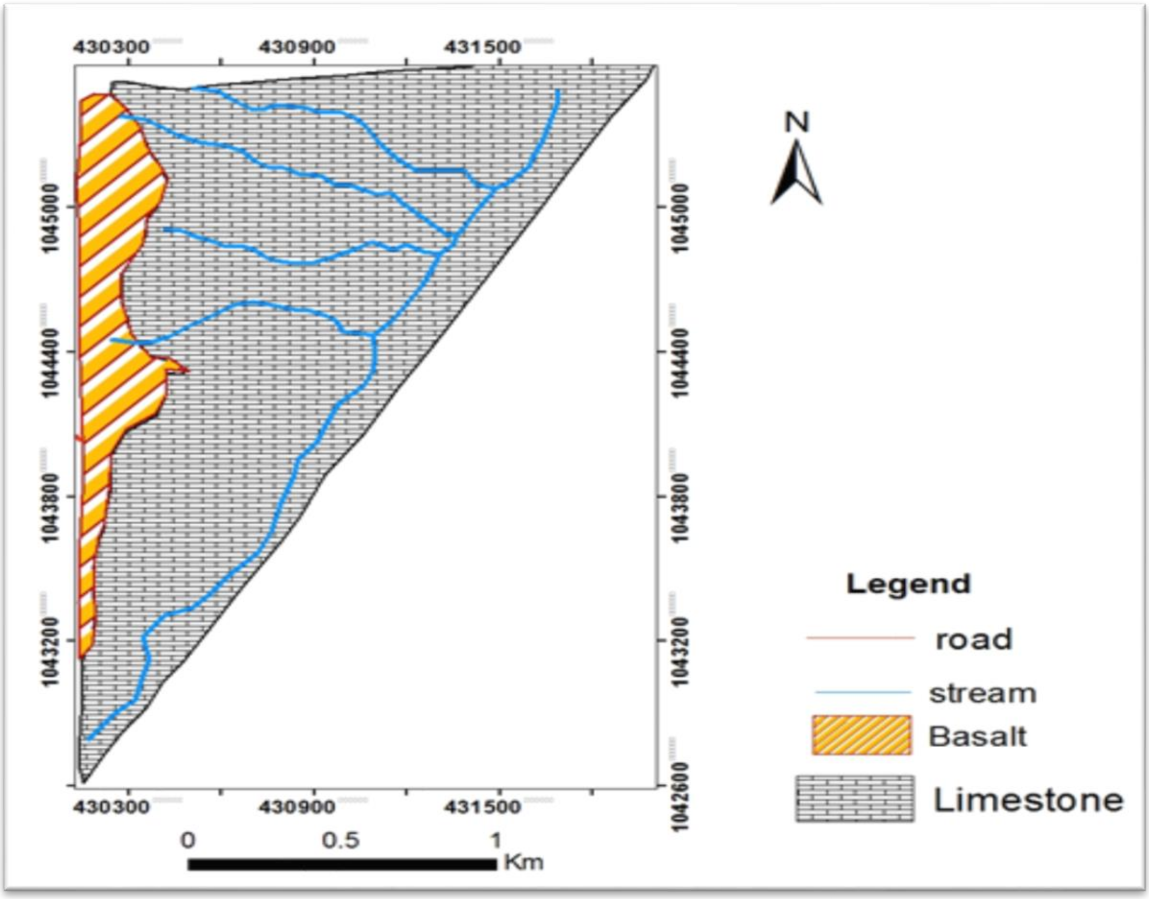


Figure 3-5: Geology map of the study area

- Note: The quarry site occurred limestone at the bottom and basaltic rock unite from top.

3.4.2 Surface Geology of Open Pit Mine

Mugher valley are one of the sub basin of Abay and the quarry lies at the western part of Sodble river the contact of the different unit rocks that exposed in the area. The rock that exposed in the area from bottom to top that word used because of the area is sedimentary formation so those are gypsum, sandstone, limestone, Quaternary basalt. Detailed description of the geology of the area is discussed below.

In general the exposed rock in the quarry is from top to bottom

Quaternary basalt found at the top and has different types of basalt like columnar basalt, massive basalt

Limestone that characterized by degree of weathering (moderately to highly weathered), formation micritic and calcic limestone

Limestone quarry is topographically part of Mugher valley and northwestern Ethiopian plateau. The area lies in the north-western flank of Sodeble River which is the part of Abay basin. It lies between 2900 and 1300m elevation above from sea level. The quarry mine activity roughly started at 2900m above from the sea level. The raw material is aligned with in the regional sedimentary stratification direction which is the strike direction is towards the west. s

Figure 3-6: Out crop of limestone beds compact on top and shaly at the bottom

3.5 Method of Mining in the Study Area

Different mining methods have been developed for exploitation of mineral. The selection of mining method depends upon the topography, geological setting, geological structure and physical characteristics of the deposit such as shape, grade, hardness and the required production of the ore. In general two types of mining are adopted for exploitation of mineral i.e. surface mining and underground mining. The mineral deposit which occurs near to surface having significant thickness of ore with low overburden are generally exploited by opencast mining. In case, where the mineral occurs at relatively greater depth with considerable overburden, the mineral is generally exploited by underground mining method.

The various methods of mining, which are in practice, are mentioned below:

- Contour strip mining

This method of mining is mainly applied in hilly topography. The mineral is stripped from the top by formation of terrace (benches).

- Opencast Mining

This method of mining is applicable in flat terrain where the overburden is less and the production requirement is large. In this method the mineral is exploited by formation of benches below ground level.

- Rat hole Mining

This method of mining is applicable for exploitation of very thin mineral deposit covered by thick overburden. The mineral is exploited by driving of small diameter hole along the strike direction of the mineral.

- Underground Mining

This method of mining is adopted for extracting mostly precious minerals/ metals, which have mineralized at greater depths. The mineral is exploited by driving shaft and adit along the zone of mineralization.

Further opencast mining can be adopted by application of continuous and discontinuous mining methods depending on the rock characteristics and economics of operation.

The Mugher limestone/ marl deposit on the basis of its location, topography, geology, structure and other mining parameters is considered amenable to fully mechanized **opencast** method of mining utilizing excavator dumper combination in conjunction with deep hole blasting.

3.5.1 Mechanical Working

- Miscellaneous Operation

For clearing of the area, preparation and maintenance of the roads and access ramps, cleaning of benches, collection of blasted material for efficient loading by excavators, excavation of overburden material, hydraulically operated bull dozers of about 300-450 HP fitted with a suitable ripper is proposed.

Figure 3-7: Drilling pattern of the quarry site

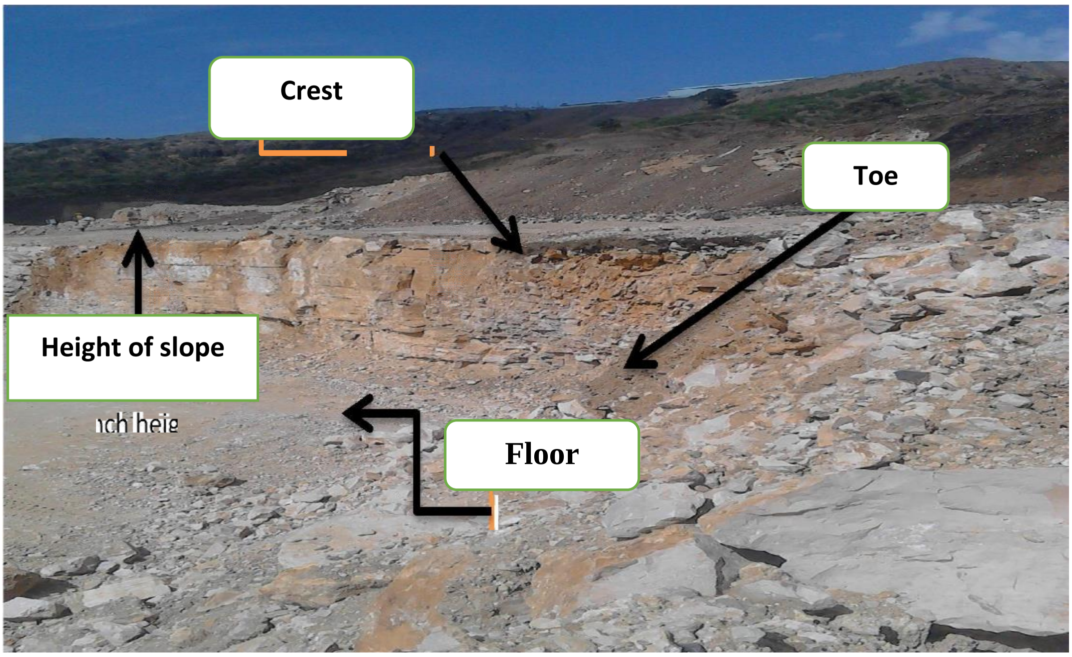


Figure 3-8: Mode of excavation in the study area

For efficient operations of main mining equipment and to facilitate various other operations, ancillary equipment such as motor grader, explosives van, mobile maintenance van, pick up van, water sprinkler arrangements (mounted on truck chassis) etc. is also proposed.

- Removal of Overburden

The overburden comprising of marl and shale is removed by dozer and excavator and loaded for transport to waste dump yard by dump trucks.

- Drilling

For primary drilling job, 110-130 mm diameter crawler mounted hydraulic drills operated by Screw Air compressors mounted on board, FAD 630 cm at 350 psi air pressure shall be used.

Normally it shall be ensured that boulders generated on blasting do not exceed 1.0 m dimension. Bigger boulders generated shall be reduced in size by using crawler mounted hydraulic impact rock breaker.

- Blasting

The delay detonators shall be used to blast multi-holes at a time with 2 rows to 3 rows in suitable pattern. Major blasting shall be attempted once a week in general, utilizing SG/ OCG explosives as boosters and slurry explosives as column charge.

The blasting shall be done twice in a week in the daylight between 12 noon to -2 pm. Multi row (max. 3 row) with use of delay detonator, 50-60 holes in a single blast shall be charged and fired to achieve about 20,000- 25,000 t of limestone.

Based on the calculation and experience of the consultant, the explosives charge per hole works out to about 83 kg (primer column charge) in the proportion of 20: 80 respectively. No secondary blasting for reduction of oversized boulder is envisaged.

- Loading and Handling

Diesel engine operated crawler mounted hydraulic excavators (front shovel) with bottom dump bucket (capacity 5.6 m^3), 523 HP with a bucket reach up to 10 m height shall be used for limestone loading.

Diesel engine operated crawler mounted hydraulic excavators (back hoe), 320 HP, with bucket capacity of 3.2 m^3, with about 10 m digging depth shall be used for overburden clay and inter burden excavation and loading and creation of water sumps in limestone as and when required.

- Transportation

The limestone shall be loaded by hydraulic excavators on 45 ton capacity rear dump trucks with net power 535 HP shall be used for transportation to crusher while the overburden clay and inter burden i.e. low-grade limestone, dolomitic limestone, siliceous limestone and siliceous rock is proposed to be transported by 20-25 ton capacity articulated rear dump trucks to reject dump yard.

I. Drilling

- Diameter of the hole – 127 to 152 mm

For the proposed bench height of 10m, two crawler mounted 110-130 mm diameter hydraulic drill with screw air compressor mounted on board is recommended for primary holes including standby drill machine. The compressor shall operate at 600-625 cm with 10.5 kg pressure.

- Spacing - 127 mm diameter machine

Spacing (i.e. the distance between two adjoining holes in the same row) is taken at 1 to 1.5 times the burden. In the present case spacing of 4.0 m is considered safe.

II. Blasting

- Charge Length - 7.4 m

Normally explosives are charged up to 2/3rd of hole length, the balance 1/3rd consist of stemming. On this basis, for 11.15 m length of blast hole, the charge length works out to 7.4m.

- Explosive Factor (Powder factor) - 6 tonnes / kg of explosives

The explosive factor is the yield of material (limestone) in tones per kg of explosive on blasting.

3.5.2 Specification of Benches

- Height of the Bench

Taking into consideration the nature of deposit, its thickness, qualitative uniformity, production envisaged, the height of bench is proposed at 10 m.

- Width of the bench

Considering the safety of men and equipment, width required for safe movement of excavators / dumpers / dozers / drills etc. on benches and expected width of blasted rock pile at face(s), the minimum width of benches proposed to be provided is minimum 20m.

- Bench Slope: Bench slope of 70^0 to 80^0 has been considered safe.

4. RESULT AND DISCUSSION

4.1 Background

In this section of the paper the results obtained from research survey analysis, field observations sample collection and laboratory analyses of rock, in-situ measurements of strength of the rock parameters, current condition of the mining site are presented.

In order to minimize the amount of waste rock and increase the amount of production, the ultimate slope of an open pit generally excavated to the steepest possible angle. Sometimes the economic benefit gained can be negative (invalid) by major slope failure. Consequently, continual evaluation of the slope stability of the ultimate slope is vital part of open pit planning. As the presence and the characteristics of discontinuity have an important influence upon the stability of the slope. The excavation of the quarry planning and slope design has not only to improvement in the slope stability and safety but has given rise to cost saving.

Hard-rock quarry workings may be wet or dry, depending on the depth to water table. It is not common practice to allow pits to flood during operation and pumping may be necessary if water collects within the pit during working. This may require the formation of profiled floors and sumps to collect water prior to pumping. The stability and slope design studies the important engineering properties of which have to be considered are uni-axial compression strength unit weight of the rock and shear strength parameter of the rocks along the discontinuity of plane (Johnson and DeGraff, 1991; Hoak and Bray, 1981). The precise arrangements will reflect the rate of inflow (normally a function of the porosity and permeability, mainly through joints and fissures, of the rock mass).

Excavations of hard-rock quarries will generally require fragmentation of the rock to allow subsequent handling and digging. This is necessary to break the rock mass and produce a rock pile with lump sizes that can be handled by the excavation and haulage plant. The desired material mined for cement production consists primarily of limestone mining usually occurs in open quarries. During a typical quarrying mining operation, shovels or bulldozers remove overburden, rock is blasted, and buck fill excavator or front power shovels load the blasted rock into trucks or railroad cars. The quarry or at the cement plant, Overburden, or waste rock, is often disposed on site in or adjacent to the quarry. The size of the mined rock is up to one meter in diameter. The rock is transported to the crushing plant located in raw materials are extracted from earth through mining and in different quarrying. Quarrying operation consists of the process of clearing the over burden, drilling by rig machine, blasting, loading by using buck fill excavator and front shovels and transportation by using load track (dumper).

4.2 Geotechnical properties of the Dangote Limestone Quarry

Assessment of the engineering geological & geotechnical properties of the study area was made based on the following:

- ✓ Field description of the properties of rock (including rock type, discontinuity characteristics, weathering condition)
- ✓ In situ strength testing of rocks using geological Hammer
- ✓ Evaluation of results of laboratory test of rock and data from previous study in the study area.

4.2.1 Rock Mass Rating (RMR) in Dangote Limestone Quarry

The rock mass classification and shear strength parameter for rock mass was estimated at critical slope section. According to Bieniawski (1989) Geomechanical classification of rock follows six parameters based on geological condition such as uniaxial compressional strength, rock quality designation, spacing of discontinuity, condition of discontinuity (surface roughness, persistence, thickness and degree of weathering), groundwater condition and orientation of discontinuity. For the characterization of the rock mass for stability analysis, Bieniawiski's rock mass rating system known as the Geomechanical classification (1989) has been adopted. The data pertaining to RMR has been collected from five section.

I. Unconfined Compressive Strength (UCS) of rocks

The UCS of rocks was determined by using geological Hammer (in the field) using the strength classification suggested by (ISRM, 1981b) (Table 4.1)

Table 4-1: Unconfined Compressive Strength classification (ISRM, 1981b)

Grade	Description	Field identification	Approximate range of uniaxial compressive strength (MPa)
R_6	Extremely strong rock	Specimen can only be chipped with Geological Hammer	>250
R_5	Very strong rock	Specimen require many blows of geological hammer to fracture it	100-250
R_4	Strong rock	Specimen require more than one blows of geological Hammer to fracture it	50-100
R_3	Medium strong rock	Cannot be scraped or peeled with pocket knife, specimen can be fracture with single firm blow of geological Hammer	25-50
R_2	Weak rock	Crumbles under firm blows with point of geological Hammer	5.0-25
R_1	Very weak rock	Crumbles under firm blows with point of geological hammer and can be peeled by a pocket knife	1.0-5.0
R_0	Extremely weak rock	Indented by thumb nail	0.25-1.0

Remark: the above data of UCS is taken from the slope surface on slightly weathered to fresh rock walls.

Results of the Geological Hammer rock strength test indicate that all the rock fall in the category (R_3) medium strong to (R_4) strong rock with average of strong rock.

Table 4-2: Unconfined compressive strength (UCS) values from geological Hammer test of rocks exposed along from Dangota limestone quarry

Rock type	Number of tests	Range of UCS value (MPa)	Average UCS value (MPa)
Limestone	15	40-100	70

Remark: all the test were carry out on surface rock outcrops with slightly weathered and in dry condition.

II. The Rock Quality Designation (RQD) of the rock along Dangote Limestone quarry

The rocks exposed along the Dangote limestone quarry were assessed for their RQD value based on classification made by Deere (1964) (Table 4.3)

Table 4-3: Classification of rock quality based on RQD (Deree, 1964)

No	RQD %	Rock Quality
1	90-100	Excellent
2	75-90	Good
3	50-75	Fair
4	25-50	Poor
5	0-25	Very poor

In this study RQD is estimated from the number of joints (discontinuity) per unit volume (Jv) collected in the field survey. The relationship which was used to convert Jv into RQD for clay free rock masses is the method proposed by Palmstone (1982) as per Eqns 1.1 and 1.2

Results of the analysis is summarized in table 4.4

RQD= 115-3.3 Jv……………………………………..Eqn 1.1

Where Jv represents the total number of joints per cubic meter or the volumetric joint count.

$$J_V = \frac{1}{S1}+\frac{1}{S2}+\frac{1}{S3}+\cdots\frac{1}{Sn}+N_{r\,/(5\sqrt{A}\ )} \qquad \text{Eqn. 1.2}$$

Where

- $S_1, S_2, S_3 \ldots\ldots S_n$ are average spacing for joint sets in meter
- N_r is the number of random joints in the actual location which is estimated at field
- A is area in m^2

Table 4-4: Classification of rock quality based on RQD (Deree, 1966) of rock exposed along the slope of Dangote limestone quarry

No	Rock type	Number of station (measurement)	RQD (%)	Rock quality (Deree, 1964)
1	Limestone	10	50-75	Fair

Remark: The rock is slightly weathered and measurement was made at slope surface indicating that the surface of limestone rock is more fractured.

III. Weathering and Chemical Alteration

The outcrop rock mass is fresh to slightly weathered discolored by weathering. During field observation it has been found that weathering affects the near surface limestone rock and its degree varies from place to place. The extent of weathering is largely controlled by the grade of fracturing and joint opening. No chemical alteration was found in the study limestone rocks.

The joint surfaces are normally clean, occasionally iron stained and sandy clay infillings are found between joint. The limestone quarry in Dangote have angular grain boundary with high to moderately interlocking grade.

Table 4-5: Weathering grades (wyllie & W. Mah, 2004)

Term	Description	Grade
Fresh	No visible sign of rock material weathering, perhaps slightly discolored on major discontinuity surface	I
Slightly weathered	Discoloration indicates weathering of rock materials and discontinuity surface. All the rock material maybe discolored by weathering and may be somewhat weaker externally than its fresh condition	II
Moderately weathered	Less than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discolored rock is present either as a continuous framework or as core stone.	III
Highly weathered	More than half of the rock material is decomposed and or disintegrated to a soil. Fresh or discolored rock is present either as a discontinuous framework or as a core stone.	IV
Completely weathered	All rock material is decomposed & or disintegrated to soil. The original mass structure is still large intact.	V
Residual soil	All rock material is converted to soil. The mass structure and material fabric are destroyed. There is a large change in volume, but the soil has not been significantly transported	VI

RMR (Biniawski; 1989) is one of the empirical design approach in rock engineering in order to evaluate the quality of the rock exposed along the Dangote limestone quarry area, six input parameters of RMR namely UCS of intact rock, RQD, spacing and condition of discontinuities.

Table 4-6: Rock mass classes and corresponding design parameter (Bieniawski, 1989)

Class No	I	II	III	IV	V
RMR	100-81	80-61	60-41	40-21	<20
Description	Very Good	Good	Fair	Poor	Very Poor

Groundwater condition and orientation of discontinuity were readily collected and determined in the field using geological Hammer, geological compass, and meter tapes. The standards of RMR is presented in table 4.6, and Results of the RMR value is summarized in Table 4.7

Table 4-7: RMR values of rock exposed along the Dangote Limestone Quarry

No	Rock type	RMR value %	Rock mass
1	Limestone	50-60	Fair rock

Based on the average result of RMR determination the result lays under fair rock mass classification (50 – 60%).

Table 4-8: Result of Geomechanical (RMR) measurement the study area

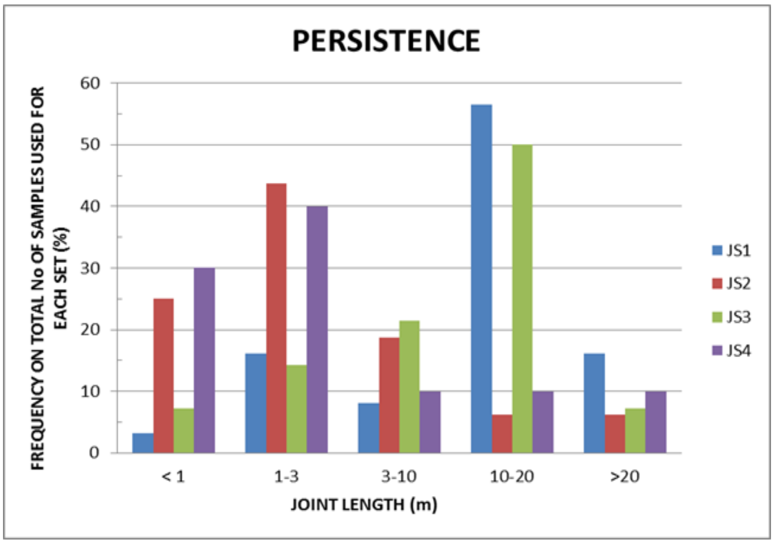
Parameter (average rating)													
Loc.	**UCS[a]**		**RQD[b]**			**Sp.dis[c]**	**C.dis[d]**	**Gwc.[e]**	**RMR[f]**	**Ori.[g]**		**Angle of internal friction(ϕ**	**Cohesion (C)(kg/cm3)**
		Ucs ra.	**Jv.**	**RQD**	**ra.**					**Dir**	**am.**		
LST1	80	7	17	59	13	10	20	10	60	14	58	54.54	0.443
LST2	70	7	19	52	13	10	20	10	60	13	61	53.98	0.393
LST3	70	7	15	62	13	10	20	10	60	10	58	53.98	0.393
LST4	55	7	18	56	13	15	10	10	55	14	58	51.68	**0.229**
LST5	60	7	19	59	13	15	10	10	55	15	49	52.14	0.246

Where: a-Uniaxial compressive strength, b- Rock Quality Designation, c- Spacing of discontinuities. d- Condition of discontinuities, e-Groundwater conditions, f-Rock Mass Rating, g-Orientation of discontinuities.

Remark: the rock are light Brown, medium strong to strong, fine grained with strong to weak joint sets, characterized by slightly weathered (locally moderately weathered), open to slightly open (1mm-1cm), medium spaced (6cm-60cm), slightly rough, persistent to medium persistent joints in filled with sandy clays and limonite (soft and hard material) (Ø 1mm-1cm)

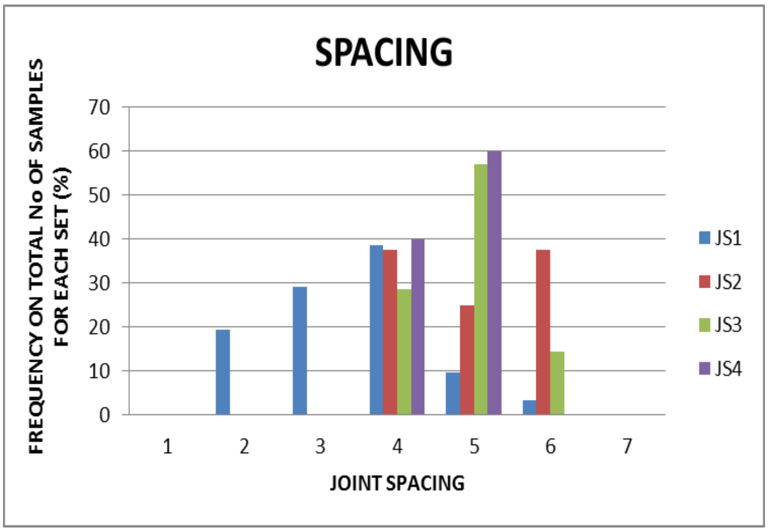
IV. Condition of discontinuity

In RMR, each and individual joint sets structure has its own effect on slope stability of quarry sites. For this purpose the whole amount of data has been filtered, excluding the joints with very tight aperture (<0.1mm).



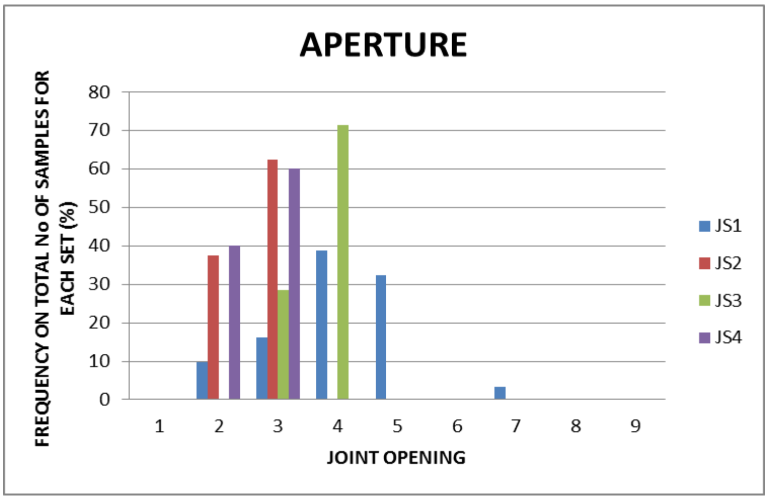
Total No of samples for each set			
JS1	JS2	JS3	JS4
62	16	14	10

1, Very low persistency: <1m
2, Low persistency: 1-3m
3, Medium persistency: 3-10m
4, High persistency: 10-20m
5, Very high persistency: >20m



Total No of samples for each set			
JS1	JS2	JS3	JS4
62	16	14	10

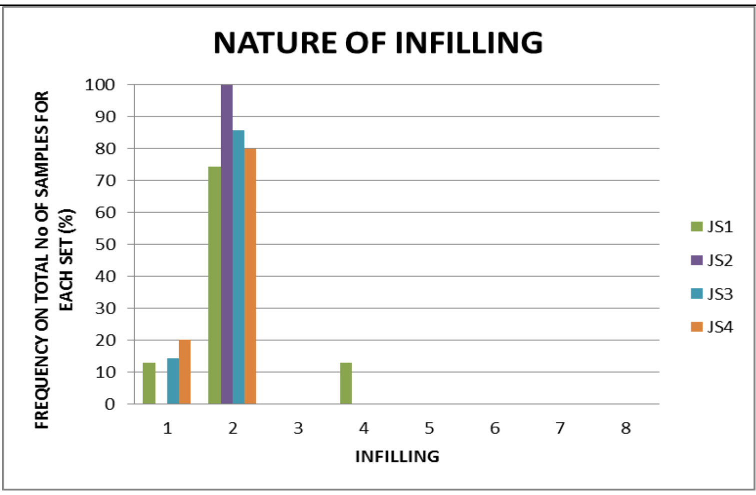
1,Extremely close spacing: <0.02m
2,Very close spacing: 0.02-0.06m
3, Close spacing: 0.06-0.2m
4, Moderate spacing: 0.2-0.6m
5, Wide spacing: 0.6-2m
6, Very wide spacing: 2-6m
7, Extremely wide spacing: >6m



Total No of samples for each set			
JS1	JS2	JS3	JS4
62	16	14	10

1,Very tight: <0.1mm
2,Tight: 0.1-0.25mm
3,Partly open: 0.25-0.5mm
4, Open: 0.5-2.5mm
5, Moderately wide: 2.5-10mm
6, Wide: >10mm
7, Very wide: 1-10cm
8, Extremely wide: 10-100cm
9, Cavernous: >1m

Figure 4-1: Joint properties: Persistency, Spacing and Aperture



Total No of samples for each set			
JS1	**JS2**	**JS3**	**JS4**
62	**16**	**14**	**10**

1, Clean
2, Surface staining
3, Non-cohesive
4, Intactive clay or clay matrix
5, Swelling clay or clay matrix
6, Cemented
7, chlorite, talk and gypsum
8, other

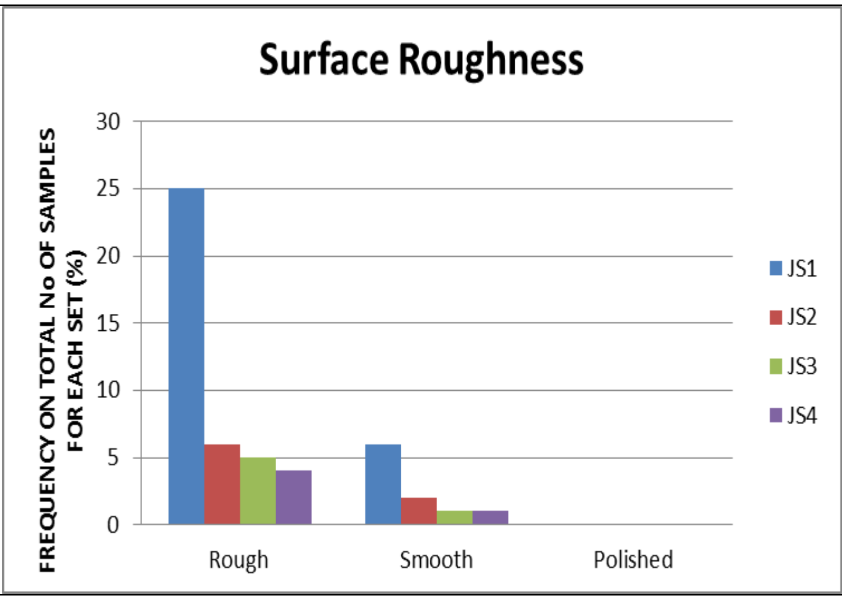


Figure 4-2: Joint properties: infilling, shape of the surface

According to the field data, it possible to conclude that all the joint sets could not affect the stability of the Dangote limestone quarry excavation, due to its geotechnical properties beside the unfavorable condition.

➢ JRC and JCS Assessment

The Joint Rough Coefficient (JRC) and Joint compression strength (JCS) values have been acquired on site through visual estimation and the use of geological Hammer.

The JRC has been evaluated comparing the appearance of the discontinuity surface with the standard profiles published by Barton et.al (1977) as illustrated here below:

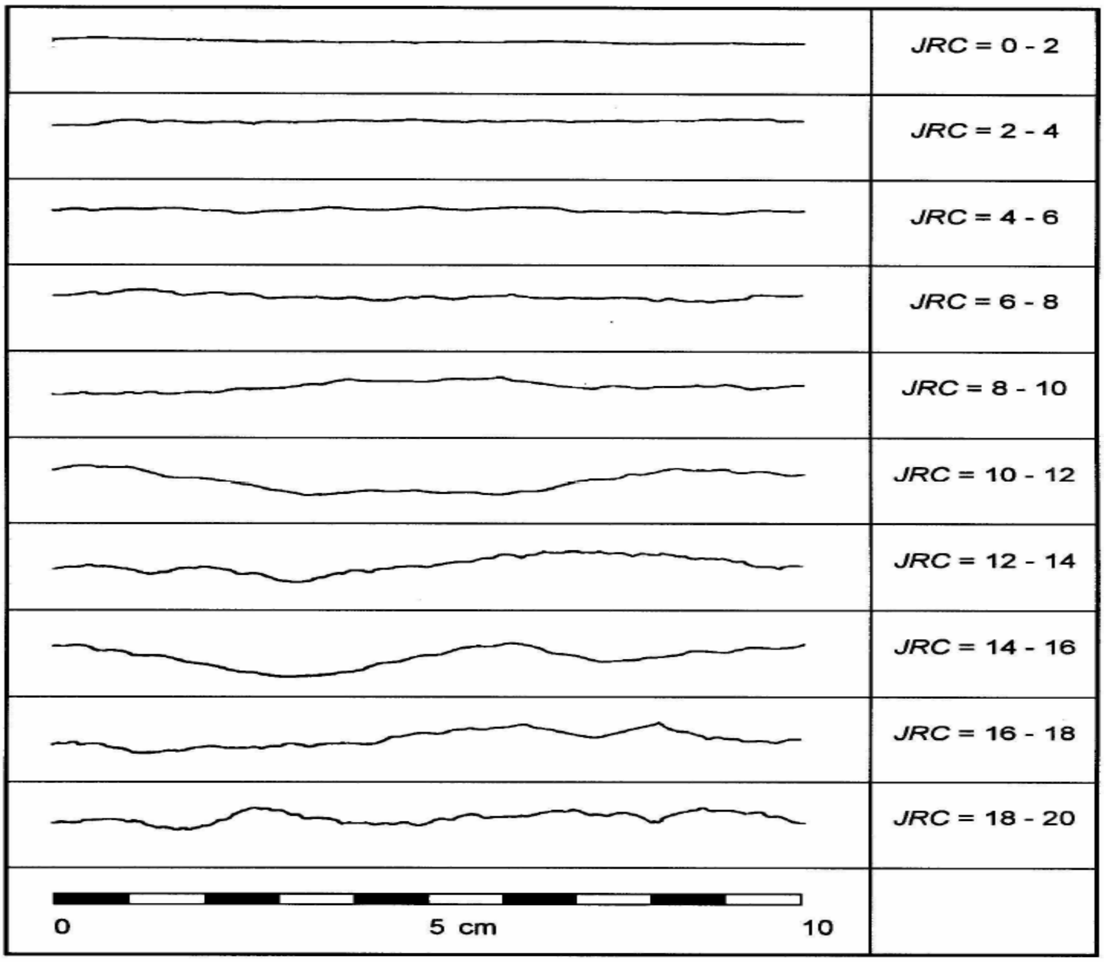


Figure 4-3: Roughness profile and corresponding JRC values (After Barton and Choubey, 1977)

The results are conservative, to avoid the inaccuracy of the visual comparison with the standard profiles. Accordingly, the study joint sets most of them have the same joint surface profile (i.e. slightly rough joint surface), relevant to stability, 4-6 JRC value is given to all joint set in the study area.

The joint compression strength (JCS) has been estimated using geological Hammer, as given in Table 4.9 bellow for each joint sets in the study area.

Table 4-9: JCS Results for Dangote limestone quarry

Joint Set	JCS(MPa)
JS1	70
JS2	70
JS3	80
JS4	80

The effect of weathering is considered in evaluating JCS, which affect the value of unconfined compressive strength of the rock (UCS). If the joint are completely unweathered, JCS will be equal to UCS (Barton and Choubey, 1977).

4.3 Estimation of Shear Strength of Rocks

For the stability analysis of rocks slope, shear strength properties of the rock mass along the potential of discontinuity planes are important parameters (Hoek and Bray, 1989; Johnson and DeGraff, 1991; Sherma et al., 1999). Thus, the analysis of shear strength of the joint sets was made using Barton et al and Palmstone (1982) equations below. Due to the non-availability of strength of the joint sets, the shear strength of this joint surface was estimated using the empirical law of frictions for rock joints, which can be used for extrapolating and predicting shear strength data (Barton, 1973).

In order to estimate RMR, the shear strength parameter at various locations present in table 4.1 Factors that determines shear strength are degree of cohesion(C) and angle of internal friction (ϕ) and normal stress on the rock surface. The determination of shear strength based on mathematical equations is.

$$\tau = C + \sigma_n \tan \phi$$

As Surface roughness increases, shear strength of the surface also increased and this relation is very important for stability analysis. Barton et al. (1973, 1976, 1977, and 1990) has studied on the behaviour natural rock joint is great detailed and have proposed the shear strength of discontinuity planes by mathematical relations (Hoek, et.al. 1995):

$$\tau = \sigma_n \tan [\phi b + JRC \log10 (JCS/\sigma_n)]$$

Where, JRC is the joint roughness coefficient and JCS is the joint wall compressive strength.

In order to estimate the angle of friction (ϕ) for the potential failure planes the law of friction (Barton, 1973) has been applied. Inspection of table 4.8 indicates that the estimated values of angles of frictions are on the higher side. In relation to the larger persistence of joints slickensides to slightly rough and moderately weathered surface, the values estimated using the law of friction (Barton, 1973) may not represent the realistic conditions. More over the angle of internal friction of the rocks mass at all critical slope section, as derived from RMR, is much lower (Table 4.10) than what estimated using the law of friction. Therefore to be on conservative side, the angle of friction (ϕ) estimated by RMR has been considered for the stability analysis.

Table 4-10: Estimate shear strength of rock mass along potential discontinuity planes

Slope section	Basic friction angle(ϕ_b)	Joint rough coefficient (JRC)*	JCS[a] (kgcm-2)	Compressive strength of surface rock	Effective normal stress acting joint surface	Angle of friction tan^{-1} (τ/σ_n)
LST1	35	5	70	70	1.01	36.5
LST2	35	4	70	70	8.6	36.22
LST3	35	6	80	80	8.8	39.1
LST4	35	5	80	80	.11	46.03
LST5	35	2	80	80	6.7	36.00

*JRC as determine by roughness profile chart proposed by Barton and Choubey (1977). 'a'= Joint Compressive Strength

4.4 Fracture Analysis

Study area rock mass contains discontinuity surface dipping towards the slope face at angle between 4^0-25^0 & mostly contains vertical and horizontal joints (discontinuity) but some points dip & dip direction reaches up to 40^0. The rock mass forming the Dangote limestone quarry mining consist of discontinuity planes mainly joint and small local fault. Using Schmidt projection lower hemisphere plotted the measurement data comes from field and density analysis facility program the poles were contoured on Schmidt counting net.

Table 4-11: Uniaxial compressive strength and unit weight of rocks

Location of the sample	rock type	unit weight (tone m-3) ucs
Lst1	limestone	2.5
Lst2	limestone	2.5
Lst3	limestone	2.5
Lst4	limestone	2.5
Lst5	limestone	2.5

The major planes dip direction and dip amount are plotted in dip software. The fracture analysis has been used for kinematic analysis check for each slope sections.

4.5 Kinematic Analysis

A kinematic (limit equilibrium analysis) analysis is the first step in evaluating rock slope stability. Kinematics refers to the motion of bodies without reference to the forces that cause them to move (Goodman, 1989).

To determine the slope stability of the quarry first identified the possible mode of failure. The mode failure is depend on different factors those are Geometry of the slope, slope height, slope angle and upper slope angle, structural discontinuities their preferred orientation, shear strength properties of discontinuities cohesion 'C' and angle of internal friction ‘ϕ’, and water saturation conditions. The influence of each factor may vary from slope to slope with in the conditions (Bieniawski, 1989).

The stability of hard rock slopes is typically controlled by discontinuities (joint and joint sets) within the rock; Failures tend to occur as discrete blocks. Discontinuities form intersecting planes of weakness without discontinuities, rock slopes; even some composed of relatively weak rock could stand hundreds of meter long without the potential for failure. Kinematic analysis of the discontinuities is performed to determine the potential modes of failure. Highly fractured rock slopes in which there is likely no single or distinct discontinuity surface on which movement will occur should also be analyzed in this fashion. These analyses require a value for φ (friction angle) and c (cohesion), which can be determined with lab tests or software analysis after field measurement.

Table 4-12: Preferred orientation of discontinuity plane and possible mode of failure.

	Geometry of the critical slope		**Preferred orientation of discontinuity plane dip direction /dip amount**				**Possible mode of failure**
S.s.	**Slope inclination(αf)**	**Upper slope (αs)(^{0}) /inclination**	**Height(m)**	**J1**	**J2**	**J3**	
Lst1	N120/75	N120/20	12	N217/15	N140/23	N155/07	----------
Lst2	N115/65	N115/25	12	N155/25	N215/13	N180/35	----------
Lst3	N115/72	N115/20	12	N127/09	N165/40	N194/13	----------
Lst4	N120/55	N120/15	12	N103/19	N109/23	N165/15	----------
Lst5	N150/28	N150/09	12	N198/20	N160/05	N130/09	----------

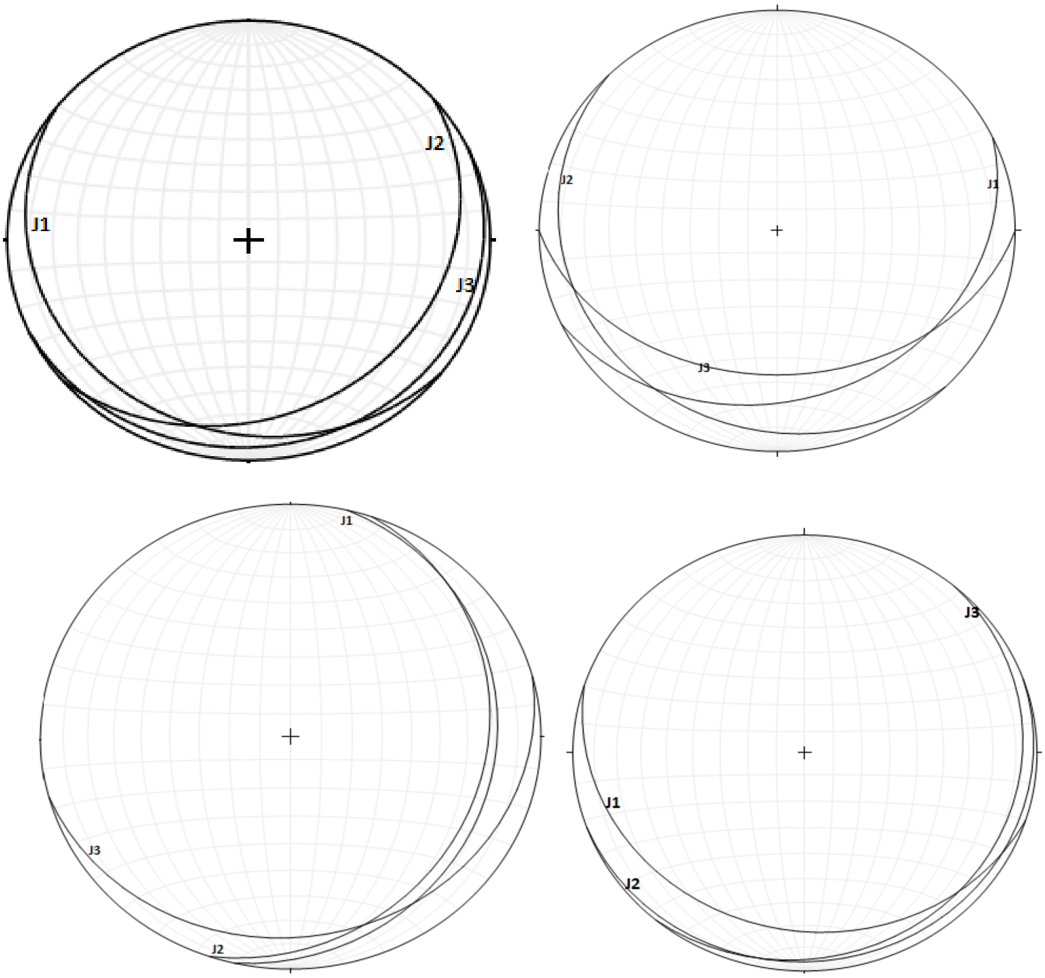


Figure 4-4: The orientation of discontinuity plane, geometry of slope

Figure 4.4 the orientation of discontinuity plane, geometry of slope and possible mode of failure in critical slope section shows the slope of geometry and orientation of discontinuity is sub horizontal direction. For determination of kinematic, check Markland test (Hoek and Bray, 1989; Johnson and DeGraff, 1991, Yoon et al., 2002) has been applied to all critical slope section. Structural data, along with the slope inclination and a 'phi' circle corresponding to the angle of internal friction (ϕ) of the rock mass has been plotted on equal area projection 'Schmidt net'.

Table 4-13: possible potential failure critical slope section

S.s	Slope angle (αf) (^{0})	Upper slope (αs)(^{0})	Failure plane angle αp (^{0})	Cohesion (C)	Angle of internal friction (ϕ)	Density of rocks	Unit weight of water	Height (m)
Lst1	75	20	N140/17	2.08	54.74	2.5	1	12
Lst2	65	25	N215/13	0.94	54.29	2.5	1	12
Lst3	72	20	N165/20	0.93	55.54	2.5	1	12
Lst4	55	15	N165/15	2.091	54.34	2.5	1	12
Lst5	28	09	N160/08	2.089	57.74	2.5	1	12

The angle of friction has been estimated from RMR data (Table 4.8) present the stereonet plot showing there is no any possible mode of failure in critical slope section. Therefore, it does not need further analyses for factor of safety (FOS) under existing and expected (dynamic & static) conditions. Rock failure was modeled and simulated using Rocscience.RocPlane.v2.029 software.

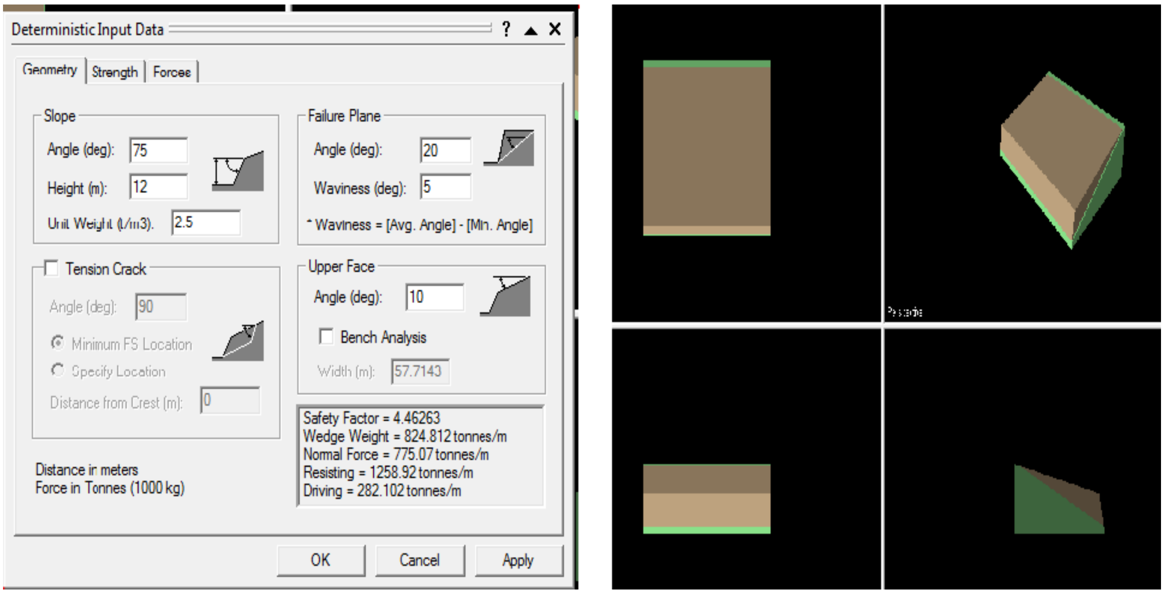


Figure 4-5: Model and Simulation possible failure mode in critical rock slope sections 1

Using the orientation of discontinuity plane and geometry of slope in Table 4.4 the simulation of possible mode of failure has been done. And based on the simulation result there is no possible mode of failure in every critical slope sections in figure 4.5, which is kinematically stable. Hence, the area does not need further analysis for stability of mining i.e. the result indicates that all limestone quarry cut slope section is stable for the existing condition (static dry) and will remain stable even for dynamic condition when it is dry. The simulation result for the rest of the sections is attached to Appendix A.

4.6 Slope Design (pit design)

Determination of the slope stability analysis of rocks is vital for designing safe slopes in open pit mines. A proper slope design not only leads to improvements in slope stability and safety but also reduces costs, extends the life of mines and decreases the stripping ratio (Bye and Bell, 2001, Naghadehi et al., 2011).

Rock cut slope design is performed to evaluate existing and proposed rock cuts, and to determine the cut slope angle for the steepest, continuous & stable slope without intermediate slope benches. The design accounts for cut slope performance and safety while optimizing excavation quantities. Slope stabilization and rock fall protective measures may be required to minimize localized or small scale instabilities within the overall cut Manfakh et al., (1998), Wyllie and Mah (2004) and Hoek and Bray (1989).

I. Data applied for Open Pit Design Utility

Inputs for open pit design using Datamine studio 3.21 software are:

- Bench Height 12m,
- Bench interval 3m,
- Total Bench Height 36m,
- Reference elevation 2032m (bottom of open pit) ,
- Face Angle 70^0,
- Inter ramp Angle 63.3^0,
- Berm width 5m,
- Road width 20m,
- Road Gradient 10%, and
- Direction – clockwise.

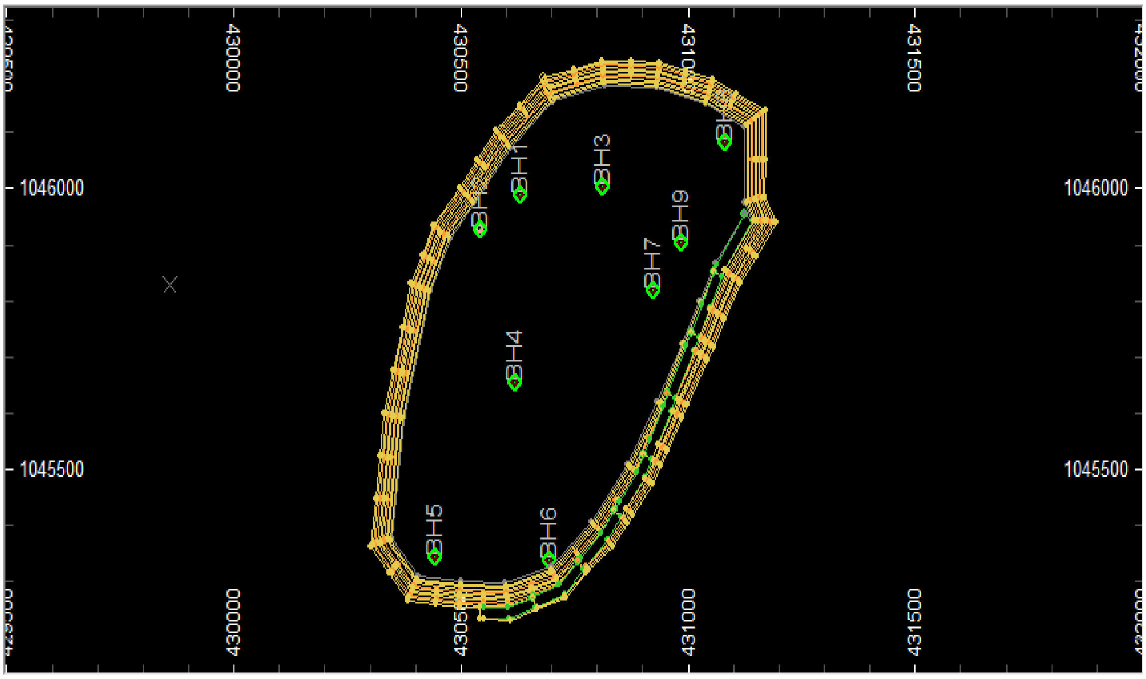


Figure 4-6: Open pit design of Dangote quarry

The above figure 4.6 conceders as slope design model, were how the mining activity is started based on the elevation direction of the raw material i.e. starting of logistic activity (excavation and transportation) of the raw material. This also indicate horizontal shape rather than conical shape and excavating with in the given bench height intervals. The green diamond in the figure shows it's a bore hole data point at which the sample is taken.

Table 4-14: Resource estimation of the study area

Object: Trimmed orebodytr/Trimmed orebodypt (wireframe)

Enclosed volume	= 19034625.86
Enclosed tonnage (@1.00)	= 19034625.86
Centre of gravity	= 430583.19, 1045709.76, 2081.25
Projected lower area	= 411803.57
Projected upper area	= 268555.45
Total surface area	= 852257.23
Minimum elevation	= 1951.58
Maximum elevation	= 2152.97
Minimum X co-ord	= 430346.01
Maximum X co-ord	= 431183.79
Minimum Y co-ord	= 1045315.27
Maximum Y co-ord	= 1046121.32
Minimum surface dip	= 2.35
Maximum surface dip	= 90.00
Number of triangles	= 158

Preliminary resource estimation is done by using Datamine studio 3 software using 9 drill holes having 1.9 million tons of deposit from 0.85 square kilometer of total surface are.

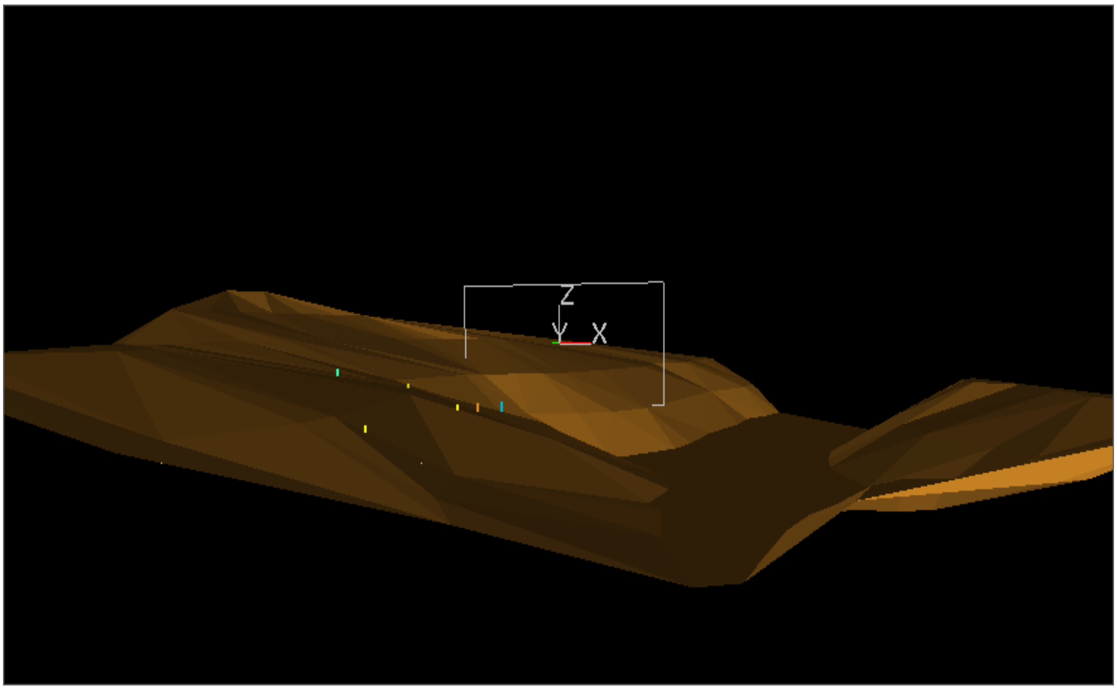


Figure 4-7: Topographic Map of the study area

From figure 4.7 3D map of the mining site shows different elevation i.e. at the right side of the figure indicates a gorge which is namely a Mugher valley and away from the valley elevation is increasing which shows an abundant resources.

II. Resource Estimation

Preliminary resource estimation is done by using Datamine studio 3 software using 9 drill holes having a total of 98.62m depth and revealed the following table result.

Table 4-15: Open pit wireframe calculation Report

Object: trimmed openpittr/trimmed openpitpt (wireframe)

Enclosed volume	= 1663916.77
Enclosed tonnage (@1.00)	= 1663916.77
Centre of gravity	= 430471.82, 1045717.53, 2063.97
Projected lower area	= 0.00
Projected upper area	= 466503.99
Total surface area	= 501867.56
Minimum elevation	= 2032.44
Maximum elevation	= 2128.44
Minimum X co-ord	= 430303.62
Maximum X co-ord	= 431095.98
Minimum Y co-ord	= 1045258.78
Maximum Y co-ord	= 1046210.18
Minimum surface dip	= 0.00
Maximum surface dip	= 70.00
Number of triangles	= 239

The following assumptions were made during the resource estimation;

- ✓ Since the drill holes are not adequate enough to represent the overall population of the resource it is declared as inferred resource
- ✓ To simplify the calculation of tonnage an earth density of 1 g/c.c. is taken
- ✓ The overall resource indicates the future potential of the deposit, and hence do not represent the minable part (the reserve) of the raw material for the production of cement.
- ✓ The ore body generally plunges south, evidenced by the thick soil cover (overburden thickness).

4.7 Determination of Sequence Excavations

In the mining company the main problem is the lack of indication of starting point of mining, most of the time the mining process starts randomly. This problem increases the cost of the excavation and transportation of the raw material. Limestone quarry production scheduling problem can be defined as specifying the sequence in which 'blocks' should be removed from the quarry in order to maximize the total discounted profit from the quarry subject to a variety of physical and economic constraints associated with the limestone quarry and cement plant (Joshi et al., 2012).

Currently, the industry has realized the potential impact of cost savings in producing raw materials from the quarry operations. Therefore, it is focusing on the means towards the development of most favorable alternatives to plan and operate limestone quarries. The sequencing techniques differ from one another based on the direction of mining; i.e. for the same starting point (base block) each technique will follow a different preferred direction, and hence, gives a different raw mix quality due to difference in chemical composition of the exposed area on bench. The directional sequencing technique accepts the directional weights and quality of quarry, i.e., the number of blocks to be considered for mining in the north, south, east, and west direction of the base bench or the starting point.

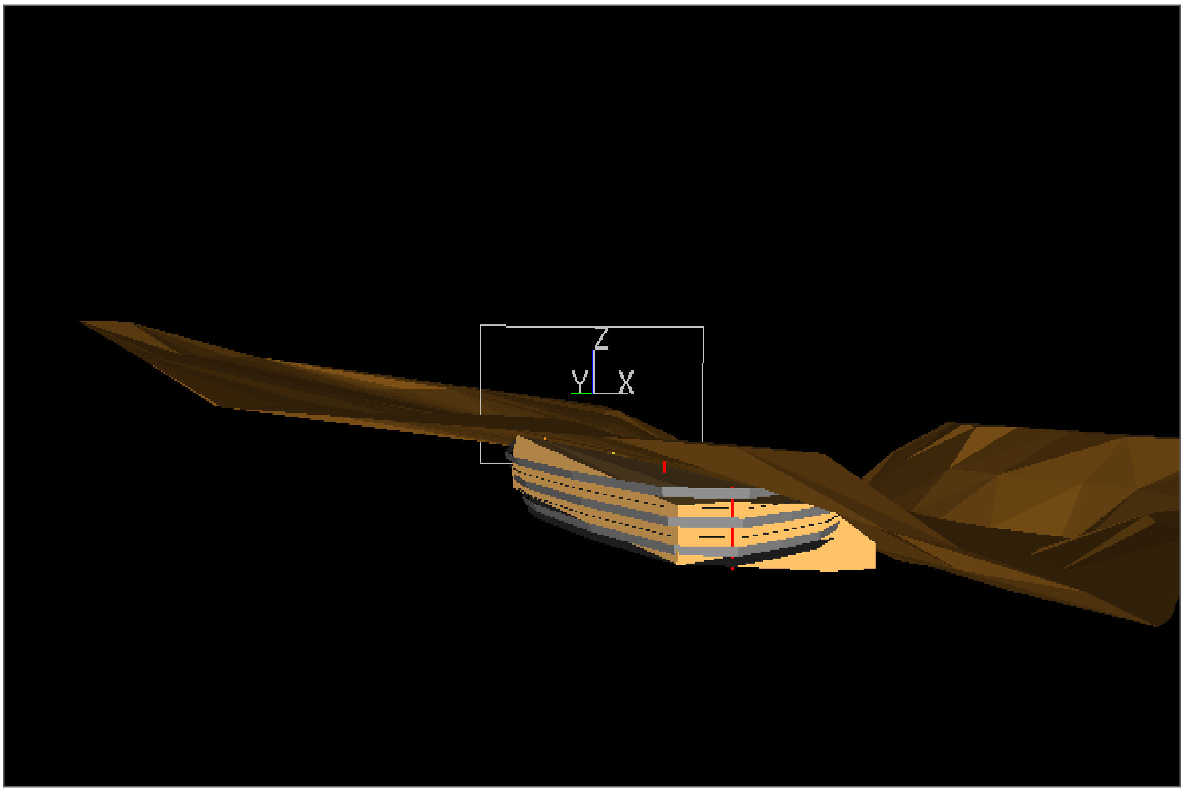


Figure 4-8: Open pit design with slope direction

The sequential direction is determined based on the ratio of deposit of overburden to ore body deposit. The mining activity starts from the smallest ratio of overburden to ore body. From figure 4.7, the large amount of overburden indicated in the direction of southwest, and the large amount of ore body is indicated from the northwest direction. Based on this, the smallest overburden to ore body ratio is in the direction of northwest. Therefore, the sequential direction of excavation have to start along northwest direction for the long term quarry planning and cost effectiveness.

4.8 Rock quality

The usage of different industrial minerals being significant in the various engineering applications and the need for increased production, a more effective approach is needed to solve its exploitation problems. Limestone is a sedimentary rock composed primarily of calcium carbonate with the occasional presence of magnesium. Most limestone is biochemical in origin meaning the calcium carbonate in the stone originated from shelled oceanic creatures.

According to British geological survey (2011) in seeking to identify limestone as being fit for particular industrial applications there are many different qualities of the mineral needs to be taken into account. Limestone consists principally of calcium carbonate; with an increase in magnesium carbonate, limestone grades into dolomite. Most limestone contain varying amounts of impurities in the form of sand, clay and iron bearing materials. These impurities are usually present in small proportions in industrial limestone which are generally valued for their ‘high purity’ i.e. greater than 96-97% calcium carbonate defining high purity limestone and greater than 98-98.5% being very high purity limestone. For many applications, however, it is the level, or absence, of the specific impurities present or the consistency or color of the limestone which are of paramount importance, rather than the absolute values for calcium carbonate. For this reason, the Plan uses the term ‘industrial’ limestone rather than ‘high purity’ limestone. And the long range planning is required to understand the amount of limestone can be supplied to the plant from the quarry (Joshi et al., 2012).

Table 4-16: Classification and uses of limestone by calcium carbonate content (British geological survey, 2011)

Category	$CaCO_3$ (%)	possible industrial usage (Grouped by minimum $CaCO_3$ specification)
Very high purity	>98.5	steal, rubber, plastic, paint
High purity	97-98.5	iron, ceramic, Portland cement
Medium purity	93.5-97	paper (subjected to color)
Low purity	85-93.5	Asphalt
Impure	<85	Mineral wool and natural cements (subject to the silica/clay mineral ratio)

Table 4-17: Limestone purity classification (BGS, 2011)

<table>
<tr><th>Purity classification</th><th>$CaC0_3$ (%)</th><th>CaO (wt %)</th><th>SiO_2 (wt %)</th><th>MgO (wt %)</th><th>Fe_2O_3 (wt %)</th></tr>
<tr><td>Very high purity</td><td>>98.5</td><td>>55.2</td><td><0.2</td><td><0.8</td><td>0.05</td></tr>
<tr><td>High purity</td><td>97-98.5</td><td>54.3-55.2</td><td>0.2-0.6</td><td>0.8-1.0</td><td>0.05-0.1</td></tr>
<tr><td>Medium purity</td><td>93.5-97</td><td>52.4-54.3</td><td>0.6-1.0</td><td>1.0-3.0</td><td>0.1-1.0</td></tr>
<tr><td>Low purity</td><td>85-93.5</td><td>47.6-52-4</td><td><2.0</td><td rowspan="2">>3.0</td><td rowspan="2">>1.0</td></tr>
<tr><td>Impure</td><td><85</td><td><47.6</td><td>>2.0</td></tr>
</table>

4.8.1 Petrographic descriptions

Eight rock samples collected from two quarry sites Mugher at the same lithology and studied for petrographic analysis at geological thin-section laboratory. Under petrographic microscope the detail explanations for 4 representative limestone samples were made to confirm field observations. According to the petrographic analysis various major carbonate components like allochems (varieties of skeletal grains, ooids, peloids and intraclasts) and interstitial materials (microcrystalline calcite ooze/micrites and sparites), textures are identified. All these components are varying in abundances, in sizes, colors, and texture from place to place throughout the studied sections. The proportions among various carbonate components in all collected samples were identified and the rocks are classified according to Dunham (1962) and Folk (1962) carbonate classification schemes.

The sample is designated as M1 M2 M3 and M4, where M is stands for site name and numbers from 1 to 4 is the order of the sample.

Samples M1 and M2

Petrographic analysis it has not as such variable minerals it’s dominated by micrite, sprite and some iron oxide. Most of the analyzed samples are limestone (they contain > 70% micrite, 20% spirit and minor fossils and iron oxide minerals). According to (folk 1959, 1962) limestone classification system sample being a matrix support limestone is less than 10% allochemes during this time the fossils are microfossil which means according to folk classification the limestone is micritic limestone. Facies is the microfacies in which dominant, larger size mud peloidal grains ~ 30% are imbedded in the micrite and sprite dominated fine materials.

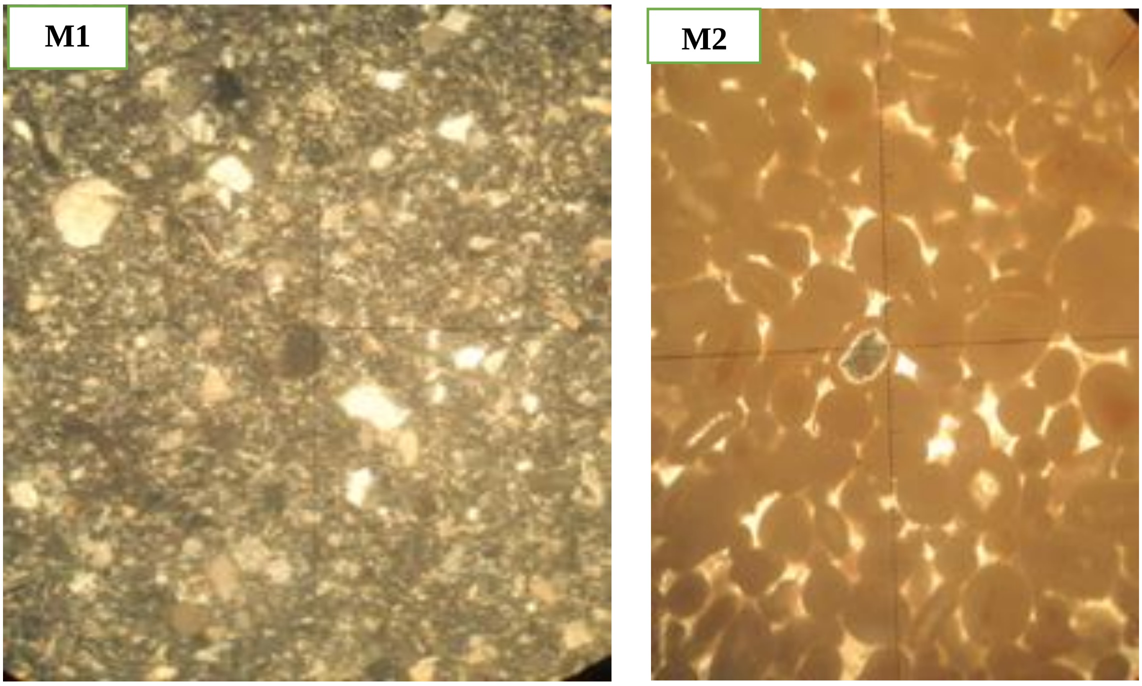


Figure 4-9: Photomicrography of samples M1 and M2 respectively, showing the various shaped carbonate clasts (cls) are imbedded in the sparry calcite cements and some micrite. The grains are poorly sorted and irregular in shape. (XPL, 40X).

According to (folk 1959, 1962) limestone classification system sample being a matrix support limestone is less than 10% allochemes is grouped under micritic limestone.

Table 4-18: Petrographic descriptions of carbonate rocks samples

S. N	Rock's major components (modal composition) (%)						Rock name	
	Allochems				Interstitial materials		Fe-oxide	According to Dunham/Folk
	Fossil	Ooids	Peloid	Intra	Micrite	Spharite		
M1	7	5	10`	5	20	53	-	Mudstone / Micritic
M2	3	-	-	-	47	20	-	Mudstone / Micritic
M3	-	25	35	-	25	10	5	Mudstone / Micritic
M4	4	-	-	-	45	45	6	Mudstone / Micritic

4.8.2 Quality (Purity) of the Limestone

The size of the quarry site is 1.8 square kilometer in which two bench of almost 1.2 square kilometer is taken. This bench is divided into five drilling patterns among this three of them are taken from bench one which is equal in size and have six boreholes. And the second bench has two drilling patterns which are different in size. Every drilling pattern had six boreholes. So from every boreholes from a single pattern the XRF samples were takes and analyzed in the laboratory. Hence the percentage of the main oxide minerals were identified. Then for every drilling pattern the average result were taken. Based on this the sample of drilling pattern is designated us DB1B1,DB2B1,DB3B1,DB4B2 and DB5B2 were D stands for Dangote, B1 and B2 stands for bench number, and the number from 1to 5 stands for drilling patterns. Which is analogy to sample number.

According to BGS (2011) purity of limestone examine for different field of application specification based on major oxide mineral content. British Geological Survey specification standard limestone purity classification is based on the calcium carbonate content.

Table 4-19: Result of (XRF) chemical analysis of the limestone of Dangote quarry

Sample type	S. no.	CaO%	MgO%	SiO_2%	Fe_2O_3%	Al_2O_3%	H_2O	Total
Limestone	DB1B1	47.14	1.31	9.46	1.46	1.69	1.96	63.02
Limestone	DB2B1	46.92	14.0	9.03	1.75	1.96	1.60	75.26
Limestone	DB3B1	46.98	1.25	9.05	1.76	2.07	1.40	62.51
Limestone	DB4B2	48.00	1.19	8.30	1.43	1.61	1.80	62.33
Limestone	DB5B2	47.37	1.43	9.24	1.33	1.49	2.46	63.22
Average		47.2	3.8	9.0	1.5	1.8	1.8	65.1

During industrial mineral quality or purity study we have to focus on composition of sedimentary rock that may occur in limestone are dolomite and other carbonate minerals (such as siderite), silica (as fie-grained quartz or chert), clay minerals (such as kaolinite, illite or chlorite), organic matter (often bituminous), pyrite and florite. Trace amounts of 'accessory' minerals such as zircon, tourmaline, feldspar, iron minerals (haematite, magnetite and limonite), garnet and titanium minerals (ilmenite, rutile and leucoxene) may also occur (Summerson et al. 1957).

The average value of each major oxide mineral of rock from XRF results are listed accordingly: CaO < 47.6wt. %, MgO > 3wt. %, SiO_2 > 2wt. %, Fe_2O_3 > 1wt%. In the study area result CaO =47.2wt. %, MgO = 3.8wt. %, SiO_2 = 9wt. %, Fe_2O_3 =1.8 wt. %. Hence, according to BGS standard classification it lies under impurity limestone. Therefore, the major output of result is that used for Mineral wool and natural cements (subject to the silica/clay mineral ratio).

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The instability and dilution of the rocks was the major problem for mining site and industries as it may take their incomes, times interrupts their daily activities of the mining. Therefore, in this paper the evaluation of the limestone quarry planning and the slope stability of open pit mining of limestone quarry has been studied.

In-situ tests were conducted for the determination of rock mass rating (RMR), evaluation of geologic structures and sample systematically collected every 100m difference from mining site. For determination of purity for further applications and mineralogical and chemical test were made in Ethiopian geological survey, Dangote cement factory laboratory. For the analysis of slope stability design (open pit design) Datamine studio 3.21 software were used. Thus, based on the results and discussions of the paper, arising from field observation, laboratory results and software analysis the following conclusion were made:

- ✓ Results of the Geological Hammer rock strength test indicate that all the rock fall in the category (R_3) medium strong to (R_4) strong rock with average of strong rock.
- ✓ All the test (UCS, RQD, condition of discontinuity,) were carry out on surface rock outcrops with slightly weathered and in dry condition.
- ✓ The rock is slightly weathered and measurement was made at slope surface indicating that the surface of limestone rock is more fractured.
- ✓ Based on the average result of RMR determination the result lays under fair rock mass classification (50 – 60%).
- ✓ The rock are light Brown, medium strong to strong, fine grained with strong to weak joint sets, characterized by slightly weathered (locally moderately weathered), open to slightly open (1mm-1cm), medium spaced (6cm-60cm), slightly rough, persistent to medium persistent joints in filled with sandy clays and limonite (soft and hard material) (Ø 1mm-1cm)
- ✓ According to the field data, it possible to conclude that all the joint sets could not affect the stability of the Dangote limestone quarry excavation.
- ✓ The results are conservative, to avoid the inaccuracy of the visual comparison with the standard profiles. Accordingly, the study joint sets most of them have the same

joint surface profile (i.e. slightly rough joint surface), relevant to stability, 4-6 JRC value is given to all joint set in the study area.

- ✓ Based on the simulation result there is no possible mode of failure (plane failure, wedge failure, circular failure) in every critical slope sections, which is kinematically stable. Which is, the area does not need further analysis for stability of mining i.e. the result indicates that all limestone quarry cut slope section is stable for the existing condition (static dry) and will remain stable even for dynamic condition when it is dry.
- ✓ The large amount of overburden indicated in the direction of southwest, and the large amount of ore body is indicated from the northwest direction. Based on this, the smallest overburden to ore body ratio is in the direction of northwest. Therefore, the sequential direction of excavation have to start along northwest direction for the long term quarry planning and cost effectiveness.
- ✓ According to (folk 1959, 1962) limestone classification system most of the analyzed samples are limestone (they contain > 70% micrite, 20% spirit and minor fossils and iron oxide minerals).
- ✓ According to BGS (2011) purity of limestone examine for different field of application specification based on major oxide mineral content. British Geological Survey specification standard limestone purity classification is based on the calcium carbonate content. The average value of each major oxide mineral of rock from XRF results are listed accordingly: CaO < 47.6wt. %, MgO > 3wt. %, SiO_2 > 2wt. %, Fe_2O_3 > 1wt%.
- ✓ Hence, according to BGS standard classification it lies under impurity limestone. Therefore, it used for Mineral wool and natural cements (subject to the silica/clay mineral ratio).

5.2 Recommendation

Based on the findings of this research, ease of further study and recommend, the following measurement is recommended for the study area.

- ✓ For more understanding of the pit design in quarry I recommend detail started again from northwest direction to minimize cost of product
- ✓ For more understanding of the quality I recommend why Mugher valley limestone has law purity needs further study

Reference

Abdullah, A. (1990). Effects of search parameters on kriged reserve estimation. *International journal of mining and geological engineering*. **8**: 319–331.

Alejano, L.R., Ferrero, A.M., Oyanguren, P.R., Fernandes, M.I.A. (2011). Comparison of limit equilibrium, numerical and physical models of wall slope stability. *International Journal of Rock Mechanics and Mining Science*, **48**: 16–26.

Alula, H.G.; Gasaw Beza, M.; Kibre, T.; Tessfaye, D. (1992). *The geology of Sola area*, Report, Ministry of Mines and Energy: Addis Ababa; 20p.

Asad, M.W.A. (2008). Multi-Period Quarry Production Planning through Sequencing Techniques and Sequencing Algorithm. *J. Min. Sci*. **44**(2): 206–217.

Asfawossen Asrat, A., Demissie, M., Mogessie, A. (2009). Geotourism in Ethiopia. Shama Books, Addis Ababa, Ethiopia, 187 p

Asfawossen Asrat (2015). Geology, geomorphology, geodiversity and geoconservation of the Sof Omar Cave System, Southeastern Ethiopia, *Journal of African Earth Sciences*. **108**: 47-63

Assaminew Gebeyehu (2007). GIS-Based Groundwater Vulnerability Mapping of Holeta River Catchment, unpublished MSc. thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Barton, N. and Choubey, V. (1977). The shear strength of rock joints in theory and practice, Rock Mech. 10:1–54.

Barton, N. (1973). Review of a new shear strength criteria for rock joints. Eng. Geol. 7:287–330.

BGS (British Geological Survey) (2011). High purity limestone quest, conducts a reconnaissance assessment at a high purity limestone deposit in the Middle East.

Bieniawiski, Z.T. (1989). Engineering Rock Mass Classifications. Wiley, New York, pp. 251.

Binks RM, Fairhead JD. (1992). A plate tectonic setting of Mesozoic rifts of West and Central Africa. *Tectono physics* **213**: 141–151.

Bosellini A. (1989). The continental margins of Somalia: their structural evolution and sequence stratigraphy. *Memorie di Scienze Geologische, Padova* **41:** 373–458.

Bosellini A, Russo A, Fantozzi PL, Assefa G, Solomon T. (1999). The succession of the Mekele Outlier (Tigre Province, Ethiopia).*Memorie di ScienzeGeologische, Padova***49**: 95–116.

Bye, A.R., Bell, F.G. (2001). Stability assessment and slope design at Sandsloot open pit, South Africa. *International Journal of Rock Mechanics and Mining Science*. **38**: 449 466.

Bromhead E.N. (1999). *The Stability of Slopes*. Taylor & Francis, New York, 416 pp.

Cox, FC, Bridge, McC. & Hull, JH. (1977). Procedures for the assessment of limestone resources. Institute of Geological Sciences, Mineral Assessment Report 30, pp. 20.

Chatterjee, S., Bhattacherjee,A., Samanta, B., Pal, S.K.(2006). Ore grade estimation of a limestone deposit in india using an artificial neural network, a*pplied GIS*. **2**(1):1-20

Deere, D. U. and Miller, R. P. (1966) Engineering Classification and Index Properties of Intact Rock. Air Force Weapons Laboratory, Kirkland Air Force Base, New Mexico.

Dolley, T.P. (2007). Stone, Dimension. USGS 2006 Minerals Yearbook. Vol. 1, Metals & Minerals.

Dunbaven, M. (1983) Discussion on R.S.Evans (1981) *Q. J. Eng. Geol.* **16**: 243–245.

Dunham, R.J. (1962). Classification of carbonate rocks according to their depositional texture. IN (W.D.Ham. (ed).) Proceedings of Classification of carbonate rocks. *Amer.Assoc.Petrol.Geol.Mem*., **1**:108-121.

Ethiopian Institute of Geological Survey (1989). Generalized geological and mineral occurrences of Ethiopia. Ministry of Mines and Energy. Unpublished report.

Evans, R.S. (1981). An analysis of secondary toppling rock failures—the stress redistribution method, *Q. J. Eng. Geol.* **14**, 77–86.

Fadel, M.A.M., Zabidi, H and Ariffin, K.S. (2015). Monitoring the Quarry Pit Development Materials, Minerals and Environment (RAMM) and Materials, Mineral and Polyme (MAMIP). **In**: Proceedings of the. 5th and 2nd Int. Cong, pp.721 – 728.Nibong Tebal, Penang, Malaysia.

Fair Head JD. (1988). Mesozoic plate tectonic reconstructions of the central South Atlantic Ocean. The role of West and Central African rift system. *Tectono physics* **155**: 181–181.

Folk, R. L. (1962). Spectral subdivision of limestone types. In Ham, W.E.(ed), Classification of Carbonate Rocks-A Symposium: American Association of Petroleum Geologists Memoir 1, pp. 62-84, Tulsa, OK.

Gani, N. DS. , Abdelsalam, M. G., Gera, S. and Gani, M. R. (2008). Stratigraphic and structural evolution of the Blue Nile Basin, Northwestern Ethiopian Plateau.,*Geol. J.* , Published online in Wiley InterScience, (www.interscience.wiley.com)

Gani, N.D.S., Abdelsalam, M.G., Gera, S., Gani, M.R. (2009).Stratigraphic and structural Evolution of the Blue Nile Basin, North-western Ethiopian Plateau. *Geological Journal,* **44**: 30–56

Getachew Nigussie (1974). Intern report on the exploration of limestone in the Mugher valley (shewa province) unpublished report, Ethiopian Institute of Geological Surveys, Ethiopia. pp. 5-17

Getaneh Assefa (1988). Potential hydrocarbon-generating rock units within the Phanerozoic sequence of the Ogaden Basin, Ethiopia: a preliminary assessment using the Lopatin model. *J. Petrol. Geol.* **11**: 461–472.

Getaneh Assefa (1991). Lithostratigraphy and environment of deposition of the Late Jurassic Early Cretaceous sequences of the central part of the North - western Plateau, Ethiopia. *N. Jb. Geol. Paläont. Mh*. **182**: 255–284.

ESAP (Ethiopian Society of Animal Production) (2007). *Pastoral Livestock Systems: Opportunities and Challenges as a Livelihood Strategy*. **In** Proceedings of the Annual conference of the Ethiopian Society of Animal Production (ESAP) held in Addis Ababa, Ethiopia, ESAP 4–6.

Getaneh Assefa (1991). The mineral resources potential of Ethiopia, department of geology, *Addis Ababa University,* **3(2):**111-137

Getaneh, Assefa (1985). The mineral industry of Ethiopia: present conditions and future proposals. *Journal of African Earth Sciences*, **3:** 331-345.

Gibre Yohanes (1989). Facies, depositional environments, digenesis and hydrocarbon potential of the Jurassic Hamanlei Formation (carbonate–evaporate rocks) in Ogadan Basin SE Ethiopia. M.Phil. Thesis, University of Reading, p. 183

Goodman, R.E., Bray, J.W. (1976). Toppling of rock slopes. Proc. Specialty Conference on Rock Eng. for Foundations and Slopes, Boulder, Colorado, ASCE 2.

Goodman R.E., (1989). *Introduction to Rock Mechanics* (2nd edition), Wiley, New York.562p.

Guiraud R, Maurin JC. (1992). Early Cretaceous rifts of west and Central Africa: an overview. In Geodynamics of Rifting, Volume II, Case History Studies on Rifts: *North and South America and Africa, Ziegler PA (ed.). Tectono physics* **213**: 153–168

Gumerov, L., Aklilu Asefa (1981).An evaluation of cement raw materials for the 5th cement plant. EIGS, Addis Ababa. Unpublished report, pp.50.

Hoek - Brown (2002). Failure Criterion, Proc. NARMS-TAC Conference, Toronto, 2002, 1, 267-273

Hoek, E. (1973). Methods for the rapid assessment of the stability of three dimensional rock slopes. *Q. J. Eng. Geol*. **6**:243–255.

Hoek, E. and Bray, J.W. (1981). Rock Slope Engineering, 3rd ed., Institute of Mining and Metallurgy, London, pp. 358.

Hoek, E. and Bray, J. (1977). *Rock Slope Engineering*, 1st edn, IMM, London UK.

Hoek, E., Kaiser, P.K. and Bawder, W.F. (1995) support of underground evcavation hard rock A.A.Balkan/Rotterdam Bookfield.

Inthavongsa I., Drebenstedt C.,Bongaerts J., Sontamino P. (2016). Real options decision framework: Strategic operating policies for open pit mine planning, *journal of Resources Policy, Elsevier*. 142 -153

International Society of Rock Mechanics (ISRM) (1981b) Rock Characterization, Testing and Monitoring; ISRM Suggested Method. Pergamon Press, Oxford, UK.

Johnson, R.B. and Degraff, J.V. (1991). *Principles of Engineering Geology*, John Wiley and Sons, New York, pp. 497.

Joshi, D., Chatterjee, S., and Equeenuddin, Sk. Md. (2015). Limestone quarry production planning for consistent supply of raw materials to cement plant, *Journal of Mining Science*, **51**, 980–992.

Karaman, k., Ercikdi, B. and Kesimal, A. (2013). The assessment of slope stability and rock excavate ability in a limestone quarry. *Earth Sci. Res. SJ.* **17**(2), 169 – 181

Kazmin, V. (1972). Geology of Ethiopia (Explanatory note to Geological map of Ethiopia, 1:2,000,000), Geological Survey of Ethiopia, Imperial Ethiopian Government Ministry of Mines; Addis Ababa (unpublished)

Keir, D., Ebinger, C., Stuart,G., Ayele, A. (2003). Seismicityof the northern main Ethiopian rift and southern red sea rifts: EAGLE M. American Geophysical Group, NASA ADS.

Kliche, C.A. (1999). Rock slope stability. SME, Littleton, CO.

Kulatilake, P.H.S.W., Wang, L., Tang, H., Liang, Y. (2011). Evaluation of rock slope stability for Yujian River dam site by kinematic and block theory analyses. *Computers and Geotechnics*, **38**: 846–860

Mohr, P. A. (1971). The Geology of Ethiopia, College of Addis Ababa press; Addis Ababa (unpublished).

Naghadehi, M.Z., Jimenez, R., KhaloKakaie, R., Jalali, S.M.E. (2011). A probabilistic systems methodology to analyze the importance of factors affecting the stability of rock slopes. Engineering Geology, 118: 82–92.

Nayak, B; Mallik, P. K. (2002). 'Characterisation of Portland cement clinker manufactured by down draft sintering and vertical shaft kiln processes'. Advances in cement research 14 (1): 1–7.

Olaleye, B.M and Ajibade Z.F. (2011) Kinematic Analyses of Different Types of Rock Slope Failures in a Typical Limestone Quarry in Nigeria. *Journal of Emerging Trends in Engineering and Applied Sciences,* **2** (6): 914-920

Palmstrom, A. (1982). The volumetric joint count – a useful and simple measure of the degree of jointing. In: Proceedings of the 4th Int. Cong, pp. 221–228. IAEG, New Delhi, India.

Pantalidis, L. (2009). Rock slope stability assessment through rock mass classification system. *International Journal of Rock Mechanics and Mining Science*, **46**: 315–325

Pariseau, W. G. (2007).*Design Analysis in Rock Mechanics,* Taylor & Francis, Netherlands, 578 pp.

Philip A. and John R. (2005). *Basin analysis: principles and applications*, 2nd ed, Blackwell, UK, 562 pp.

Raaben, V.F. and Kitachew W/Tsadik (1980). Evaluation of Oil and Gas Prospects of Ethiopia, Ethiopian Institute of Geological Survey, Ministry of Mines, Energy and Water Resource, 2: Addis Ababa (unpublished)

Russo A, Getaneh Assefa, Balemwal Atnafu (1994). Sedimentary evolution of the Abay River (Blue Nile) Basin, Ethiopia. *Neues Jahrbuch für Geologie und Palae¨ontologie Monatshefte* **5**:291308; Stuttgart.

Schiller, B., and Ellerbrock, H.G. (1992) "The Grinding and Properties of Cement with Several Main Constituents," Zement-Kalk-Gips, 45(7) pp. 325-334.

Serawit Amene and Tamrat Mojo (1999). The geology of Mugher cement factory area Abay basin, north shewa, unpublished report, ministry of mines and energy. Pp. 5-25

Solomon Tadesse, Milesi, J.P. and Deschamps, Y. (2003). Geology and mineral potential of Ethiopia: a note on geology and mineral map of Ethiopia, *Journal of African Earth Sciences* **36**: 273–313.

Sharma, S., Raghuvanshi, T.K. and Anbalagan, R. (1995). Plane failure analysis in rock slopes, *Geot and Geol. Eng*. **13**:105–113.

Sharma, S., Raghuvanshi, T.K. and Sahai, A. (1999). An engineering geological appraisal of the Lakhwar Dam, Garhwal Himalaya, *India. Eng. Geol*. **53**:381–398.

Summerson, CH, Jackson, RR, Moore, CV and Struble, RA. (1957). Insoluble residue studies of the Columbus and Delaware limestone in Ohio, *The Ohio Journal of Science*, 57 (1):**43**:4361

Tibebu Mengistu, Abera, S., Fentaw Hailemichael., Esuyawkal, T., Tadele,H., Million, H.M., Wall, H., Tesfaye, I., Mammo, Wondaferash., Melka,T. (1993).Assessment of cement raw materials in the surrounding of Mekele town. EIGS, Addis Ababa. Unpublished report pp. 121.

Tilahun Mammo (2005).Site-specific ground motion simulation and seismic response analysis at proposed bridge sites within the city of Addis Ababa, Addis Ababa, Ethiopia Eng. Geol. **79**: 127-150.

Ulusay, R., Gökçeoğlu, C., Sönmez, H. and Tuncay, E. (2001). Cause, mechanism and environmental impacts of instabilities at Himmetoğlu coal mine and possible remedial measurements. *Environmental Geology* **40** (6): 769–786.

University of Tennessee Center for Clean Products (2008). Limestone quarrying and processing: A Life-Cycle Inventor, A Report Prepared for: The Natural Stone Council, 2-28 pp.

Varenfdorff, (2003). Confidence in mine planning: the role of intelligent technologies. **In**: Proceedings of Conference on Mine Planning and Equipment Selection. pp. 35–40.

Wolela Assefa (1997). Sedimentation of the Triassic–Jurassic Adigrat Sandstone Formation, Blue Nile (Abay) Basin, Ethiopia, *Journal of African Earth Science.* **52**: (2008) 30–42.

Wyllie and Mah.W. (2004). Rock Slope Engineering, 3rd ed., Institute of Mining and Metallurgy, London, pp. 358

(http://www.dot.ca.gov/hq/esc/geotech/geo_manual/page/Geotechnical_Archive_May 2013.pdf)

(*http://www.dangotecement.com/wpcontent/uploads/reports/2016/Q1/DangoteCementGroup_Presentatio).*

http://www.iitbhu.ac.in/faculty/min/rajeshrai/NMEICTSlope/Pdf/02%20Causes%20of%20slope%20failur

Appendix

APPENDIX –A MODEL AND SIMULATION POSSIBLE FAILURE MODE

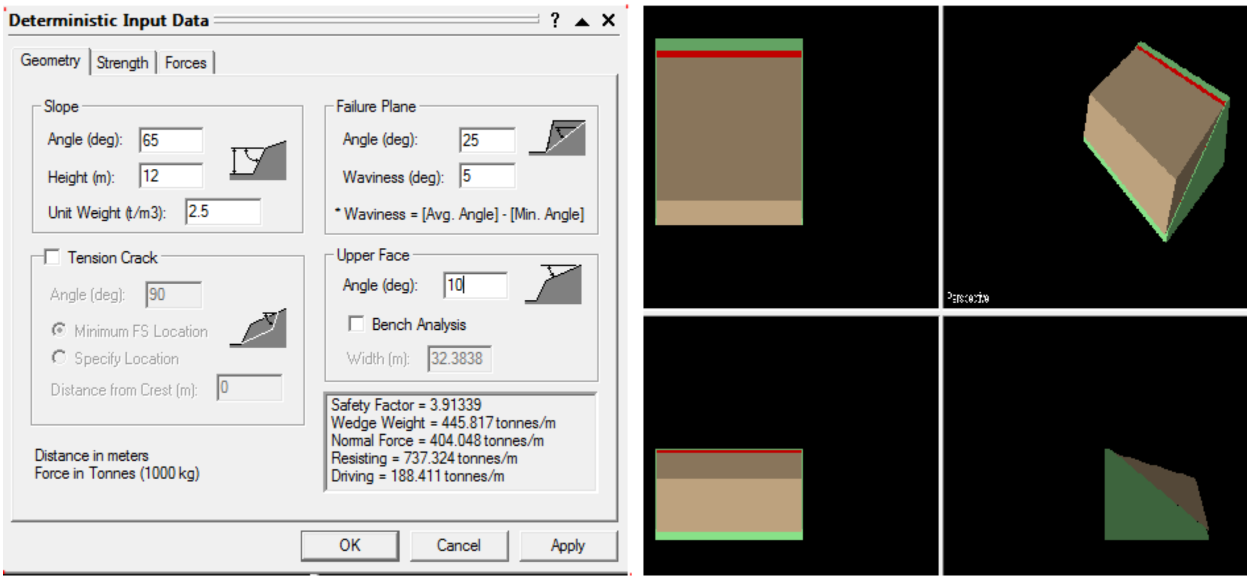


Figure A1: Model and Simulation possible failure mode in critical rock slope section2

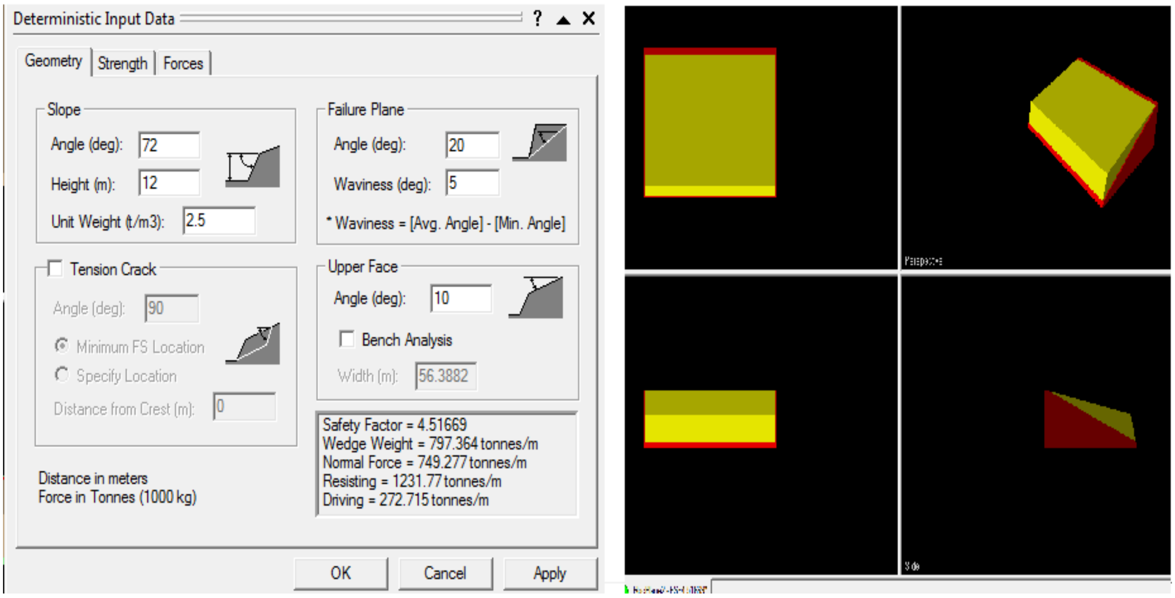


Figure A2: Model and Simulation possible failure mode in critical rock slope section 3

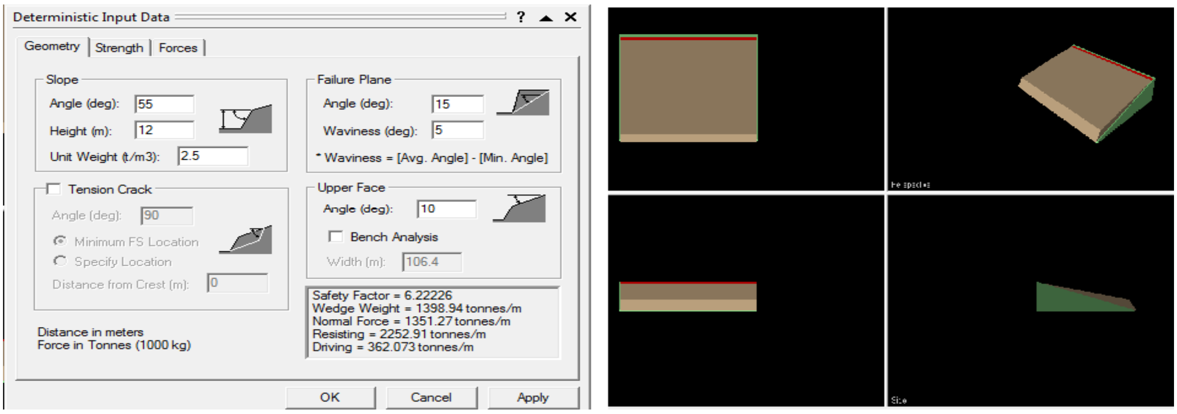


Figure A3: Model and Simulation possible failure mode in critical rock slope section 4

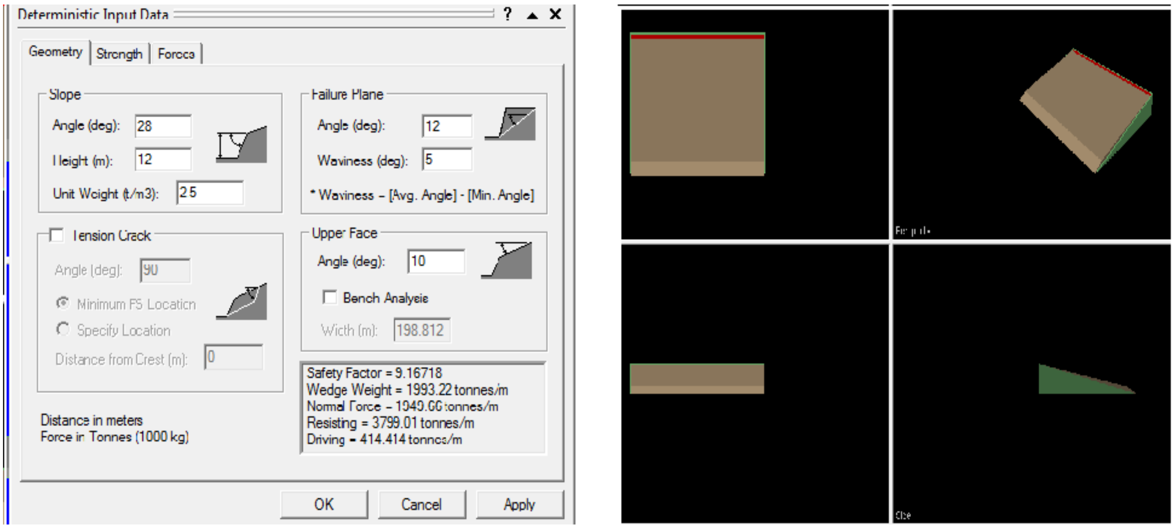
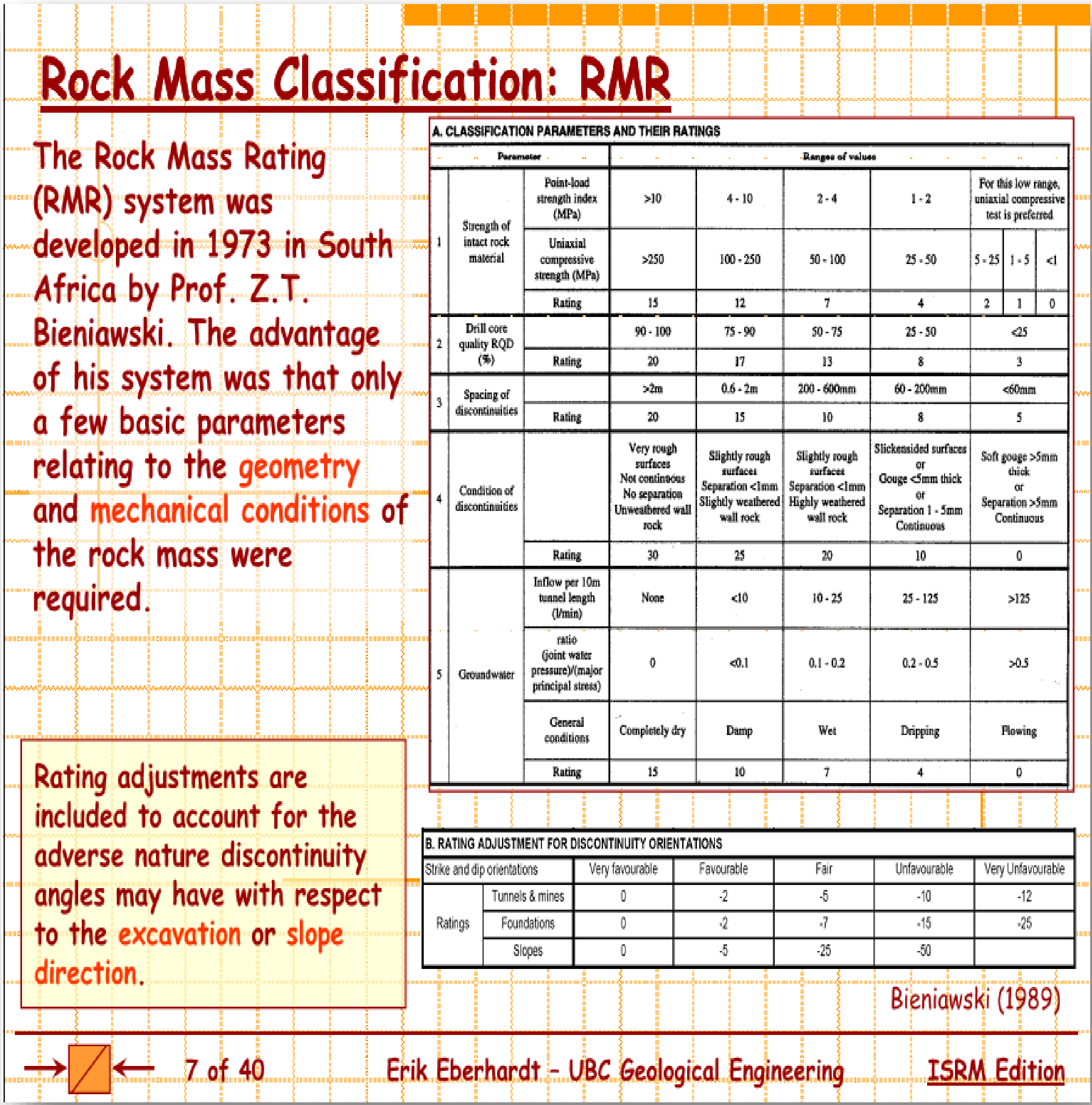


Figure A4: Model and Simulation possible failure mode in critical rock slope section 5

APPENDEX- B Rock Mass classification



APPENDIX-C DANGOTE LIMESTONE QUARRY BOREHOLE 1-9 (COLLAR)

BHID	XCOLLAR	YCOLLAR	ZCOLLAR	DEPTH
BH9	430986	1045904	2074	100.2
BH8	431083	1046083	2062	98.5
BH7	430923	1045817	2076	100
BH6	430694	1045338	2086	100
BH5	430442	1045343	2120	100.4
BH4	430619	1045653	2121	100.55
BH3	430813	1046003	2112	99.72
BH2	430542	1045928	2150	100.2
BH1	430631	1045989	2148	99.05

APPENDEX- D DANGOTE LIMESTONE QUARRY (BOREHOLE 1-9) LITHOLOGY DESCRIPTION

BHID	FROM	TO	ROCKTYPE	BHID	FROM	TO	ROCKTYPE
BH1	0	9	SOIL	BH6	0	5.45	SOIL
BH1	9	10	LMST	BH6	5.45	6.45	SOIL
BH1	10	11	LMST	BH6	6.45	7.4	BASALT
BH1	11	12	LMST	BH6	7.4	8.2	LMST
BH1	12	13	LMST	BH6	8.2	9.9	LMST
BH1	13	14	LMST	BH6	9.9	10.05	LMST
BH1	14	15	LMST	BH6	10.05	11.05	LMST
BH1	15	15.5	LMST	BH6	11.05	11.8	LMST
BH1	15.5	17	LMST	BH6	11.8	12.8	LMST
BH1	17	18	LMST	BH6	12.8	13.7	LMST
BH1	18	18.7	MARL	BH6	13.7	14.8	CLMST
BH1	18.7	19.7	MARL	BH6	14.8	15.8	CLMST
BH1	19.7	21.15	CLMST	BH6	15.8	16.6	CLMST
BH1	21.15	23.5	CLMST	BH6	16.6	17.6	FLMST
BH1	23.5	24	CLMST	BH6	17.6	18.6	FLMST
BH1			CLMST	BH6	18.6	19.4	FLMST
BH1	24	25	CLMST	BH6	19.4	20.6	FLMST
BH1	25	25.4	CLMST	BH6	20.6	21.5	FLMST
BH1			CLMST	BH6	21.5	22.5	FLMST
BH1	25.4	26	CLMST	BH6	22.5	23.3	FLMST
BH1	26	27	CLMST	BH6	23.3	24.3	FLMST
BH1	27	28	CLMST	BH6	24.3	25.3	FLMST
BH1	28	29	CLMST	BH6	25.3	26.25	FLMST
BH1	29	30	CLMST	BH6	26.25	27.25	FLMST
BH1	30	31	CLMST	BH6	27.25	28.25	FLMST
BH1	31	32	CLMST	BH6	28.25	29.25	FLMST
BH1	32	33	CLMST	BH6	29.25	30.25	FLMST
BH1	33	34	CLMST	BH6	30.25	31.15	FLMST
BH1	34	35	CLMST	BH6	31.15	32.15	FLMST
BH1	35	35.85	CLMST	BH6	32.15	33.15	FLMST
BH1	37.65	38.55	CLMST	BH6	33.15	34.15	FLMST
BH1	38.55	39	LMST	BH6	34.15	35	FLMST
BH1	39	40	FLMST	BH6	35	36	FLMST
BH1	40	41	CLMST	BH6	36	37	FLMST
BH1	41	42	CLMST	BH6	37	38	FLMST
BH1	42	42.45	CLMST	BH6	38	39	FLMST
BH1	42.45	43.45	CLMST	BH6	39	40	FLMST
BH1	43.45	44	LMST	BH6	40	40.8	FLMST
BH1	44	44.4	LMST	BH6	40.8	41.8	CLMST
BH1			LMST	BH6	41.8	42.8	CLMST
BH1	44.4	45.5	LMST	BH6	42.8	43.7	CLMST

BH1	45.5	46.5	FLMST	BH6	43.8	44.7	CLMST
BH1	46.5	47.5	FLMST	BH6	44.7	45.7	CLMST
BH1	47.5	48.55	FLMST	BH6	45.7	46.7	FLMST
BH1	48.55	49.55	FLMST	BH6	46.7	47.6	FLMST
BH1	49.55	50.6	FLMST	BH6	47.6	48.6	FLMST
BH1	50.6	51.6	FLMST	BH6	48.6	49.6	FLMST
BH1	51.6	52.6	FLMST	BH6	49.6	50.6	FLMST
BH1	52.6	53.6	FLMST	BH6	50.6	51.6	FLMST
BH1	53.6	54.6	FLMST	BH6	51.6	52.6	FLMST
BH1	54.6	55.1	FLMST	BH6	52.6	53.6	FLMST
BH1	55.1	55.7	FLMST	BH6	53.6	54.6	FLMST
BH1	55.7	56.55	FLMST	BH6	54.6	55.5	FLMST
BH1	56.55	57	FLMST	BH6	55.6	56.6	FLMST
BH1	57	57.75	SST	BH6	56.6	57.6	FLMST
BH1	57.75	58.55	SST	BH6	57.6	58.6	FLMST
BH1	58.55	59.15	SST	BH6	58.6	59.6	FLMST
BH1	59.15	60	SST	BH6	59.6	60.55	FLMST
BH1	60	61.25	SST	BH6	60.55	61.55	FLMST
BH1	61.25	61.7	SST	BH6	61.55	62.55	LMST
BH1	61.7	62.9	SHALE	BH6	62.55	63.55	LMST
BH1	62.9	64	FLMST	BH6	63.55	64.55	LMST
BH1	64	65.1	FLMST	BH6	64.55	65.5	FLMST
BH1	65.1	66	FLMST	BH6	65.5	66.5	FLMST
BH1	66	67	SHALE	BH6	66.5	67.5	FLMST
BH1	67	67.75	SHALE	BH6	67.5	68.5	FLMST
BH1	67.75	68.1	LMST	BH6	68.5	69.5	FLMST
BH1	68.1	69.25	SHALE	BH6	69.5	70.35	FLMST
BH1	69.25	70.3	FLMST	BH6	70.35	71.35	FLMST
BH1	70.3	71.3	SHALE	BH6	71.35	72.35	FLMST
BH1	71.3	72.3	SHALE	BH6	72.35	73.35	FLMST
BH1	72.3	73	SHALE	BH6	73.35	74.35	FLMST
BH1	73	73.65	SHALE	BH6	74.35	75.05	FLMST
BH1	73.65	74.65	LMST	BH6	75.05	76.05	FLMST
BH1	74.65	75.3	LMST	BH6	76.05	77.05	FLMST
BH1	75.3	76.25	LMST	BH6	77.05	78.05	FLMST
BH1	76.25	77.25	LMST	BH6	78.05	79.05	FLMST
BH1	77.25	78.25	LMST	BH6	79.05	79.9	FLMST
BH1	78.25	79.25	LMST	BH6	79.9	80.45	FLMST
BH1	79.25	80	LMST	BH6	80.45	81.4	FLMST
BH1	80	81	LMST	BH6	81.4	82.85	FLMST
BH1	81	82	LMST	BH6	82.85	83.85	FLMST
BH1	82	83	LMST	BH6	83.85	84.8	FLMST
BH1	83	84	LMST	BH6	84.8	85.8	FLMST
BH1	84	85.3	LMST	BH6	85.8	86.8	FLMST

BH1	85.3	86.5	LMST	BH6	86.8	87.8	FLMST
BH1	86.5	87.5	LMST	BH6	87.8	88.8	FLMST
BH1	87.5	88.5	LMST	BH6	88.8	89.65	FLMST
BH1	88.5	89.5	LMST	BH6	89.65	90.65	FLMST
BH1	89.5	90.1	LMST	BH6	90.65	91.6	FLMST
BH1	90.1	91.1	LMST	BH6	91.6	92.6	FLMST
BH1	91.1	92.1	LMST	BH6	92.6	93.6	FLMST
BH1	92.1	92.65	LMST	BH6	93.6	94.6	FLMST
BH1	92.65	93.6	LMST	BH6	94.6	95.6	FLMST
BH1	93.6	94.6	LMST	BH6	95.6	96.6	FLMST
BH1	94.6	95.6	LMST	BH6	96.6	97.6	FLMST
BH1	95	96.6	LMST	BH6	97.6	98.6	FLMST
BH1	96.6	97.6	LMST	BH6	98.6	100	FLMST
BH1	97.6	98.6	LMST	BH7	0	3.6	SOIL
BH1	98.6	99.05	LMST	BH7	3.6	4.3	CLMST
BH2	0	6	SHALE	BH7	4.3	6.3	CLMST
BH2	6	7.2	BLMST	BH7	6.3	7	CLMST
BH2	7.2	7.8	BLMST	BH7	7	7.4	CLMST
BH2	7.7	9	BLMST	BH7	7.4	8.4	CLMST
BH2	9	10	BLMST	BH7	8.4	9.3	CLMST
BH2	10	11	BLMST	BH7	9.3	10.7	CLMST
BH2	11	12	BLMST	BH7	10.7	11.1	CLMST
BH2	12	13	BLMST	BH7	11.1	11.5	CLMST
BH2	13	14	BLMST	BH7	11.5	12.5	CLMST
BH2	14	15	BLMST	BH7	12.5	13.35	CLMST
BH2	15	16	BLMST	BH7	13.35	14.35	CLMST
BH2	16	17	BLMST	BH7	14.35	15.35	CLMST
BH2	17	18	BLMST	BH7	15.35	16.35	CLMST
BH2	18	19	BLMST	BH7	16.35	17.35	CLMST
BH2	19	20	BLMST	BH7	17.35	18.35	CLMST
BH2	20	21	BLMST	BH7	18.35	19.35	CLMST
BH2	21	22	BLMST	BH7	19.35	20.6	CLMST
BH2	22	23	BLMST	BH7	20.6	21.6	CLMST
BH2	23	24	BLMST	BH7	21.6	22.6	CLMST
BH2	24	25.05	BLMST	BH7	22.6	23.6	CLMST
BH2	25.05	26.05	BLMST	BH7	23.6	24.85	CLMST
BH2	26.05	27.05	BLMST	BH7	25.45	26.3	CLMST
BH2	27.05	28.05	BLMST	BH7	26.3	27.3	CLMST
BH2	28.05	29.05	BLMST	BH7	27.3	28.3	CLMST
BH2	29.05	30	BLMST	BH7	28.3	29.3	CLMST
BH2	30	31	BLMST	BH7	29.3	30.3	MLMST
BH2	31	32	BLMST	BH7	30.3	31.3	MLMST
BH2	32	33	BLMST	BH7	31.3	32.3	MLMST
BH2	33	34	BLMST	BH7	32.3	33.3	MLMST

BH2	34	34.8	BLMST	BH7	33.3	34.25	MLMST
BH2	34.8	36	BLMST	BH7	34.25	35.25	MLMST
BH2	36	37	BLMST	BH7	35.25	36.25	MLMST
BH2	37	38	BLMST	BH7	36.25	37.05	MLMST
BH2	38	39.2	BLMST	BH7	37.05	38.05	MLMST
BH2	39.2	40	BLMST	BH7	38.05	39.05	MLMST
BH2	40	41	BLMST	BH7	39.05	40.05	MLMST
BH2	41	42	BLMST	BH7	40.05	41.1	MLMST
BH2	42	43	BLMST	BH7	41.1	42.1	MLMST
BH2	43	44	BLMST	BH7	42.1	43.1	MLMST
BH2	44	45	BLMST	BH7	43.1	44.2	MLMST
BH2	45	46	FLMST	BH7	44.2	45.2	MLMST
BH2	46	47	FLMST	BH7	45.2	46	MLMST
BH2	47	48	FLMST	BH7	46	46.6	MLMST
BH2	48	49	FLMST	BH7	46.6	47.4	MLMST
BH2	49	50	FLMST	BH7	47.4	47.9	MLMST
BH2	50	51	FLMST	BH7	47.9	48.7	MLMST
BH2	51	52	FLMST	BH7	48.7	49.7	MLMST
BH2	52	53	FLMST	BH7	49.7	50.6	MLMST
BH2	53	54.1	FLMST	BH7	50.6	51.6	MLMST
BH2	54.1	55.2	FLMST	BH7	51.6	52.55	MLMST
BH2	55.2	56.2	LMST	BH7	52.55	53.55	MLMST
BH2	56.2	57.2	LMST	BH7	53.55	54.6	MLMST
BH2	57.2	58.2	LMST	BH7	54.6	55.3	MLMST
BH2	58.2	59.2	LMST	BH7	55.3	56.5	MLMST
BH2	59.2	60.2	LMST	BH7	56.5	57.5	MLMST
BH2	60.2	61.2	SST	BH7	57.5	58.5	MLMST
BH2	61.2	62.2	SST	BH7	58.5	59.5	MLMST
BH2	62.2	63	SST	BH7	59.5	60.2	MLMST
BH2	63	64.1	SST	BH7	60.2	61.25	CLMST
BH2	64.1	64.6	SST	BH7	61.25	61.9	CLMST
BH2	64.6	65	SST	BH7	61.9	62.9	CLMST
BH2	65	60.4	SHALE	BH7	62.9	63.7	CLMST
BH2	66.4	67	FLMST	BH7	63.7	64.7	CLMST
BH2	67	67.45	SHALE	BH7	64.7	65.4	CLMST
BH2	67.45	68.2	FLMST	BH7	65.4	66.4	CLMST
BH2	68.2	68.9	FLMST	BH7	66.4	67.1	FLMST
BH2	68.9	69.9	SHALE	BH7	67.1	67.9	LMST
BH2	69.9	70.9	LMST	BH7	67.9	68.9	LMST
BH2	70.9	72.1	SHALE	BH7	68.9	69.6	LMST
BH2	72.1	73.25	SHALE	BH7	69.6	70.5	LMST
BH2	73.25	74.45	FLMST	BH7	70.6	71.5	LMST
BH2	74.45	75.4	SHALE	BH7	71.5	72.5	LMST
BH2	75.4	76.05	FLMST	BH7	72.5	73.5	LMST

BH2	76.05	77.05	FLMST	BH7	73.5	74.4	LMST
BH2	77.05	78	FLMST	BH7	74.4	75.4	LMST
BH2	78	79	FLMST	BH7	75.4	76.3	LMST
BH2	79	80	LMST	BH7	76.3	77.3	LMST
BH2	80	81	LMST	BH7	77.3	78.7	LMST
BH2	81	82	LMST	BH7	78.7	79.4	LMST
BH2	82	83	LMST	BH7	79.4	80.15	LMST
BH2	83	84	LMST	BH7	80.15	81.15	LMST
BH2	84	84.75	LMST	BH7	81.15	81.45	LMST
BH2	84.75	86	FLMST	BH7	81.45	82.45	LMST
BH2	86	87	BLMST	BH7	82.45	83.25	LMST
BH2	87	88	BLMST	BH7	83.25	84.1	LMST
BH2	88	89	BLMST	BH7	84.1	84.8	LMST
BH2	89	89.65	BLMST	BH7	84.95	85.95	LMST
BH2	89.65	90.6	BLMST	BH7	85.95	86.95	LMST
BH2	90.6	91.6	BLMST	BH7	86.95	87.95	LMST
BH2	91.6	92.6	BLMST	BH7	87.95	88.55	LMST
BH2	92.6	93.6	BLMST	BH7	88.55	89.55	LMST
BH2	93.6	94.6	BLMST	BH7	89.55	90.55	LMST
BH2	94.6	95.6	BLMST	BH7	90.55	91.55	LMST
BH2	95.6	96.6	BLMST	BH7	91.55	92.55	LMST
BH2	96.6	97.8	BLMST	BH7	92.55	93.55	LMST
BH2	97.8	99	FLMST	BH7	93.55	94.55	LMST
BH2	99	100.2	FLMST	BH7	94.55	95.55	LMST
BH3	0	9	SOIL	BH7	95.55	96.55	LMST
BH3	9	9.6	LMST	BH7	96.55	97.45	LMST
BH3	9.6	12.5	LMST	BH7	97.45	98.45	LMST
BH3	12.5	17.6	BASALT	BH7	98.45	99.45	LMST
BH3	17.6	18	LMST	BH7	99.45	100	LMST
BH3	18	18.8	LMST	BH8	0	1.8	SOIL
BH3	19.3	20	SST	BH8	1.8	2.8	SLMST
BH3	20	20.8	SST	BH8	2.8	3.1	SLMST
BH3	20.8	22.6	SHALE	BH8	3.1	3.7	SLMST
BH3	22.6	23.3	SHALE	BH8	3.7	4.4	SLMST
BH3	23.3	25.1	SHALE	BH8	4.4	5.45	BLMST
BH3	25.1	26.8	SHALE	BH8	5.45	6.7	BLMST
BH3	26.8	27.3	LMST	BH8	6.7	6.8	BLMST
BH3	27.3	28.8	SHALE	BH8	6.8	7.8	BLMST
BH3	29.1	31.1	SHALE	BH8	7.8	8.8	BLMST
BH3	31.2	33.1	FLMST	BH8	8.8	9.45	BLMST
BH3	33.1	34	FLMST	BH8	9.45	10	BLMST
BH3	34	36.15	SHALE	BH8	10	10.7	BLMST
BH3	36.25	37	SHALE	BH8	10.7	11	BLMST
BH3	38.5	39.5	FLMST	BH8	11	11.45	BLMST

BH3	39.5	40.5	FLMST	BH8	11.45	12.5	BLMST
BH3	40.5	41.4	FLMST	BH8	12.5	13.3	BLMST
BH3	41.4	42.3	FLMST	BH8	13.3	14.5	BLMST
BH3	43	44.3	SHALE	BH8	14.5	15.7	BLMST
BH3	45.2	46.3	FLMST	BH8	15.7	16.7	BLMST
BH3	46.3	47.8	FLMST	BH8	16.7	17	BLMST
BH3	49.6	50	LMST	BH8	17	19.8	BLMST
BH3	50	51.45	LMST	BH8	19.8	20.5	BLMST
BH3	52.25	53.1	LMST	BH8	20.5	21	BLMST
BH3	53.9	55.25	LMST	BH8	21	21.4	SLMST
BH3	55.25	56.65	LMST	BH8	21.4	22.4	SLMST
BH3	57.5	58.45	LMST	BH8	22.4	22.85	SLMST
BH3	58.45	59.5	LMST	BH8	22.85	23.4	SLMST
BH3	59.5	60.55	LMST	BH8	23.4	24.75	SLMST
BH3	60.55	61.6	LMST	BH8	24.75	25.1	SLMST
BH3	61.6	62.7	LMST	BH8	25.1	26.1	SLMST
BH3	62.7	63.45	LMST	BH8	26.1	27.1	SLMST
BH3	63.55	65	LMST	BH8	27.1	28.1	SLMST
BH3	65	65.9	FLMST	BH8	28.1	29.1	SLMST
BH3	65.9	66.7	FLMST	BH8	29.1	30.1	SLMST
BH3	66.7	67.3	FLMST	BH8	30.1	30.35	SLMST
BH3	67.3	68.25	FLMST	BH8	30.35	30.75	SLMST
BH3	68.25	69.15	FLMST	BH8	30.75	31.9	SLMST
BH3	69.15	70.75	FLMST	BH8	31.9	32.8	SLMST
BH3	70.75	71.75	FLMST	BH8	32.8	33.9	SLMST
BH3	71.75	72.75	FLMST	BH8	33.9	34.8	SLMST
BH3	72.75	73.75	FLMST	BH8	34.8	35.8	SLMST
BH3	73.75	74.55	FLMST	BH8	35.8	36.8	SLMST
BH3	74.55	75.45	FLMST	BH8	36.8	37.8	SLMST
BH3	75.45	76.45	FLMST	BH8	37.8	39.3	SLMST
BH3	76.45	77.45	FLMST	BH8	39.3	39.3	SLMST
BH3	77.45	78.45	FLMST	BH8	39.3	40.8	SLMST
BH3	78.45	79.45	FLMST	BH8	40.8	41.8	SLMST
BH3	79.45	80.45	FLMST	BH8	41.8	42.15	SLMST
BH3	80.45	81.45	FLMST	BH8	42.15	43.1	SLMST
BH3	81.45	82.45	FLMST	BH8	43.1	44.1	SLMST
BH3	82.45	83.45	FLMST	BH8	44.1	44.55	SLMST
BH3	83.45	84.4	FLMST	BH8	44.55	45.05	SLMST
BH3	84.4	85.4	FLMST	BH8	45.05	46.05	SLMST
BH3	85.4	86.6	FLMST	BH8	46.05	46.4	SLMST
BH3	86.6	87.6	FLMST	BH8	46.4	47.15	SLMST
BH3	87.6	88.6	FLMST	BH8	47.15	47.65	SLMST
BH3	88.6	89.9	FLMST	BH8	47.65	48.55	SLMST
BH3	89.9	91.1	FLMST	BH8	48.55	49.55	BLMST

BH3	91.1	92.35	FLMST	BH8	49.55	50.55	SLMST
BH3	92.35	93.35	FLMST	BH8	50.55	51.55	SLMST
BH3	93.35	94.45	FLMST	BH8	51.55	52.55	SLMST
BH3	94.45	95.45	FLMST	BH8	52.55	53.2	SLMST
BH3	95.45	96.6	FLMST	BH8	53.2	54.2	SLMST
BH3	96.6	97.9	FLMST	BH8	54.2	55.2	SLMST
BH3	97.9	98.5	FLMST	BH8	55.2	56.2	SLMST
BH3	98.5	98.75	FLMST	BH8	56.2	57.2	SLMST
BH3	98.75	99.7	FLMST	BH8	57.2	58.2	SLMST
BH4	0	6.3	SOIL	BH8	58.2	59.2	SLMST
BH4	6.3	9.3	CLMST	BH8	59.2	60.2	SLMST
BH4	9.3	10.6	CLMST	BH8	60.2	60.4	SLMST
BH4	10.6	11.3	FLMST	BH8	60.4	61	SLMST
BH4	11.3	12	SST	BH8	61	62	SLMST
BH4	13.75	14.85	SST	BH8	62	63	SLMST
BH4	14.85	15.3	SHALE	BH8	63	64	SLMST
BH4	15.3	16.7	SHALE	BH8	64	65.1	SLMST
BH4	16.7	19.15	SHALE	BH8	65.1	66.1	SLMST
BH4	19.15	20.05	SHALE	BH8	66.1	67.1	SLMST
BH4	20.05	20.95	LMST	BH8	67.1	67.9	SLMST
BH4	20.95	24.2	SHALE	BH8	67.9	68.9	SLMST
BH4	24.2	25.2	FLMST	BH8	68.9	69.9	SLMST
BH4	25.2	26.2	FLMST	BH8	69.9	70.9	SLMST
BH4	26.2	27.2	FLMST	BH8	70.9	71.5	SLMST
BH4	27.2	28.2	FLMST	BH8	71.5	72.5	SLMST
BH4	28.2	29.15	FLMST	BH8	72.5	73.5	SLMST
BH4	29.15	30.1	FLMST	BH8	73.5	74.5	SLMST
BH4	30.1	31.05	FLMST	BH8	74.5	75.5	SLMST
BH4	31.05	32.05	FLMST	BH8	75.5	76.5	SLMST
BH4	32.05	33.05	FLMST	BH8	76.5	77.5	SLMST
BH4	33.05	34.05	FLMST	BH8	77.5	78.5	SLMST
BH4	34.05	35.05	FLMST	BH8	78.5	79	SLMST
BH4	35.05	36	FLMST	BH8	79	79.65	SLMST
BH4	36	36.8	FLMST	BH8	79.65	80.65	SLMST
BH4	36.8	37.9	FLMST	BH8	80.65	81	SLMST
BH4	37.9	38.9	FLMST	BH8	81	81.95	SLMST
BH4	38.9	39.9	FLMST	BH8	81.95	82.95	SLMST
BH4	39.9	40.3	FLMST	BH8	82.95	83.95	SLMST
BH4	40.9	42.3	FLMST	BH8	83.95	84.95	SLMST
BH4	42.3	43.3	FLMST	BH8	84.95	85.95	SLMST
BH4	43.3	44.3	FLMST	BH8	85.95	86.95	SLMST
BH4	44.3	45.25	FLMST	BH8	86.95	87.95	SLMST
BH4	45.25	45.8	FLMST	BH8	87.95	88.95	SLMST
BH4	45.8	46.8	FLMST	BH8	88.95	89.95	SLMST

BH4	46.8	47.8	FLMST	BH8	89.95	91	SLMST
BH4	47.8	49.3	FLMST	BH8	91	92	SLMST
BH4	49.3	50.3	FLMST	BH8	92	93	SLMST
BH4	50.3	51.6	FLMST	BH8	93	94	SLMST
BH4	51.6	52.55	FLMST	BH8	94	94.65	SLMST
BH4	52.55	53.55	FLMST	BH8	94.65	95.65	SLMST
BH4	53.55	54.55	FLMST	BH8	95.65	96.3	SLMST
BH4	54.55	55.3	FLMST	BH8	96.3	97	SLMST
BH4	55.3	56.4	FLMST	BH8	97	97.75	SLMST
BH4	56.4	57.4	FLMST	BH8	97.75	98.5	SLMST
BH4	57.4	58.4	FLMST	BH9	0	15.4	SOIL
BH4	58.4	59.4	FLMST	BH9	15.4	16	BLMST
BH4	59.4	60.4	FLMST	BH9	16	17	BLMST
BH4	60.4	61.4	FLMST	BH9	17	18	BLMST
BH4	61.4	62.5	LMST	BH9	18	19	BLMST
BH4	62.5	63.1	LMST	BH9	19	20	BLMST
BH4	63.1	64.4	LMST	BH9	20	21	BLMST
BH4	64.4	65.2	LMST	BH9	21	22.2	BLMST
BH4	65.2	66.2	FLMST	BH9	22.2	23.2	BLMST
BH4	66.2	67.2	FLMST	BH9	23.2	24.3	BLMST
BH4	67.2	68.2	FLMST	BH9	24.3	25.3	BLMST
BH4	68.2	69.2	FLMST	BH9	25.3	26.3	BLMST
BH4	69.2	70.1	FLMST	BH9	26.3	27.3	BLMST
BH4	70.1	71	FLMST	BH9	27.3	28.35	BLMST
BH4	71	72	FLMST	BH9	28.35	29.35	BLMST
BH4	72	73	FLMST	BH9	29.35	30.35	BLMST
BH4	73	73.55	FLMST	BH9	30.35	31.35	BLMST
BH4	73.55	74.55	FLMST	BH9	31.35	32.35	BLMST
BH4	74.55	75.85	FLMST	BH9	32.35	33.35	BLMST
BH4	75.85	76.85	FLMST	BH9	33.35	34.45	BLMST
BH4	76.85	77.85	FLMST	BH9	34.45	35.45	BLMST
BH4	77.85	78.85	FLMST	BH9	35.45	36.45	BLMST
BH4	78.85	79.55	FLMST	BH9	36.45	37.45	BLMST
BH4	79.55	80.4	FLMST	BH9	37.45	38.5	BLMST
BH4	80.4	81.4	FLMST	BH9	38.5	39.5	BLMST
BH4	81.4	82.55	FLMST	BH9	39.5	40.5	BLMST
BH4	82.55	83.55	FLMST	BH9	40.5	41.5	BLMST
BH4	83.55	84.35	FLMST	BH9	41.5	42.5	BLMST
BH4	84.35	85.3	FLMST	BH9	42.5	43.5	BLMST
BH4	85.3	86.3	FLMST	BH9	43.5	44.5	BLMST
BH4	86.3	87.3	FLMST	BH9	44.5	45.5	FLMST
BH4	87.3	88.55	FLMST	BH9	45.5	46.6	FLMST
BH4	88.55	89.55	FLMST	BH9	46.6	47.6	FLMST
BH4	89.55	90.15	FLMST	BH9	47.6	48.6	FLMST

BH4	90.15	91.15	FLMST	BH9	48.6	49.6	FLMST
BH4	91.15	92.15	FLMST	BH9	49.6	50.6	SLMST
BH4	92.15	93.55	FLMST	BH9	50.6	51.6	BLMST
BH4	93.55	94.45	FLMST	BH9	51.6	52.6	BLMST
BH4	95	96	FLMST	BH9	52.6	53.2	FMST
BH4	96	97	FLMST	BH9	53.2	54.2	SLMST
BH4	97	98	FLMST	BH9	54.2	55.2	BLMST
BH4	98	99	FLMST	BH9	55.2	56.2	BLMST
BH4	99	99.85	FLMST	BH9	56.2	57.2	SLMST
BH4	99.85	100.55	FLMST	BH9	57.2	58.25	SLMST
BH5	0	20.2	SOIL	BH9	58.25	59.25	SLMST
BH5	20.2	21.4	SHALE	BH9	59.25	60.35	FLMST
BH5	21.4	23	SHALE	BH9	60.35	61.35	FLMST
BH5	23	23.5	SHALE	BH9	61.35	62.35	LMST
BH5	23.5	25	LMST	BH9	62.35	63.35	SLMST
BH5	25	25.2	FLMST	BH9	63.35	64.35	SLMST
BH5	25.2	26.5	FLMST	BH9	64.35	65.35	SLMST
BH5	26.5	26.75	FLMST	BH9	65.35	66.35	SLMST
BH5	26.75	27.3	FLMST	BH9	66.35	67.4	SLMST
BH5	27.3	28.3	FLMST	BH9	67.4	68.1	BLMST
BH5	28.3	29.3	FLMST	BH9	68.1	69.2	BLMST
BH5	29.3	30.3	FLMST	BH9	69.2	70.2	SLMST
BH5	30.3	31.3	FLMST	BH9	70.2	70.9	SLMST
BH5	31.3	32.3	FLMST	BH9	70.9	71.9	FLMST
BH5	32.3	34.3	LMST	BH9	71.9	72.8	FLMST
BH5	33.3	34.3	LMST	BH9	72.8	73.9	SLMST
BH5	34.3	35.3	FLMST	BH9	73.9	74.9	SLMST
BH5	35.3	36.3	FLMST	BH9	74.9	75.9	SLMST
BH5	36.3	37.3	FLMST	BH9	75.9	77	SLMST
BH5	37.3	38.3	FLMST	BH9	77	77.65	SLMST
BH5	38.3	38.7	FLMST	BH9	77.65	78.65	SLMST
BH5	38.7	40.1	FLMST	BH9	78.65	79.65	SLMST
BH5	40.1	41.1	BLMST	BH9	79.65	80.65	SLMST
BH5	41.1	41.5	BLMST	BH9	80.65	81.65	SLMST
BH5	41.5	41.8	SHALE	BH9	81.65	82.65	SLMST
BH5	41.8	42.6	SHALE	BH9	82.65	83.65	SLMST
BH5	42.6	43.4	BLMST	BH9	83.65	84.65	SLMST
BH5	43.4	44.4	BLMST	BH9	84.65	85.65	SLMST
BH5	44.4	46.1	BLMST	BH9	85.65	86.65	SLMST
BH5	46.1	47.1	BLMST	BH9	86.65	87.15	SLMST
BH5	47.1	48.1	BLMST	BH9	87.15	88.15	FLMST
BH5	48.1	49.2	BLMST	BH9	88.15	88.9	FLMST
BH5	49.2	50.2	BLMST	BH9	88.9	89.6	SLMST
BH5	50.2	50.7	BLMST	BH9	89.6	90.6	SLMST

BH5	50.7	51.2	BLMST	BH9	90.6	91.6	SLMST
BH5	51.2	52.2	BLMST	BH9	91.6	92.6	SLMST
BH5	52.2	53.2	BLMST	BH9	92.6	93.6	SLMST
BH5	53.2	54.2	BLMST	BH9	93.6	94.6	SLMST
BH5	54.2	55.2	BLMST	BH9	94.6	95.6	SLMST
BH5	56.3	57.3	BLMST	BH9	95.6	96.6	SLMST
BH5	57.3	58.3	BLMST	BH9	96.6	97.6	SLMST
BH5	58.3	59.3	LMST	BH9	97.6	98.6	SLMST
BH5	59.3	60.3	BLMST	BH9	98.6	99.75	SLMST
BH5	60.3	61.4	BLMST				
BH5	61.4	62.4	BLMST				
BH5	62.4	63.4	BLMST				
BH5	63.4	64.4	BLMST				
BH5	64.4	65.45	BLMST				
BH5	65.45	66.45	BLMST				
BH5	66.45	67.45	BLMST				
BH5	67.45	68.45	BLMST				
BH5	68.45	69.45	BLMST				
BH5	69.45	70.45	BLMST				
BH5	70.45	71.45	FMST				
BH5	71.45	72.45	FMST				
BH5	72.45	73.55	FMST				
BH5	73.55	74.55	FMST				
BH5	74.55	75.6	FMST				
BH5	75.6	76.6	SLMST				
BH5	76.6	77.6	SLMST				
BH5	77.6	77.6	SLMST				
BH5	78.6	79.6	SLMST				
BH5	79.6	80.6	SLMST				
BH5	80.6	81.6	SLMST				
BH5	81.6	82.65	SLMST				
BH5	82.65	83.65	SLMST				
BH5	83.65	84.75	SLMST				
BH5	84.75	85.75	FLMST				
BH5	85.75	86.75	FLMST				
BH5	86.75	87.75	SLMST				
BH5	87.75	88.85	FLMST				
BH5	88.85	89.9	FLMST				
BH5	89.9	90.9	SLMST				
BH5	90.9	91.9	SLMST				
BH5	91.9	92.9	SLMST				
BH5	92.9	93.9	SLMST				
BH5	93.9	94.9	SLMST				
BH5	94.9	95.9	SLMST				

BH5	95.9	96.9	SLMST
BH5	96.9	98	SLMST
BH5	98	99	SLMST
BH5	99	100.4	SLMST