Government of Nepal
Ministry of Energy, Water Resources, and Irrigation
Department of Electricity Development
Sanogaucharan, Kathmandu
www.doed.gov.np

March, 2025

GUIDELINES FOR
ESTIMATION OF EXPLOSIVE QUANTITY
FOR HYDRO TUNNEL CONSTRUCTION

This page intentionally left blank

Foreword

The Government of Nepal (GoN) has prioritized development of hydropower projects as one of its focus area in the economic development of the nation by formulating various plans and policies. As Nepal continues to unlock its vast hydropower potential, we stand at the forefront of a transformative era in energy development. The use of explosive materials is an integral part of this journey as it remains a necessary but complex aspect of construction and excavation. So, explosive materials must be managed with precision, responsibility, and foresight. In line with the Department of Electricity Development's mandate to regulate, accommodate, promote, and facilitate the hydropower sector in Nepal, the guidelines have been prepared to address the safe and effective use of explosive materials in hydropower projects.

Hydropower projects are a collective endeavor, requiring the cooperation of government agencies, private sector partners, and local communities. The safe management of explosive materials is a shared responsibility that demands vigilance, expertise, and adherence to best practices. The guidelines outlined herein are based on national and international best practices, ensuring that all activities involving explosive materials are conducted in a manner that prioritizes safety, environmental protection, and regulatory compliance.

Although, the title of the guidelines mention estimation of explosive quantity only, the guidelines cover all the explosive material related activities in hydropower projects of Nepal. Thus, the guidelines has been designed to provide a comprehensive framework regarding (1) estimation, usage, handling, storage, transportation, and procurement of explosive materials, (2) instructions on operational health and safety measures for various activities related to explosive materials, and (3) management strategies to formalize inspection and monitoring of explosive materials related activities for all parties/stakeholders involved in hydropower projects.

It is my expectation that all stakeholders will adhere to these guidelines by preparing the Blasting Assessment Report (BAR) for implementing explosive materials related activities in hydropower projects of Nepal while contributing to the sustainable and responsible development of Nepal's hydropower resources.

Government of Nepal
Ministry of Energy, Water Resources and Irrigation
Department of Electricity Development
2050

....

Nabin Raj Singh

Director General

Department of Electricity Development (DoED)

This page intentionally left blank

Acknowledgment

The *Guidelines for Estimation of Explosive Quantity for Hydro Tunnel Construction* is the culmination of collaborative efforts, expertise, and unwavering support from various officials, consultants, related experts, TSG members, hydropower developers, and related stakeholders,. On behalf of the *Department of Electricity Development* (DoED), we extend our heartfelt gratitude to all those who contributed to the successful development of this guideline.

To DoED Officials
We extend our sincere thanks to the dedicated officials of the Department of Electricity Development namely Mr. Nabin Raj Singh (Director General), Mr. Sunil Poudel (Deputy Director General), Mr. Chiranjib Jha (Senior Divisional Engineer), and Mr. Sabindra Bahadur Shrestha (Engineering Geologist) for their relentless efforts in coordinating, reviewing, and refining the guideline as a member of Technical Support Group (TSG). Your expertise, diligence, and commitment to promoting safety and efficiency in the hydropower sector have been pivotal in bringing this guideline to fruition.

To Consultants
Our heartfelt gratitude goes to the team of consultants led by Mr. Bibek Karanjit including Mr. Prayag Maharjan (Senior Geologist) and Mr. Saransh Mool (Civil/Geotechnical Engineer) who provided their technical expertise, research, and recommendations throughout the development process. Your contributions have ensured that the guideline is comprehensive and aligned with both national and international best practices, while addressing the unique challenges of Nepal's hydropower sector.

To Technical Support Group (TSG) Members
We would like to extend our special gratitude to the members of Technical Support Group (TSG) apart from the DoED Officals mentioned above namely Mr. Prakash Man Shrestha (Hydropower Expert), Mr. Kangada Prasai (Geological Expert), Mr. Santosh Kumar Yadav (Geotechnical Expert nominated by IOE, Pulchowk), Mr. Anand Chaudhary (Representative from IPPAN), Mr. Bijay Rana (Major – nominated by Nepal Army), and Mr. Saroj Ghimire (Environmental Engineer) for their exceptional contributions to the development of the guideline. The TSG played a pivotal role in providing technical expertise, conducting thorough reviews, and ensuring that the guideline adheres to the highest standards of safety, efficiency, and regulatory compliance.

To Hydropower Developers
We are grateful to the 18 hydropower developers for sharing their practical experiences, explosive material related information, challenges, and suggestions. We would like to extend our special gratitude to the Upper Trishuli-I Hydroelectric Project (216 MW), Tanahu Hydropower Project (140 MW), and Lower Solu Hydroelectric Project (82 MW) for facilitating the primary data collection, providing ground insights during the field visit, and participating in the residential workshop for reviewing the Guideline Framework Report which was critical in ensuring that the guideline is not only theoretically sound but also practical and implementable in real-world scenarios.

To All Contributors
This guideline would not have been possible without the collective efforts of all individuals and organizations who participated in the residential workshop for Guideline Framework Report and Presentation of Draft Report during the preparation of this guideline. We would like to extend our special gratitude to Mr. Subarna Khanal (SDEG of DoED) for his contribution in developing the MS Sheet (template for estimation of explosive materials). We are confident that this guideline will serve as a valuable resource for all stakeholders and contribute to the sustainable development of Nepal's hydropower projects.

Once again, we thank everyone who played a role in the development of this guideline. Your contributions are deeply appreciated and will have a lasting impact on the hydropower sector and beyond.

Sincerely,
Department of Electricity Development (DoED)

This page intentionally left blank

Final Report Preparation and Quality Check-up

Project Name: Preparation of Guidelines for Estimation of Explosive Quantity for Hydro Tunnel Construction

Client: Department of Electricity Development (DoED)

Consultant: Joint venture of Hydro-Consult Engineering Limited, Environment and Resource Management Consultant (P.) Ltd. And Full Bright Consultancy (Pvt.) Ltd. (HCE-ERMC-FBC JV)

Type of Report: Approved Final Report	Report Submitted on: March 2025

Quality Control Assurance

Report Prepared and Checked by the Key Professionals

Designation	Name	Signature	Date
1. Civil/Mechanical Engineer (Team Leader)	Mr. Bibek Karanjit		
2. Engineering Geologist	Mr. Achyuta Koirala		
3. Geotechnical Engineer	Ms. Muna Khadka		
4. Environmental Safeguards Specialist/ Occupational Health and Security Expert	Mr. Arun Acharya		
5. Engineering Geologist (Team Member in pursuant to Section 3.6 of ToR)	Mr. Sabindra Bdr. Shrestha		
6. Engineering Geologist	Mr. Prayag Maharjan		
7. Civil/Geotechnical Engineer	Mr. Saransh Mool		

Representative from the Joint Venture

Name: Mr. Manohar Shrestha	Name: Ms. Rita Khadka	Name: Mr. Thakur P. Sharma
Designation: CEO, Hydro-Consult Engineering Ltd.	Designation: MD, Environment Resource Management (P) Ltd. (ERMC)	Designation: MD, Full Bright Consultancy (Pvt.) Ltd.
Signature:	Signature:	Signature:
Seal	Seal:	Seal:

This page intentionally left blank

Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ANNEXURES

Please click on the link below to download all Annexures. To download specific Annexures, Kindly access the respective links mentioned in the list above.

Annex-All

This page intentionally left blank

LIST OF ACRONYMS

APF	Armed Police Force
ANFO	Ammonium Nitrate-Fuel Oil
AOP	Air Overpressure
BAR	Blasting Assessment Report
BES	Brief Environmental Study
DAO	District Administration Office
DBM	Drilling and Blasting Method
DoED	Department of Electricity Department
DoM	Date of Manufacture
E & A	Explosive and Accessories
EIA	Environmental Impact Assessment
ERMC	Environment and Resource Management Consultant Pvt. Ltd.
ESMS	Environment and Social Management System
FBC	Full Bright Consultancy
GIS	Geographic Information System
GoN	Government of Nepal
GSI	Geological Strength Index
HCE	Hydro-Consult Engineering
HEP	Hydroelectric Project
HFT	Himalayan Frontal Thrust
HHC	Higher Himalayan Crystallines
HPP	Hydropower Project
HRT	Headrace Tunnel
IEE	Initial Environmental Examination
ITSZ	Indus-Tsangpo suture
IOE	Institute of Engineering
IPPAN	Independent Power Producers' Association Nepal
IPPs	Independent Power Producers
JHA	Job Hazard Analysis
JV	Joint Venture
kg/m^3	Kilogram per cubic metre
km	Kilometre
KWh	Kilowatt hour
L_{max}	Peak Particle Velocity Maximum
m	Metre
MBT	Main Boundary Thrust
MCT	Main Central Thrust
MFT	Main Frontal Thrust
MMSM	Mohan Man Shakti Man

MoD	Ministry of Defense
MoEWRI	Ministry of Energy, Water Resource, and Irrigation
MoFA	Ministry of Foreign Affairs
MoFE	Ministry of Forest and Environment
MoHA	Ministry of Home Affairs
MW	Megawatt
NEA	Nepal Electricity Authority
NGS	Nepal Geological Society
NHF	North Himalayan Fault
NOC	No Objection Certificate
NTA	Nepal Tunneling Association
NTS	Norwegian Tunneling Society
NWEDC	Nepal Water and Engineering Development Company Private Limited
OHS	Occupational Health Safety
PES	Potential Explosion Site
PLI	Point Load Index
PPA	Power Purchase Agreement
PPE	Personal Protective Equipment
PPV	Peak Particle Velocity
PRoR	Peaking Run-off-the River
Q	Rock Mass Quality Index developed at Norwegian Geotechnical Institute
RBS	Relative Bulk Strength
RWS	Relative Weight Strength
RoR	Run of the River
RMR	Rock Mass Rating
RQD	Rock Quality Designation
SOP	Standard Operating Procedure
STDS	South Tibetan Detachment System
TARP	Trigger Action Response Plan
ToR	Terms of Reference
TRT	Tailrace Tunnel
TSG	Technical Support Group
UCS	Unconfined Compressive Strength
UOS	Unit of Space
UT 1	Upper Trishuli 1
VAT	Value Added Tax
VfM	Value for Money
VOD	Velocity of detonation

GLOSSARY

Term	*Definition*
Air blasts	A rapid displacement of air caused by a ground collapse or a detonation of explosives.
Air overpressure	An energy transmission in the form of pressure waves from the blast site within the atmosphere
Aisles	A passage between rows
Blasting Assessment Report (BAR)	A document prepared for the estimation of the explosive materials required to initiate its procurement and other related activities for hydropower projects in Nepal.
Blasting safety	Safety measures applied during blasting
Bunker facilities	Any building or structure approved for the storage of explosive materials.
Commercial explosive	Substances used in industries for controlled explosions in tasks like mining and excavation, designed to be safe yet capable of releasing significant energy when triggered.
Detonators	A mechanical or electrical explosive device or a small amount of explosive; can be used to initiate the reaction of a disrupting explosive.
Explosive magazine	Any building or structure approved for the storage of explosive materials.
Excavation	The process of removing earth, rock, or other materials to create space or access buried structures and resources
Explosives	Chemical that causes a sudden, almost instantaneous release of pressure, gas, and heat when subjected to sudden shock, pressure, or high temperature.
Explosive materials	A set of explosives and Initiation system
Environmental impacts	The effect or influence of an activity or project on the natural environment, including changes to ecosystems, pollution, and resource depletion.
Estimation	A tentative calculation of the value, number, quantity, or extent of something.

Term	*Definition*
Exposed Site	Location within the project area which is exposed to the effects of an explosion (or fire) at the potential explosion site (PES) under consideration such as magazine, cell, stack, truck or trailer loaded with ammunition, explosives workshop, inhabited building, assembly place and public traffic route among others.
Initiation System	An initiation system provides the initial energy required to detonate an explosive used for any blasting operation.
Fly rocks	Rock or any earth materials that are ejected from the blast site during blasting operation.
Heavy walled building	Building of non-combustible construction used for explosive storage with walls of at least 450 mm reinforced concrete (RC), or 700 mm brick, or equivalent penetration resistance of other materials, with or without a protective roof.
Hazardous substances	Any solid, liquid, or gaseous material that is radioactive, toxic, explosive, flammable, corrosive, or otherwise physically or biologically threatening to health.
Hazard	Potential event that creates a threat to life, health, property, and the environment among others
Independent Power Producers (IPP)	Private hydropower developers of Nepal.
Lightning strike	Lightning event in which the electric discharge takes place between the atmosphere and the ground.
Methodological framework	A methodology or approach for doing a given task or activities in a pre-intended and structure manner.
Master Blaster	The job title of a senior explosives engineer working with explosive materials
Misfire	Explosive misfires occur when an explosive charge fails to detonate as intended. Misfires are the serious hazard in blasting operation as they can lead to accidental detonation at an unexpected time.
No Objection Certificate (NOC)	A standard measure in storage systems representing a specific volume or capacity, often used to organize and manage inventory efficiently

Term	*Definition*
Operational Health and Safety (OHS) measures	Prevention of workplace incidents and occupational diseases is addressed through the implementation of occupational safety and health programs at company level
Pallet	Packet or box of emulsion.
Personal Protective Equipment (PPE):	PPE is equipment used to prevent or minimize exposure to hazards
Potential Explosion Site (PES)	A location where a quantity of explosives could cause blast, fragment, thermal, or debris hazards if accidentally detonated
Pumped storage	A method of storing energy by cycling water between two reservoirs; surplus energy pumps water to a higher reservoir, and during high demand, the water is released to generate electricity.
Project boundary	The boundary approved by the DoED for the construction/survey of any hydropower project.
Quantity and Separation Distances	Appropriate distances to be used to support the safe, effective and efficient storage and handling of conventional ammunition and provides an acceptable level of protection to surrounding personnel and ES.
Run-of River (RoR):	A facility that generates electricity by directing river water through a turbine, typically with minimal storage, providing a continuous base load and some flexibility for daily demand changes.
Storage Scheme	A large system using a dam to store water for generating electricity by releasing it through a turbine, capable of providing consistent base load and meeting peak demand with long-term storage capacity
Surface excavation	Excavation of the surface slopes, surface roads, and channels
Stack	A quantity of ammunition weighing approximately 1 (one) tonne and occupying 1 (one) cubic meter, similar to the Unit of Space (UOS) concept used in depot storage.
Unit of Space (UOS)	A standard measure in storage systems representing a specific volume or capacity, often used to organize and manage inventory efficiently

This page intentionally left blank

1 INTRODUCTION

Government of Nepal (GoN), Ministry of Energy, Water Resources and Irrigation (MoEWRI) had envisaged water resources development potential of Nepal by the promulgation of Hydropower Development Policy (2001). With the view to maintain and stabilize the energy generation mix of the country, GoN through the white paper (2075 Baisakh) aims to develop storage/pumped storage projects and Peaking Run-of River (PRoR) Hydropower Projects along with the conventional Run-of River (RoR) type of Hydropower Project (HPP). Moreover, the Independent Power Producers (IPP) are also developing numerous hydropower projects throughout the country.

Most of these hydropower projects requires both surface excavation as well as underground excavation during the construction stage as well as for the construction of exploration adit during the construction stage. Thus, there is a growing need for the Explosive Materials Management Standard/Guidelines in order to provide the framework to ensure that explosive materials management strategies are in place to control the use of explosive materials by incorporating best practices; minimize the risk of injury to all personnel and mitigate environmental impacts from explosive materials during storage, transport, and use.

Hence, the GoN intends to prepare a guideline for estimating the explosive material required for the excavation of hydro tunnel (underground structures). In this regard, this guideline has been prepared to provide the framework ensuring the above-mentioned management strategies as well as to (1) formalize inspection and inventory processes of explosive materials, (2) minimize disruptions and eliminate damage associated with explosive materials and (3) provide employees who are responsible for handling and using explosive materials onsite with the requirements to do so.

1.1 Objective of the Guideline

1.1.1 Overall Objective of theStudy

a) The objective of the guidelines is to regulate and facilitate various activities related to explosive materials such as estimation, usage, handling, storage, transportation, and procurement among others by incorporating best and relevant practices. However, the guidelines is not limited to the underground excavation of the hydropower facilities only, but also considers the explosives requirements for the construction of overall layout of the hydropower projects of Nepal including its access road as well;
b) The intent of this guideline is to describe the theory, concepts, and procedures related to operational health and safety measures for various activities of explosive material such as estimation, usage, handling, storage, transportation, and procurement among others; and
c) This guideline intends to provide the framework for management strategies to formalize inspection and monitoring of various activities of explosive material such as estimation, usage, handling, storage, transportation, and procurement among others.

1.1.2 Expected Output of the Study

By the end of the contract period under this TOR (Annex-1), the Consulting Firm is expected to produce a comprehensive guideline for the estimation of explosive materials required for the hydropower projects of Nepal, with definite implementation plan of the recommended scheme based on the alternatives/configurations/technologies considered, among others.

1.2 Organization of the Guidelines

This guideline has been organized in seven different chapters. The overview of the chapters has been mentioned below:

Chapter-1

a) Explains the intent and organization of the guideline and the limitation encountered during the preparation of the guideline; and
b) Present the background for preparing this guideline.

Chapter- 2

a) Explains the methodological framework used during the preparation of these guideline;
b) Presents the process for developing and presenting all the geotechnical information related to explosive materials;
c) Review of the best national and international practices related to estimation, usage, handling, storage, transportation, and procurement of the explosive materials; and
d) Presents all the prevailing policies and legal instruments related to explosive material in Nepal.

Chapter- 3

a) Explains the guideline framework and related requirements for estimation, usage, handling, storage, transportation, and procurement of the explosive materials;
b) Presents the Department's requirement of Blasting Assessment Report (BAR) for getting the consent of procuring the explosive materials;
c) Specifies presentation content and format for the BAR;
d) Explains the explosive procurement procedure in Nepal; and
e) Specifies the consideration and methods of estimation of explosive material for both surface and underground excavation.

Chapter-4

a) Explains the guideline framework and related requirements for the operation health and safety regarding estimation, usage, handling, storage, and transportation of the explosive materials;
b) Specifies the general requirements for any drilling and blasting operations in a hydropower project of Nepal; and
c) Explains the blasting safety for surface blasting in a separate section.

Chapter-5

a) Specifies the management strategies required to formalize inspection and monitoring of explosive materials;
b) Explain duties, procedures, and method of inspection related to explosive materials; and
c) Defines the responsibilities of each specific personnel exposed to explosive material estimation, usage, handling, storage, transportation, and procurement.

Chapter-6

a) Presents the process for the analysis, development, presentation of geotechnical information regarding the determination of the specific charge (powder factor) during the explosive material estimation of any hydropower project in Nepal;
b) Presents an overview of the geotechnical data collected through questionnaire survey and site visits through graphical and tabular representation;

Chapter-7

a) Provides conclusion for explosive materials estimation, usage, handling, storage, transportation, and procurement along with conclusion for operational health and safety measures to be adopted for explosive materials and conclusion for formalizing, inspection, and monitoring of explosive materials;

b) Provides guidance for documenting and reporting results from geotechnical investigations and approved technical and environmental reports of the given hydropower project in order to prepare the Blasting Assessment Report (BAR) required for getting the consent related to explosive material procurement;
c) Includes general recommendations for documenting different aspects of the explosive material for the future works; and
d) Includes recommendations for amendment of Explosive Act (2018) and Explosive Regulation (2020.

1.3 Limitation Of The Guidelines

1) As per the spirit of ToR, this guideline has been prepared mainly based on data collected from the different hydropower projects in Nepal. During the preparation, it was very difficult to collect the information related to explosive material usage in the hydropower sector of Nepal in the common basket as the collected project data were poorly organized, recorded, and hardly stored in their projects' archive. Out of all potential data sources, i.e., 74 hydropower projects (both constructed and under-construction projects), 18 different hydropower projects only provided their explosive consumption record of 14971 drilling and blasting operation. Thus, preparing the master table and master figure for the estimation of explosive materials of this guideline based on complete / partial data from 18 hydropower projects only is one of the limitation of this guideline.
2) A total of 14971-collected explosive consumption record of drilling and blasting operation did not cover every tectonic zones and rock types of the Nepal Himalaya. For instance, the explosive consumption record of various types of rocks belonging to the Tethys Himalaya and Siwaliks of Nepal Himalaya. Thus, another limitation of this guideline is not recommending typical curves based on regional geology for Tethys Himalaya and Siwaliks.
3) Though the scope of this guideline also covers the surface excavation as well, the relevant data are barely available. Only six explosive consumption data out of 14971 collected were of the drilling and blasting operation for bench blasting of surface excavation. So, the limited explosive consumption data for surface excavation compelled to use estimation of the explosive material through empirical methods provided by various authors rather than the information acquired from the hydropower projects of Nepal Himalaya.
4) Similarly, the analytical tools used in this assessment is limited to a simplified and convenient estimation of explosive materials for both surface and underground excavation with the help of statistical office MS-Excel software statistical MS-Excel software only. Although, computer aided tunnel/blasting design and management software are readily available in the market, this guideline could not apply such computer-aided software.

This page intentionally left blank

2 METHODOLOGICAL FRAMEWORK

The preparation of this guideline employed an observation and review based methodological framework for analyzing the best practices for the estimation, usage, handling, transportation, storage and procurement of the explosive materials, operational health and safety of the projects regarding explosive materials and management strategies to formalize inspection and monitoring of the explosive materials which have been discussed in the upcoming chapters in detail.

2.1 Data Collection

For the preparation of the guidelines, the relevant and necessary data were collected from the following methods.

1) From field visit of the three hydropower projects which were at the under-construction stage;
2) From questionnaire survey to various HPPs (both constructed and under construction projects);
3) By retrieving laboratory test results of core samples from the geotechnical report of various HPPs at various stages of development;
4) By exploring all the available information, documents, practices related to explosive materials in particular; and
5) By organizing residential workshop and presentation of the guideline framework report and draft report in order to get perspectives of different stakeholders regarding the guideline.

2.1.1 Field Visit

In pursuant to the Terms of References (ToR), primary data were collected during site visit of three under-construction hydropower projects. The representative projects for data collection for the site visits have been confirmed based on geology, rock type, and rock classes representing different tectonic units of Nepal. Beside this, different type of drilling method to be used for drilling charging holes i.e., manual or mechanized, size of tunnel, and ground water conditions were also considered during the selection of representative projects. During the Inception phase, six-probable under-construction hydropower projects were short-listed for site visit as shown in the Table 2-1.

Among them, upon consent of the DoED, site visits have been made to Upper Trishuli -1 Hydro Electric Power Projects (UT-1), Tanahu Hydropower Project (THP), and Lower Solu Hydropower Project (LSHP). These three projects lie in three different locations; one each in the Central, Western and Eastern part of the Nepal Himalaya lying in varied geology, rock type and rock quality along with different secondary parameters such as groundwater conditions, drilling method, size of tunnels, and explosive material among others. The data and observations in the site visit have helped to collect first-hand data for the preparation of the guideline. The site visits have enhanced knowledge and other logistics requirements along with their pros and cons of various national practices with regards to drilling and blasting method, health safety strategies, bunker facilities, security, storage, handling, and transportation mechanism adopted for both surface and underground excavation. The details of the field observation have been discussed in the field report presented in Annex-2.

2.1.2 Questionnaire to the Various HPPs- Constructed and Under Constructed HPPs

Altogether 74 Hydropower projects, both already constructed and projects under-construction, were listed out and screened from the website of DoED as presented in the Table 2-2 for the questionnaire survey. A common questionnaire was prepared for the screened hydropower projects and sent to the hydropower projects via letters from DoED.

a) Projects Under-construction

The 42 numbers of under-construction hydropower projects were listed and requested to provide the explosive related data via letter from DoED. The DoED's letter for under-construction projects have been presented in Annex-3.

b) Completed Projects

The 32 numbers of completed hydropower projects were listed and requested to provide the explosive related data via letter from the DoED. DoED's letter for constructed hydropower projects have been presented in Annex-4.

Table 2-1: List of potential Hydropower Project for site visit and data collection

S.N.	Name of Project	Project Location	Project Geology
1	Upper Trishuli-I Hydroelectric Project (216MW)	Rasuwa district, Bagmati Province	Lesser Himalayan Gneiss, mica schist and quartz schists
2	Nilgiri Hydroelectric Project	Myagdi district, Gandaki Province	Higher Himalayan Gneisses
3	Seti Khola Hydroelectric Project (27 MW)	Kaski district, Gandaki Province	Phyllites, Quartzites, metasandstones (Lesser Himalaya)
4	Lower Solu Hydroelectric Project (82 MW)	Solukhumbu district, Koshi Province	Lesser Himalayan Ulleri Augen Gneiss
5	Arun-3 Hydroelectric Project (900 MW)	Sankhuwashaba District, Koshi Province	Lesser Himalayan Ulleri Augen Gneiss
6	Tanahu Hydropower Project (140 MW)	Kaski district, Gandaki Province	Slates, Dolomites (Lesser Himalaya)

Table 2-2 List of hydropower projects including both constructed and under construction hydropower projects which were correspondent for the explosive related data

S.N.	Hydropower Project	Promoter
1	Arun-3 Hydroelectric Project (900 MW)	SJVN Arun-3 Power Development Company (P.) Ltd.
2	Bagmati Nadi Hydropower Project (22 MW)	Mandu Hydropower Pvt. Ltd.
3	Balephi Hydropower Project (23.52 MW)	Balephi Jalbidhyut Company Pvt. Ltd.
4	Chameliya (Cheetigad) Hydropower Project (85 MW)	Grid Nepal Co. Pvt. Ltd.
5	Chujung Khola Hydropower Project (63 MW)	Ghalemdi Hydro Limited
6	Dordi Khola (27 MW)	Himalayan Power Partner Pvt. Ltd.
7	Durbang Myagdi Khola Hydropower Project (25 MW)	Dhaulagiri Kalika Hydropower P. Ltd.
8	Ghalemdi Khola Hydropower Project (5 MW)	Ghalemdi Hydro Limited
9	Ghar Khola Hydropower Project (14 MW)	Myagdi Hydropower Limited
10	Hewa Khola A Hydropower Project (14.9 MW)	Panchathar Power Company Pvt. Ltd.
11	Indrawati -III Hydropower Project (7.5 MW)	National Hydropower Cmpany Pvt. Ltd.
12	Jagdulla Hydroelectric Project (106 MW)	Jagdulla Hydropower Company Ltd.
13	Jogmai Khola Hydropower Project (7.6 MW)	Sanvi Energy Pvt.Ltd.

S.N.	Hydropower Project	Promoter
14	Kabeli -3 Hydroelectric Project (21.93 MW)	Kabeli Hydropower Company Ltd.
15	Kabeli A hydropower Project (37.6 MW)	Kabeli Energy Limited
16	Karuwa Seti Hydroelectric Project (32 MW)	Jhyamolingma Hydropower Development Company Pvt. Ltd.
17	Khani Khola (Dolkha) Hydropower Project (30 MW)	Sasha Engineering Hydropower P. Ltd.
18	Khani Khola I hydropower Project (40 MW)	Green Life Energy Pvt. Ltd.
19	Khimti -I Hydropower Project (60 MW)	Himal Power Limited
20	Langtang Khola Small Hydropower Project (20 MW)	Multi Energy Development Pvt. Ltd.
21	Lapche Khola Hydropower Project (160 MW)	Nasa Hydropower Company P. Ltd.
22	Likhu Khola A Hydropower Project (29.04 MW)	Numbur Himalaya Hydropower Ltd.
23	Likhu-1 Hydropower Project (77 MW)	Pan Himal Energy Ltd.
24	Likhu-2 Hydropower Project (55 MW)	Global Hydropower Associate Ltd.
25	Likhu-4 Hydropower Project (52.4 MW)	Green Ventures Ltd.
26	Lower Hewa Hydropower Project (22.1 MW)	Mountain Hydro Nepal (P.) Ltd.
27	Lower Likhu Hydropower Project (28.1 MW)	Swet Ganga Hydropower and Construction Pvt. Ltd.
28	Lower Modi Khola (20 MW)	Modi Energy Pvt. Ltd.
29	Lower Solu Hydropower Project (82 MW)	Solu Hydropower Pvt. Ltd.
30	Luja Khola Hydroelectric Project (24.8 MW)	Silk Power Pvt. Ltd.
31	Madhya Bhotekoshi Hydropower Project (102 MW)	Madhya Bhotekoshi Jalbidhyut Company Limited
32	Madhya Hongu Khola A Hydropower Project (22 MW)	Apex Makalu Hydropower Limited
33	Mai Beni Hydropower Project (9.51 MW)	Samling Power Company Pvt. Ltd.
34	Mai Hydropower Project (22 MW)	Sanima Mai Hydropower Limited
35	Mai Khola Hydropower Project (4.5 MW)	Himal Dolkha Hydropower Co. Ltd.
36	Maya Khola Hydropower Project (14.9 MW)	Maya Khola Hydropower Company Pvt. Ltd.
37	Mewa Khola Hydroelectric Project (23 MW)	Union Mewa Hydro Limited
38	Mewa Khola Hydroelectric Project (50 MW)	United Mewa Khola Hydropower Pvt. Ltd.
39	Middle Hongu B Hydroelectric Project (22.9 MW)	Gaurishankhar Power Development Pvt. Ltd.
40	Middle Tamor Hydroelectric Project (73 MW)	Sanima Middle Tamor Hydropower Ltd.
41	Midim Khola Hydropower Project (3 MW)	Union Hydropower P. Ltd.
42	Mistri Khola (42 MW)	Mountain Energy Nepal Limited
43	Modi Khola Hydropower Project (14.7 MW)	Everest Energy and Infrastructure Fund Pvt. Ltd.
44	Nilgiri Khola Hydroelectric Project (100 MW)	Nilgiri Khola Hydropower Company Ltd.
45	Nyadi Khola Hydropower Project (30 MW)	Nyadi Hydropower Limited
46	Nyasim Khola Hydropower Project (35 MW)	Mountain Hydro Nepal (P.) Ltd.
47	Rahughat Hydropower Project (40 MW)	Raghu Ganga Hydropower Limited
48	Rahughat Mangale Hydroelectric Project 37 MW)	Tundi Hydropower Company Limited
49	Rasuwagadhi Hydroelectric Project (111 MW)	Rasuwagadhi Hydropower Company Limited

S.N.	Hydropower Project	Promoter
50	Singati Khola Hydropower Project (25 MW)	Singati Hydro Energy Pvt. Ltd.
51	Sipring Khola Hydropower Project (10 MW)	Synergy Power Development P. Ltd
52	Solu Khola (Dudhkoshi) Hydropower Project (86 MW)	Suhas Urja Limited
53	Sunigad Hydroelectric Project (11.05 MW)	Omega Energy Developer Pvt. Ltd.
54	Super Dordi Hydoelectric Project (37 MW)	Peoples Hydropower Company Limited
55	Super Lower Bagmati Hydroelectric Project (41.86 MW)	Bagmati Hydropower Pvt. Ltd.
56	Super Madi Hydropower Project (44 MW)	Himal Hydro and General Construction Ltd.
57	Tanahu Hydroelectric Project (140 MW)	Tanahu Hydropower Limited
58	Thapa Khola Hydropower Project (11.2 MW)	Mount Kailash Energy Co. Ltd.
59	Thulo Khola Hydropower Project (21.3 MW)	Samyukta Urja Pvt. Ltd.
60	Upper Balephi A Hydropower Project (32 MW)	Balephi Hydropower Limited
61	Upper Bhotekoshi Hydropower Project (45 MW)	Bhotekoshi Power Limited
62	Upper Chaku A hydropower Project (22.2 MW)	Shiva Shri Hydropower Pvt. Ltd.
63	Upper Chameliya Hydropower Project (40 MW)	Api Power Co. Ltd.
64	Upper Dordi A Hydropower Project (25 MW)	Liberty Energy Hydropower Pvt. Ltd.
65	Upper Khudi Hydropower Project (26 MW)	Super Khudi Hydropower Co. Pvt. Ltd.
66	Upper Lapche Khola Hydropower Project (52 MW)	Energy Ventures Pvt. Ltd.
67	Upper Madi Hydropower Project (25 MW)	Madi Power Pvt. Ltd.
68	Upper Madi Hydroelectric Project (43 MW)	Annapurna Power Company Pvt. Ltd.
69	Upper Mai Hydropower Project (12 MW)	Mai Valley Hydropower P. Ltd.
70	Upper Mai Hydropower Project (12 MW)	Panchakanya Mai Hydropower Limited
71	Upper Mai-C Hydropower Project (6.1 MW)	Panchakanya Mai Hydropower Limited
72	Upper Marsyangdi A Hydropower Project (50 MW)	Sinohydro-Sagarmatha Power Company Pvt. Ltd.
73	Upper Rahughat Hydroelectric Project (48.5 MW)	Tundi Hydropower Company Limited
74	Upper Trishuli -1 Hydropower Project (216 MW)	Nepal Water and Energy Development Co. P. Ltd.

2.1.3 Geotechnical Report of Various HPPs at different Stages of Development

The geotechnical investigation data were collected from the various hydropower projects that were studied by DoED, Hydro-Consult and some other private developers. Usually, the data related to the strength of the rock i.e. Point Load Index (PLI) and Unconfined Compressive Strength (UCS) data were retrieved and tabulated for the analysis. The data include strength tests of rocks of different, geological units, rock types and location of the Nepal Himalaya. The table of the collected data for the rock strength from various hydropower projects is presented in Annex-5.

2.1.4 Residential Workshop

Organization of residential workshop representing various stakeholders related to the explosive material is another method/scope of work for the preparation of this guideline. For this, a two-day residential workshop was organized for the discussion on this guideline after the submission of Guideline Framework Report in pursuant to Section 3.8 of the ToR. The workshop schedule has been presented in Annex-6. The workshop was organized in Aagantuk Resort, Dhulikhel from July 01, 2024 to July 02, 2024 (Figure 2-1). The details of participants representing different stakeholders have been listed in the Table 2-3. Since, the residential workshop is an integral part of the methodological framework used to prepare this guideline, the response of all the comments and suggestion provided by the participants of the workshop is important and relevant. Thus, comment incorporation sheets of the residential workshop regarding the guideline have been presented in Annex-6A.

Figure 2-1 Photograph showing participants of the residential workshop representing different stakeholders

Table 2-3 List of Participants representing different stakeholders during the residential workshop

S.N.	Name of Participants	Designation
1	Mr. Nabin Raj Singh	Joint Secrectary, MOEWRI
2	Mr. Churna Bahadur Oli	Joint Secrectary, MOEWRI
3	Mr. Jeebacch Mandal	Director General, DoED (TSG Member)
4	Mr. Gokarna Raj Pantha	Deputy Director General, DoED
5	Mr. Sunil Poudel	Deputy Director General, DoED (TSG Member)
6	Mr. Sunil Kumar Piya	Senior Divisional Engineer, DoED
7	Mr. Chiranjiv Jha	Senior Divisional Engineer, DoED (TSG Member)
8	Mr. Subarna Khanal	Senior Divisional Geologist, DoED
9	Mr. Badri Kuikel	Senior Divisional Engineer, DoED
10	Mr. Jeevan Ranamagar	Senior Divisional Engineer, DoED
11	Mr. Suresh Sunar	Under Secretary (Administration), DoED

S.N.	Name of Participants	Designation
12	Mr. Abadhkishor Prasad Kushwaha	Under Secretary (Law), DoED
13	Mr. Jaguram Chaudhary	Under Secretary (Finance), DoED
14	Mr. Shankar Bahadur Saud	Hydropower Engineer, DoED
15	Mr. Sabindra Bahadur Shrestha	Engineering Geologist, DoED (TSG Member)
16	Mr. Kameshwor Yadav	Electrical Engineer, DoED
17	Mr. Anand Chaudhary	Member, IPPAN (TSG Member)
18	Mr. Santosh Kumar Yadav	Assistant Professor, IOE, Pulchowk (TSG Member)
19	Mr. Bijay Rana	Major, Nepal Army (TSG Member)
20	Mr. Bimal Gurung	CEO, Dudhkoshi Storage Project
21	Mr. Madhab Lamsal	Geologist, Department of Environment
22	Mr. Milan Magar	Senior Geologist, Tanahu Hydropower Project, NEA
23	Mr. Giri Raj Adhikari	Technical Director, Upper Trishuli-1 HEP
24	Mr. Subhash Giri	Civil Engineer, Lower Solu HPP
25	Mr. Prajwol Shrestha	Director, Mohan Man Shakti Man
26	Mr. Manohar Shrestha	CEO, Hydro-consult Engineering Limited
27	Mr. Bibek Karanjit	Team Leader, JV HCE-ERMC-FBC
28	Mr. Saroj Lal Shrestha	Divisional Head, Hydro-consult Engineering Limited
29	Ms. Sahana Joshi	Senior Geologist, Hydro-consult Engineering Limited
30	Mr. Prayag Maharjan	Geologist, Hydro-consult Engineering Limited
31	Mr. Saransh Mool	Geotechnical Engineer, Hydro-consult Engineering Limited
32	Mr.Yadav Dhungana	Admin Officer, Hydro-consult Engineering Limited

2.1.5 Draft and Final Report Presentation

A presentation of the draft report of this guideline was organized on December 1, 2024 in DoED (Figure 2-2). The details of participants representing different stakeholders have been listed in the Table 2-4. Since, the presentation is another integral part of the methodological framework used to prepare this guideline, the response of all the comments and suggestion provided by the participants of the presentation is important and relevant. Thus, comment incorporation sheets of the presentation regarding the draft report of the guideline have been presented in Annex-6B. Similiarly, the comment response sheet of the presentation regarding final report of this guideline has been presented in Annex-6F.

Table 2-4 List of Participants representing different stakeholders during the draft and final report presentation

S.N.	Name of Participants	Designation
1	Mr. Nabin Raj Singh	Director General, DoED (TSG Member)
2	Mr. Arun Kumar Jha	Deputy Director General, DoED
3	Mr. Gokarna Raj Pantha	Deputy Director General, DoED
4	Mr. Sunil Poudel	Deputy Director General, DoED (TSG Member)
5	Mr. Sagar Raj Gautam	Deputy Director General, DoED
6	Mr. Sunil Kumar Piya	Senior Divisional Engineer, DoED

S.N.	Name of Participants	Designation
7	Mr. Chiranjib Jha	Senior Divisional Engineer, DoED (TSG Member)
8	Mr. Gopi Prasad Sah	Senior Divisional Engineer, DoED
9	Mr. Subarna Khanal	Senior Divisional Geologist, DoED
10	Mr. Shaligram Bhandari	Senior Divisional Engineer, DoED
11	Mr. Shankar Shambhu Chaudhary	Senior Divisional Engineering Geologist, DoED
12	Mr. Jeevan Ranamagar	Senior Divisional Engineer, DoED
13	Mr. Shankar Bahadur Saud	Hydropower Engineer, DoED
14	Mr. Sabindra Bahadur Shrestha	Engineering Geologist, DoED (TSG Member)
15	Mr. Dinesh Kumar Sah	Electrical Engineer, DoED
16	Mr. Avian Marasini	Mechanical Engineer, DoED
17	Mr. Ashish Chudali	Mechanical Engineer, DoED
18	Mr. Pramod Dhakal	Engineering Geologist, DoED
19	Mr. Ranju Sharma	Engineering Geologist, DoED
20	Mr. Prakash Man Shrestha	Hydropower Expert (TSG Member)
21	Mr. Kangada Prasai	Geological Expert (TSG Member)
22	Dr. Santosh Kumar Yadav	Geotechnical Expert (TSG Member)
23	Mr. Ananda Chaudhary	Member, IPPAN (TSG Member)
24	Mr. Saroj Ghimire	Environmental Engineer (TSG Member)
25	Mr. Bijay Rana	Major, Nepal Army
26	Mr. Bimal Gurung	CEO, Dudhkoshi Storage Project
27	Mr. Bharat Parajuli	Explosive Suppliers
28	Mr. Prajwal Shrestha	Explosive Suppliers
29	Mr. Yagya Subedi	Explosive Suppliers
30	Mr. Santosh Thapa	Explosive Suppliers
31	Mr. Saroj Lal Shrestha	Divisional Head, Hydro-Consult Engineering Limited
32	Mr. Balram Bhattarai	Senior Environmentalist, Hydro-Consult Engineering Limited
33	Ms. Sahana Joshi	Senior Geologist, Hydro-Consult Engineering Limited
34	Mr. Prayag Maharjan	Geologist, Hydro-Consult Engineering Limited
35	Mr. Saransh Mool	Civil/Geotechnical Engineer, Hydro-Consult Engineering Limited

2.1.6 Review of Available Information Documents and Practices

Selected portions of the following references were reviewed during the preparation of this guideline.

Environment Protection Act, 2076

Government of Nepal has enacted this Environment Protection Act in 2076 BS. Section 3 of the Act requires proponent to conduct Environmental Study: Brief Environmental Study (BES), Initial Environmental Examination (IEE) or Environmental Impact Assessment (EIA). Section 4 highlights the detailed need of alternative analysis. Section 5 and 6 relates to Scoping and ToR as well as its quality. Section 8 and 9 highlights the provision related to approval of environmental study reports and prohibition of implementation of the project without approval of the reports. Strategic Environmental Assessment, Environmental Management Plan and Supplementary EIA have been discussed in section

9-11. In terms of pollution control, section 15-20 highlights the provisions related to pollution control, import and management of hazardous chemicals, establishment of laboratory, sample collection, pollution control certification. Section 35 to 37 specifies penalty and compensation regarding provisions of this Act.

Figure 2-2 Photograph showing participants representing different stakeholders during the Draft Report Presentation

Hydropower policy 2058

Hydropower policy was developed to generate electricity at low cost by utilizing water resources available in the country, to extend the reliable and quality electric service throughout the country, to tie-up electrification with the economic activities and to develop hydropower as an exportable commodity. The various strategies and policies were set up to meet the above-mentioned objectives. The different working polices were made related to environmental provision for environmental impacts assessment study, land acquisition, resettlement and rehabilitation, provision on license, provision related to fees, facilities relating to tax and customs, institutional provision, and construction and operation of hydropower projects by government of Nepal.

White Paper 2075

Government of Nepal (GoN), Ministry of Energy, Water Resources and Irrigation (MoEWRI) published White Paper, 2075 to meet the target of the government slogan "सम्रिद्ध नेपाल, सुखी नेपाली" by the overall development of energy, water resource and irrigation sectors. The main objectives of the white paper are to find out the present condition and problems of energy, water resource and irrigation sectors and reasons behind it, to make the road map to solve the problems in these sectors utilizing the available resources, to develop road map for the development of hydroelectricity to meet the present energy demand, to make easily available clean and renewable energy, to provide irrigation facilities in the agricultural land throughout the year utilizing the available natural resources and minimizing water induced disaster by sustainable and effective management. It describes the present status, competition in the process of license, dismiss of the license on the failure of timely progress, dismiss of PPA for not starting the project on time.

Causes, impact, and control of over break in underground excavations by Singh & Xavier, 2005

The paper on the "Causes, impact, and control of over break in underground excavations" by Singh, S.P. and Xavier, P. published in the journal of Tunneling and Underground Space Technology in 2005. The study focusses on the cause of over break whether it is due to blasting practice or poor rock mass quality. The study involves the physical models of small-scale blasting and the assessment of blast damage during the drilling and blasting operations.

The damage was measured by the half cast factor, percentage over break and the Blast damage index. The influence of rock mass features, explosive characteristics and blast design parameters on over break have been evaluated in this study. A new approach for the judicious design of perimeter hole pattern and charge concentration has been proposed. Implications of blast damage have also been outlined in this paper. An equation was developed including the parameters like specific charge, perimeter charge factor, maximum charge per delay, rock mass quality (Q), advancement and confinement factors.

Drilling and blasting as a tunnel excavation method by Satici & Hindistan, 2006

Drilling and blasting as a tunnel excavation method is paper by Özgür Satici and A. Hindistan, in 2006 from Middle East Technical University and Department of Geological Engineering, Ankara Turkey. The paper covers the detail about drilling and blasting method. It includes the types of explosives, drilling and blasting cycle, drilling pattern, definitions of stopping, contour hole, and look out angle, powder factor (specific charge), method of charging of blasting of holes, blasting method and cut types (parallel cut, v-cut, the fan cut), tunnel excavation method, tunneling accuracy, controlled blasting, and damage control in the tunnel among others. This paper was very helpful for preparing the guideline as it almost covers the overall scope of works except the management strategies.

Theory and Technology of Rock Excavation for Civil Engineering by Zhou, 2017

The book "Theory and Technology of Rock Excavation for Civil Engineering" not only outlines various theoretic topics on rock excavation, but also introduces various excavation techniques under the guidance of these theories. This book, which combines theory and practice with an abundance of figures, data and illustrations, can be applied as the reference material for the relevant subjects in addition to being an invaluable handbook. This book was very helpful for preparing the guideline as it almost covers the overall scope of works except the management strategies.

2.2 Policies and Legal Instruments Related to Explosive Material in Nepal

2.2.1 National Policies / Guidelines / Acts / Laws

The policy is a principle or a rule to guide decisions and achieve desired outcomes while strategy is the way or method adopted to bring about that desired outcome. Policies related to explosive material have traditionally evolved from a sense of ensuring collective action on a common resource for the good of all.

2.2.1.1 Constitution of Nepal 2015

Nepal's new constitution, adopted in 2015 ushers in the federal structure with three tiers of governance-federal, province, and the local municipalities. Article 267-provision relating to Nepal Army states that the GoN may mobilize the Nepal Army in other works including development, construction and disaster management work as provided in the federal law. Similarly, article-51 (a) - policies relating to national unity and national security states that all security organs including the Nepal Army, Nepal

Police, and Armed Police Force Nepal shall be accountable to the people on the basis of the national security policies. According to the article 266, there shall be a provision for National Security Council for making recommendation to GoN, Council of Minister regarding the policy formulation on the overall national interest, security, and defense of Nepal.

2.2.1.2 The Explosives Act, 2018 BS (1961 AD)

The explosive act, 2018 BS has provided necessary provisions for the production, use, sale, transportation and import of the explosive in the country in order to maintain peace and order. The existing legal framework for explosive material in Nepal is still set out in the explosives act 2018 (1961) as completed by the explosive rules, 2020 (1963). This act provides the definition of the explosive materials; however, it does not clearly distinguish between commercial or industrial explosives and non-commercial explosives. Thus, this act still put all explosive material into the same category. In addition, GoN may declare any material as explosive that causes harm to life and property of a person by publishing a notice in a Nepal gazette. Similarly, the act has mentioned terms and condition of a license, power to inspect, and seize, power to arrest, punishment and confiscation to control various activities related to explosives.

The amendment were made in the different interval of time as felt by the GoN. The Last amendment was done on date 2048-7-14 BS. It describes in detail about the definition of the explosives, power to declare the material as explosive, control in production, storage, use, sale, transportation and import of explosives, power of Government of Nepal to deal to explosives in production, sale, inspect, search, and seize, power to arrest, examination of accident, and power to frame rules to meet the objectives of this act.

2.2.1.3 Other Relevant National Policies / Guidelines / Acts / Laws

The review of other relevant national policies / guidelines / acts / laws has been summarized and presented in Annex-7.

2.3 Review Of Best National Practices

Blasting and Explosive Management Plan of Upper Trishuli-1 Hydroelectric Project (UT-1 HEP)

Blasting and explosive management plan was prepared by Nepal Water and Engineering Development Company Private Limited (NWEDC) in 2021 for managing construction, environment, social, health and safety, management, and monitoring of drilling and blasting activities of the project. This report includes pre-blasting assessment of nearby structures so as to confirm any reports of structural damage, mitigation measures to minimize the effects of drilling and blasting operation, legal measure taken, organizational team for control and management, tunnel planning accuracy, blast indicators, storage and transportation of the explosive materials, lightning protection system, rotation of the stack and stack packaging of the explosives in the bunker house, firefighting transportation of the explosive from bunker to the explosion site, major consequences of the blasting based safeguard activities, trigger action response plan to identify alert level for surface and underground blasting activities, post blast activities, training of the personnel, blast monitoring plan, inspection checklist for bunker and explosive material and review and reporting of the all the blasting activities to the designated officials within the quoted time.

Environment and Social Management System of Lower Solu Hydropower Project (LSHPP)

The Environment and Social Management System (ESMS) has been prepared by AECOM India Private Limited in 2022 for compliance with International Finance Corporation Sustainability Framework, 2012 and other applicable international and national requirements. The document focuses primarily on proper governance, implementation of local environmental laws and establishment of procedures to ensure employee safety, sensitivity to local cultures and customs, and maintaining a clean and healthy work place and environment.

The major objectives of the management system are as follows:

a) To access the environmental and social impacts during life cycle of the project.
b) Identify and fulfill all environmental and social obligations put forth by various external stakeholders (Government of Nepal, Global Financial Institutions such as World Bank, IFC, etc.)
c) To ensure environmental and social legal compliances of the project
d) Influence and mandate (as relevant) clients and downstream agencies to ensure legal compliance and manage environmental and social risks
e) Formulates and outlines policies, procedures, roles, and responsibilities for managing impacts, risks, and effects on environment and social aspects of the project.

Apart from this, environment and social management system includes the environmental and social organizational team for managing and monitoring the social and environmental issues including drilling and blasting activities, procedure of environment and social management, risk assessment, record keeping of job safety analysis, occupational and community health and safety management, environmental management in construction and operational phase, management of labor and working condition, grievance redressal procedure, information disclosure procedure, stakeholder engagement procedure, tunnel safety, explosives management and blasting procedure (which include, transportation, storage, handling and usage, drilling and loading, electrical shot, before and after drilling and blasting, misfires, disposal of the explosives, engagement of the personnel, training, health and first aid, communication, tunnel safety, record of drilling and blasting operation), working at extreme working condition (snowfall, monsoon, cold, high temperature), management of community development activities, and traffic management plan.

2.4 Review Of Best International Practices

A new damage criteria norm for blast-induced ground vibrations in Turkey

In the study of Karadogan, Kahriman, & Ozer (2013), numerous vibration records were taken in blasting operations performed at different sites and rock units. For these rock units, particle velocity predictions and frequency analysis were carried out. At the same time, structures in the neighborhoods of these blasts were also observed and investigated. Finally, a damage criterion norm based on risk analysis was established and proposed by using these collected data (Figure 2-3) for making the excavation work in the country more effective causing minimum environmental problems.

Code of Practice for Construction of Tunnels, Part II: Underground Excavation in Rock, Section 1: Drilling and Blasting, IS: 5878-2-1 (1970)

This standard deals with drilling and blasting for underground excavation of tunnels in rock. It briefly describes about tunnels, explosive, access tunnels, drainage, water pumps etc., shape of tunnel, location of portals, tunneling methods and cycle of tunnel construction by drill and blast method. It discusses drilling equipment, drilling of holes, blast design and patterns, blasting using explosives, detonators, safety fuse, detonating fuse, primer, circuit testers, loading and stemming, electric wiring used for blasting and inspection of handling of misfires.

Indian standard for safety code for blasting and related drilling operations, IS: 4081 -1986

Drilling and Blasting Operation is a specialized job involving many hazards that often lead to operational hazards. Therefore, it is necessary to take certain safety precautions for various operations involved in the process of blasting and drilling for the guidance of those who are engaged on the work with a view to minimizing the risk of accidents and injuries. This standard points out the safety requirements for blasting and related drilling operations in locations other than mines. It describes all the safety measures related to transportation, storage, handling and use of explosives. It also covers the safety guideline and rules for drilling and loading of explosives, electrical shot-firing circuit, blasting with safety fuse, before and after blasting, explosive disposal and account of explosives in drilling and blasting related operations.

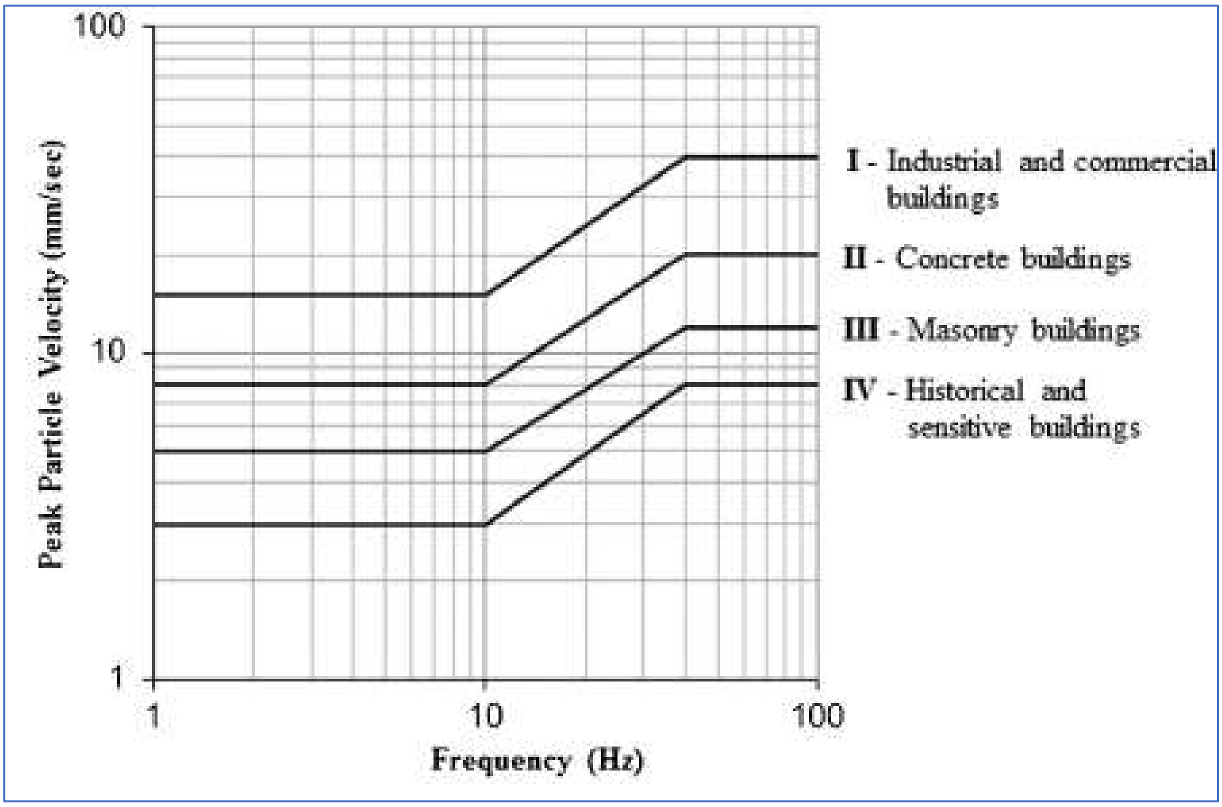


Figure 2-3: Damage Criteria Norm (Source: Karadogan, Kahriman, & Ozer, 2013)

Project Report 2A-95: Tunneling Blast Design by University of Trondheim the Norwegian Institute of Technology

The report explicitly provides the basics of blasting design for underground excavations. The report covers the topics and provide guidance systematically for the effective Tunnel Blast Design and its' execution. The report covers a) Tunnel cross sections, b) Geological parameters "Rock Blastability', c) Drilling, d) Charging, and e) Firing in detail. The chart in the report about the projected powder factor to ease the estimation of explosive quantity in the planning phase of underground construction if it is to excavate by drilling and blasting. After reviewing this report, we can say that explosive consumed data developed in the chart belongs to different geological setting when compared with the geological setting of Nepal Himalaya. Thus, this guideline has adopted similar approach by preparing maser curve and master table for the estimation of the explosive materials based on the geology of Nepal, In addition, the report mentioned the software name TUNNPLAN -Graphic, interactive design of drilling patterns for drill and blast tunneling, developed from TUKON, TUCON and TUCAD. (Jahannessen, 1995)

Safety in Norwegian Drill and Blast Tunneling by Norwegian Tunneling Society (NTS)

Safety in Norwegian Drill and Blast Tunneling was published by Norwegian Tunneling Society in 2018. It describes all the safety measures in each cycle of drill and blast method of tunneling. The aim is that the book should help the owner or client, designer and contractor to:

- think safety throughout the planning, design and execution phases of a project;
- prepare specifications and tender documents that are detailed and clear in regards to pricing of safety measures;
- clarify specific requirements in Norwegian public laws and regulations in connection with project design and execution;
- draw up Safe Job Analysis plans and Health Safety and Environment plans;
- describe the risk factors for different types of work in tunnels and rock caverns;
- provide information about the effect such factors may have on safety;
- describe measures and good practice for ensuring safety underground; and
- carry out work in tunnels, rock caverns and shafts in a safe manner.

Unified facilities guide specification on Tunnel Excavation by Blasting, 2021

The guideline describes all the terms related to the tunnel excavation using blasting such as controlled blasting, air blast, vibration, pay line, staged excavation, over-break, probe hole, shotcrete, rock support, water sheet, and drain hose among others. It describes in detail about safety procedure for drill and blast underground excavation, qualification and responsibilities of blasting consultant, blaster, blaster in-charge, magazine keeper, project manager, tunnel supervisor, engineering geologist or geotechnical engineer. The documents for the tunnel excavation include tunnel excavation plan, blasting plan, shot plan and reports, explosive consumption report, reports of loss, post blast survey and probe hole drilling report. The procedure of stemming, scaling, grouting, mucking, tunnel support, excavation sequence and water control are well explained.

2.5 Data Processing and Analysis

The data were collected from the different under construction, constructed and studied hydropower projects of Nepal. All the collected data via the methodological approach as mentioned in the Section 2.1.1, 2.1.2, and 2.1.3 used for processing and analyzing to estimate the quantity of the explosive materials including initiation system required for the development of a hydropower project. For the data processing and analysis, all the data were synthesized as average value, maximum value, and minimum value based on the rock type, geological unit, dimension of the tunnel, rock class, explosive material consumption, and ignition system consumption among others.

All together explosive consumption record of 14971 drilling and blasting operation of 18 different hydropower projects presented in Annex-8 have been synthesized, analyzed, and presented. Out of 14971 explosive consumption record, only six data of drilling and blasting operation for surface blasting have been collected. Since, the estimation of explosive materials with only six number of data is not relevant, powder factor estimation of surface excavation proposed by Gokhale (2010) based on rock strength, rock density, and joint spacing by considering collected geotechnical data in Section 2.1.3 was adopted for this guideline. For this purpose, intact rock properties (UCS and PLI), have been collected from the geotechnical reports of various hydropower projects in Nepal. For the processing and analysis of the intact rock properties (UCS and PLI), the absolutely maximum average value and absolutely minimum average value were computed. The powder factor range of all the rock types based PLI and UCS values were based on Gokhale (2010). The data related to the intact rock properties (UCS and PLI) retrieved from the different hydropower projects have been presented in the tabular form in Annex-5.

Since, 14971 drilling and blasting operation of 18 different hydropower projects presented Annex-8 were collected during the preparation of this guideline, these data were used for the powder factor estimation of underground excavation. For the processing and analysis of the explosive consumption records, the average powder factor of different rock types, blastability, rock quality, and regional geology along with different excavation cross sectional area of the various project components of 18 different hydropower projects were used. Similarly, a typical blasting pattern for tunnel diameter ranging from 1.0 m to 13.0 m have been prepared based on the parameters recommended by this guideline for the preparation of a typical curve from the graph of powder factor versus excavated cross-sectional area based on the typical blasting pattern.

With regards to the available rock types, only schist rock could be compared or co-related with the powder factor versus excavated cross-sectional area of the underground blasting proposed by ICI Australia Operations Pty Ltd (1980). For comparison and co-relation of typical curves based on blastability, this guideline has prepared a typical curve for good blastabilitiy rock and poor blastability rocks and compared it with the respective typical curves proposed by the NTNU. Lastly, the typical curve proposed by IDL has been compared with the typical curve prepared by this guideline based on all the rock types found in Nepal.

2.6 Data Presentation

For the estimation of explosive materials for surface excavation, the data for calculation of powder factor have been presented in the form of the histogram with corresponding tables showing different ranges of PLI and UCS values of different types of rocks found in the Nepal Himalaya. Since, there were significant number of data for rocks namely gneiss, schist, sandstone and limestone, the range of powder factor of different varieties of the above-mentioned rock have also presented in the form of the histogram with corresponding tables respectively.

Meanwhile, for the estimation of explosive materials for underground excavation, the data for calculation of powder factor is presented in the form of the master curve (typical curve prepared from powder factor versus excavated cross-sectional area of the underground blasting based on five different factors namely rock type, rock blastability, rock quality, regional geology and typical blasting pattern) and master table prepared and recommended by this guideline.

For the estimation of the ignition system for boulder blasting, surface excavation as well as underground excavation, the recommended range has been presented in tabular form.

3 GUIDELINES FRAMEWORK FOR ESTIMATION, USAGE, HANDLING, STORAGE, TRANSPORTATION, AND PROCUREMENT OF EXPLOSIVE MATERIALS

This guideline covers commercial explosives / industrial explosives only. According to the explosive act 2018 (1961) the explosives have been defined as any material whether or not of same category which are produced or used with the objective of bringing about the practical affect through explosion or the effect of a fire-cracker nature. All commercial explosives that are extensively used in hydropower projects should meet the following basic requirements.

a) The explosives should have a low mechanical sensitivity and proper initiation sensitivity in order to ensure (1) a convenient and reliable initiation during the drilling and blasting operation and (2) the safety during the process of production, storage, transport, and use;
b) The explosives should have a good blasting performance with enough strength for meeting various rock characters;
c) Its chemical composition should have a zero oxygen balance or near-to-zero oxygen balance to ensure less toxic fumes during blasting and no or very few poisonous components in its composition;
d) The explosives should have a proper and stable shelf life for storage and does not deteriorate or lose efficiency within the period of its shelf life;
e) The explosives should have a wide range and cheap sources of raw materials; and
f) The explosives should have a simple manufacturing process and safe operation.

During the review of available information regarding the explosive material, it was observed that explosives can indeed be considered a construction material, albeit a specialized one. Explosives are widely used in construction in many countries around the world, though the specifics of their use and the regulations governing their applications can vary. For example, in the United States, the regulation of explosives involved multiple agencies but the military generally not directly involved in the regulation of the commercial explosives for the civilian use. On the contrary, several countries such as Pakistan, Israel, Egypt, Turkey including Nepal, the regulation of the explosive involves the significant oversight by the military due to both security concerns and need to prevent misuse.

Since, the definition of the explosive has been provided in the Explosive Act (2018) and Explosive Regulation (2020) of Nepal, which does not classify the explosives as, mentioned in the Figure 3-6. This guideline recommends the amendments required for the above-mentioned legislation in the Section 7.2.1.

3.1 Explosive Material Estimation

In order to get the recommendation for the procurement of explosive materials for the hydropower project, the prospecting hydropower project must provide the estimation based on the details mentioned in this section included in a Blasting Assessment Report (BAR) as discussed in Section 3.1.5 of this guideline. The estimation of the explosive materials must be carried out having the technical specification as discussed in Section 3.1.8.

Explosive material estimation should be carried out by calculating the exact rock excavation volume for each project components or project facilities by assuming an appropriate powder factor for the given excavated cross-sectional area based on various factors discussed in this section. For the estimation of explosive materials for the hydropower projects of Nepal, this guideline recommends to assess the actual dimensions of all the project components and compute the exact rock excavation (both surface and underground) volume considering the requirements mentioned in Section 3.1.1 and the Templates for estimation of explosive materials.

The estimation of the explosive materials should be based on the geology of Nepal as discussed in Section 3.1.2 and the Templates for estimation of explosive materials. For the assumption of the powder factor of explosives as discussed in Section 3.1.3 regarding surface excavation, this guideline recommends to apply the ranges of powder factor mentioned in Figure 6-1 and consider the requirements mentioned in Section 3.1.6. Meanwhile, for the assumption of the powder factor of explosives as discussed in Section 3.1.3 regarding underground excavation, this guideline recommends to apply the ranges of powder factors presented in Figure 6-11 and Table 6-9 as well as consider the requirements mentioned in Section 3.1.7.. Similarly, for the assumption required for the estimation of ignition system (detonators and detonating cord), this guideline recommends to apply the recommended range of values as mentioned in the Table 6-13 for boulder blasting, surface excavation as well as underground excavation using the Templates for estimation of explosive materials.
However, this guideline also allow the estimation of explosive materials-based norms prepared by the Department of Roads (DoR) of Nepal if any prospecting hydropower project opt to estimate it accordingly.

3.1.1 Dimension of the Project Components for Rock Excavation Volume Calculation

Explosive estimation for a hydropower project involves detail calculation and considerations based on the specific requirements and dimensions of the project components / facilities. The size of the project components / project facilities depends up on the capacity of the project. Usually, higher the capacity project has the bigger tunnel size as well as other structures. The basic project components of any hydropower projects include headworks structure, water conveyance structures, and power house structure among others. Please refer to the "Guidelines for Study of Hydropower Projects (2018)" prepared by DoED, for details regarding the project components/facilities and its dimension of any hydropower projects.

This guideline recommends a typical rock excavation volume sheet in Table 3-1 for major project component/facilities of any hydropower projects for the total rock excavation volume estimate which is ultimately required for estimation of explosive material using drilling and blasting method**.** Thus, the hydropower project must submit the explosive material procurement application to DoED enclosing quantity estimate of rock excavation volume required based on the actual dimension of each project component/facilities presented in the issued construction drawings in the format presented in the Table 3-1 and the Templates for estimation of explosive materials.

3.1.2 Geology

It is necessary and very useful for an engineer working in the field of rock excavation to understand some basic knowledge about the main categories of different rock types. It has more than academic interest because it will assist in understanding field conditions and dealing with them in the most effective manner. The examples of three basic rock types found in Nepal have been mentioned below:

a) Igneous Rock (Granite, pegmatite, and amphibolite among other);
b) Sedimentary. Rock (Limestone, Dolomite, Shale, Sandstone, Mudstone, Conglomerate, and Breccia among others); and
c) Metamorphic. Rock (Gneiss, Schists, Phyllite, Slate, Marble, Quartzite, Metasandstone, and Amphibolite among other).

Similarly, it is also necessary and very useful for an engineer to understand some basic knowledge about the main geological settings of Nepal Himalaya in understanding field conditions and dealing with them

Table 3-1 Quantity estimate of rock excavation volume and explosive materials

Government of Nepal
Ministry of Energy, Water Resources and Irrigation
DEPARTMENT OF ELECTRICITY DEVELOPMENT
Sano Gaucharan, Kathmandu

TEMPLATE FOR QUICK ESTIMATION OF EXPLOSIVE QUANTITY FOR HYDROPOWER PROJECTS

Name of the Project: **XYZ Hydropower Project, ABC District**
Installed Cpacity: **XYZ MW**

A. Explosive Materials Estimation for Surface Excavation for Bench Blasting, Trench Blasting, and Boulder Blasting

SN	Description of Excavation Work	Type of Excavation	Excavation Dimension: Length (m)	Breadth (m)	Height (m)	Excavated X-Sec Area (m²)	Excavation Volume (m³) including 15% contingency	Geological Basis: PU/ UCS	Regional Geology	Rock Type	Emulsion Consumption (Kg/m3)	Refererance Range	Detonators (Nos/kg)	Detonating Cord (m/kg)	Contingency Required	Contingency (%) added	Required Quantity: Emulsion (Ton)	Detonators (Nos)	Detonating Cord (m)	Remarks
1	Headworks (Dam/Weir/ Barrage)	Surface	100.0	5.0	20.0		11,500.00	PU	S	Mudstone	0.50	0.12 to 0.88	1.10	2.10	No		5.75	6,330.00	12,080.00	No contingency added
2	Gravel Trap	Surface	100.0	5.0	20.0	25.0	575.00	PU	HH	Gneiss(Augen)	0.58	0.27 to 0.88	1.10	2.10	No		0.33	360.00	690.00	No contingency added
3	Surface Desander	Surface	100.0	5.0	20.0	22.0	506.00	PU	LH	Gneiss(Biotite, Plagioclase)	0.48	0.27 to 0.68	1.10	2.10	Yes		0.24	260.00	500.00	0%added as contingency
4	Spillway	Surface	100.0	5.0	20.0		11,500.00	PU	S	Sandstone/Siltstone/ Mudstone	0.15	0.12 to 0.18	1.10	2.10	No		1.73	1,900.00	3,620.00	No contingency added
5	Headrace Canal	Surface	100.0	5.0	20.0		11,500.00	UCS	TH	Schist	0.32	0.12 to 0.52	1.10	2.10	No		3.68	4,050.00	7,730.00	No contingency added
6	Forebay	Surface	100.0	5.0	20.0		11,500.00	UCS	HH	Gneiss(Feldspathic Augen)	0.53	0.33 to 0.68	1.10	2.10	No		6.10	6,700.00	12,800.00	No contingency added
7	Surface Penstock	Surface	100.0	5.0	20.0		11,500.00	UCS	LH	Schist	0.32	0.12 to 0.52	1.10	2.10	Yes		3.68	4,050.00	7,730.00	0%added as contingency
i	Anchor Blocks	Surface	100.0	5.0	20.0		23.00	PU	LH	Gneiss(Plagioclase)	0.40	0.27 to 0.52	1.10	2.10	Yes		0.01	10.00	20.00	0%added as contingency
ii	Support Piers	Surface	100.0	5.0	20.0	25.0	575.00	PU	HH	Gneiss(Augen)	0.58	0.27 to 0.88	1.10	2.10	No		0.33	360.00	690.00	No contingency added
8	Surface Powerhouse	Surface	100.0	5.0	20.0	22.0	506.00	PU	LH	Gneiss(Biotite, Plagioclase)	0.48	0.27 to 0.68	1.10	2.10	Yes		0.24	260.00	500.00	0%added as contingency
9	Surface Switchyard	Surface	100.0	5.0	20.0		11,500.00	PU	S	Sandstone/Siltstone/ Mudstone	0.15	0.12 to 0.18	1.10	2.10	No		1.73	1,900.00	3,620.00	No contingency added
10	Access Road	Surface	100.0	5.0	20.0		11,500.00	UCS	TH	Schist	0.32	0.12 to 0.52	1.10	2.10	No		3.68	4,050.00	7,730.00	No contingency added
11	Boulder Blasting	Surface	100.0	5.0	20.0		11,500.00	UCS	HH	Gneiss(Feldspathic Augen)	0.53	0.33 to 0.68	1.10	2.10	No		6.10	6,700.00	12,800.00	No contingency added
12	Diversion Tunnel Portals	Surface	100.0	5.0	20.0		11,500.00	UCS	LH	Schist	0.32	0.12 to 0.52	1.10	2.10	Yes		3.68	4,050.00	7,730.00	0%added as contingency
13	Desander Flushing Tunnel Portal	Surface	100.0	5.0	20.0		23.00	PU	LH	Gneiss(Plagioclase)	0.40	0.27 to 0.52	1.10	2.10	Yes	5%	0.01	10.00	20.00	5%added as contingency
14	Adit Tunnel and Portal	Surface	100.0	5.0	20.0		11,500.00	PU	S	Sandstone/Siltstone/ Mudstone	0.15	0.12 to 0.18	1.10	2.10	No		1.73	1,900.00	3,620.00	No contingency added
15	Adit 1 Portal	Surface	100.0	5.0	20.0		11,500.00	UCS	TH	Schist	0.32	0.12 to 0.52	1.10	2.10	No		3.68	4,050.00	7,730.00	No contingency added
16	Adit2 Portal	Surface	100.0	5.0	20.0		11,500.00	UCS	HH	Gneiss(Feldspathic Augen)	0.53	0.33 to 0.68	1.10	2.10	No		6.10	6,700.00	12,800.00	No contingency added
17	Main Access Tunnel Portal	Surface	100.0	5.0	20.0		11,500.00	UCS	LH	Schist	0.32	0.12 to 0.52	1.10	2.10	Yes	2%	3.68	4,130.00	7,880.00	2%added as contingency
18	Tailrace Tunnel Portal	Surface	100.0	5.0	20.0		11,500.00	PU	LH	Gneiss(Plagioclase)	0.40	0.27 to 0.52	1.10	2.10	Yes	4%	4.54	5,200.00	9,920.00	4%added as contingency
19	Access Tunnel Portal	Surface	100.0	5.0	20.0		11,500.00	PU	LH	Gneiss(Plagioclase)	0.40	0.27 to 0.52	1.10	2.10	Yes		4.54	5,000.00	9,540.00	0%added as contingency
20	Other Surface Comp. /Facilities	Surface	100.0	5.0	20.0		11,500.00	PU	LH	Gneiss(Plagioclase)	0.40	0.27 to 0.52	1.10	2.10	Yes		4.54	5,000.00	9,540.00	0%added as contingency
	Sub-total (A) for Surface Excavation																65.08	72,970.00	139,290.00	

B. Explosive Materials Estimation for Underground Excavation like HRT, Niche Penstock, Surge shaft, Powerhouse and tailrace)

SN	Description of Excavation Work	Shape of Excavation	Excavated Dia. (D₁)	(D₂)	Length/ Height (m)	Excavated X-Sec Area (m²)	Excavation Volume (m³) including 15% contingency	Geological Basis: Typical Curves based on	Rock Type	Emulsion Consumption (Kg/m3)	Refererance Equation	Detonators (Nos/kg)	Detonating Cord (m/kg)	Contingency Required	Contingency (%) added	Required Quantity: Emulsion (Ton)	Detonators (Nos)	Detonating Cord (m)	Remarks
1	Diversion Tunnel	Ir. Inverted D	10.0		100.0	39.3	4516.04	Regional_Geology	LH	2.86	10.278x^-0.556	1.10	2.10	Yes	10%	12.90	15610.00	29800.00	10%added as contingency
i	Diversion Tunnel Portals	Circular	4.0		100.0	12.6	1445.13	Rock_Blastability	Good	4.82	9.27 x^-0.472	1.10	2.10	Yes	2%	6.96	7810.00	14920.00	2%added as contingency
2	Underground Desander	Ir. Inverted D	5.0	2.0	100.0		115.00	Rock_Quality	Class I_Good_Blastability	8.93	27.726x^-0.704	1.10	2.10	No		1.03	1130.00	2160.00	No contingency added
i	Desander Flushing Tunnel	Horse Shoe	6.0		100.0	29.9	3433.30	Rock_Type	All rocks	3.85	9.643x^-0.513	1.10	2.10	Yes	2%	13.20	14820.00	28230.00	2%added as contingency
3	Headrace Tunnel	Horse Shoe	2.0		100.0	3.3	381.48	Rock_Type	All rocks	6.76	9.643x^-0.513	1.10	2.10	Yes	2%	2.58	2890.00	5520.00	2%added as contingency
4	Niches	Horse Shoe	3.0		100.0	7.5	858.33	Rock_Quality	Class V_Poor_Blastability	6.18	14.905x^-0.302	1.10	2.10	No		5.30	5830.00	11130.00	No contingency added
5	Adit1 Tunnel	Horse Shoe	4.0		100.0	13.3	1525.91	Rock_Quality	Class V_Poor_Blastability	4.90	14.905x^-0.302	1.10	2.10	No		7.48	8230.00	15710.00	No contingency added
6	Adit2 Tunnel	Horse Shoe	4.2		100.0	14.6	1682.32	Regional_Geology	HH	4.67	5.622x^-0.129	1.10	2.10	No		7.86	8650.00	16510.00	No contingency added
7	Surge Shaft	Horse Shoe	4.2				0.00	Blasting_Pattern	All	5.23	7.257x^-0.228	1.10	2.10	No		0.00	0.00	0.00	No contingency added
8	Vertical Shaft	Circular	4.0		100.0	12.6	1445.13	Rock_Blastability	Good	4.82	9.27 x^-0.472	1.10	2.10	Yes	2%	6.96	7810.00	14920.00	2%added as contingency
9	Horizonal Penstock Tunnel	Ir. Inverted D	5.0	2.0	100.0		115.00	Rock_Quality	Class I_Good_Blastability	8.93	27.726x^-0.704	1.10	2.10	No		1.03	1130.00	2160.00	No contingency added
10	Inclined Shaft Tunnel	Horse Shoe	6.0		100.0	29.9	3433.30	Rock_Type	All rocks	3.85	9.643x^-0.513	1.10	2.10	Yes	2%	13.20	14820.00	28230.00	2%added as contingency
11	Underground PH(Inc. All Caverns)	Horse Shoe	2.0		100.0	3.3	381.48	Rock_Type	All rocks	6.76	9.643x^-0.513	1.10	2.10	Yes	2%	2.58	2890.00	5520.00	2%added as contingency
12	Transformer Cavern	Horse Shoe	3.0		100.0	7.5	858.33	Rock_Quality	Class V_Poor_Blastability	6.18	14.905x^-0.302	1.10	2.10	No		5.30	5830.00	11130.00	No contingency added
13	PH staircase, switching station	Horse Shoe	4.0		100.0	13.3	1525.91	Rock_Quality	Class V_Poor_Blastability	4.90	14.905x^-0.302	1.10	2.10	No		7.48	8230.00	15710.00	No contingency added
14	Main Access Tunnel	Horse Shoe	4.2		100.0	14.6	1682.32	Regional_Geology	HH	4.67	5.622x^-0.129	1.10	2.10	No		7.86	8650.00	16510.00	No contingency added
15	Tailrace Tunnel	Horse Shoe	4.2		100.0	14.6	1682.32	Blasting_Pattern	All	5.23	7.257x^-0.228	1.10	2.10	No		8.80	9680.00	18480.00	No contingency added
16	Access Tunnel	Horse Shoe	4.2		100.0	14.6	1682.32	Blasting_Pattern	All	5.23	7.257x^-0.228	1.10	2.10	No		8.80	9680.00	18480.00	No contingency added
17	Other Underground Comp./ Facilities	Horse Shoe	4.2		100.0	14.6	1682.32	Regional_Geology	LH	4.63	10.278x^-0.556	1.10	2.10	Yes	2%	7.79	8740.00	16680.00	2%added as contingency
	Sub-total (B) for underground excavation															127.12	142,430.00	271,900.00	
	Total (A+B)															195.20	215,400.00	411,190.00	

***Note: 1) Contingency provision for the recommended typical curves regarding the estimation of explosive materials have been carried out in order to establish certain factor of safety during the estimation of explosive materials as mentioned in* Table 6-11

2) 15% Contingency has been added in excavation volume for both surface and underground excavation

3) Please click this link to download Templates for estimation of explosive materials.

This page intentionally left blank

in the most effective manner. The major geological setting (excluding Indo-Gangatic Plain where any hydropower project does not require any rock excavation) has been mentioned below.

3.1.2.1 Regional Geology of Nepal Himalaya

The Himalayan belt is located in the northern part of the Indian continent, forming a long (2500 km) and slightly arched chain with a WNW-ESE (N120°) orientation (Mascle et al. 2012). This orogenic arc rises from the Indo-Gangetic and Brahmaputra plains in the south, and it is bordered to the north by the Tibetan plateau and to the northwest by the mountains of the Karakorum. To the west, the Himalaya is bordered by the Baluchistan hills and to the east by the Myanmar hills (Arakan Chin). The entire Himalayan arc (Figure 3-1) has been divided into the Punjab Himalaya, Kumaon Himalaya, Nepal Himalaya, Sikkim-Bhutan Himalaya and NEFA Himalaya, respectively from west to east (Gansser, 1964).

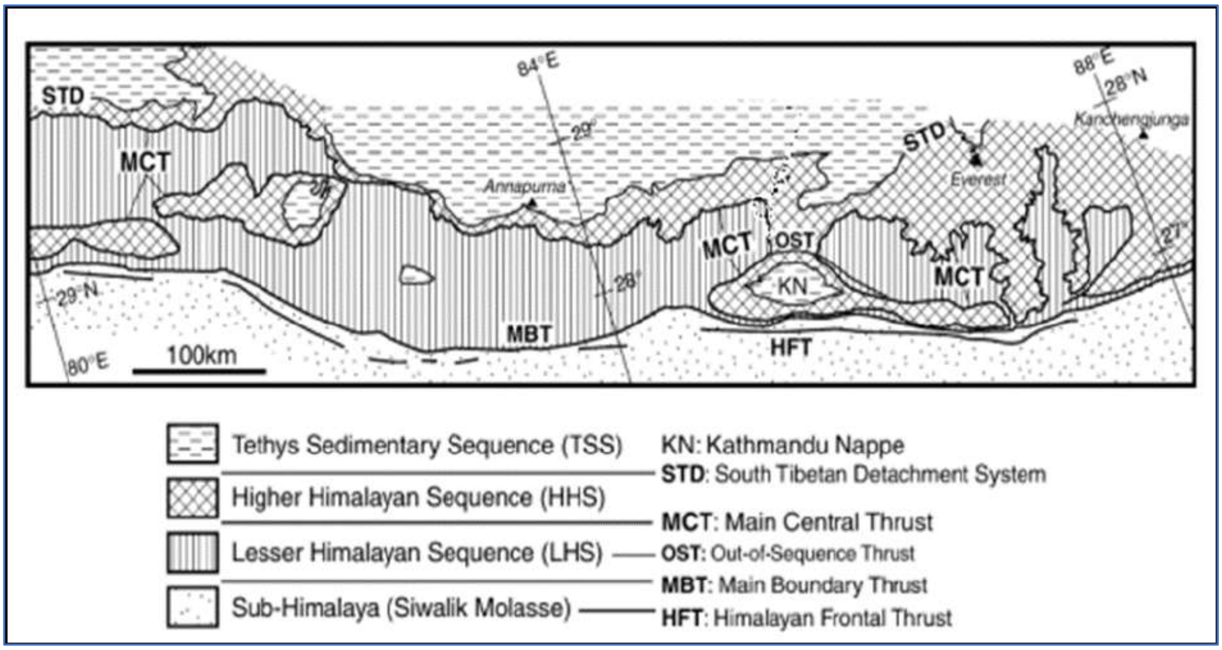


Figure 3-1 Geological map of the Nepal Himalaya and adjoining regions compiled by K Arita

3.1.2.2 Geological Division of Nepal Himalaya in brief

The overall Stratigraphy of Nepal Himalaya has been presented in Geological Division of Nepal Himalaya. Several regional geological maps of Nepal and related literatures have been published. The Himalayan belt (or Nepal Himalaya) is composed of following structural units that follow one another from north to south **(**Figure 3-2 and Figure 3-3) and are separated from each other by major discontinuities (Mascle et al. 2012 and Figure 3-3)**.**

a) The units of the Indus-Tsangpo suture (ITSZ) form the northern boundary with the Asian continent. They are thrusted onto the units of the Indian margin, forming the Tethyan Himalaya, and back thrusted with the Asian continent. They are thrusted onto the units of the Indian margin, forming the Tethyan Himalaya, and back onto the Tibetan margin.
b) The folded sedimentary series (Tethys Himalaya) are divided into series of nappes. To the south, they are separated from the crystalline basement along the North Himalayan Fault (NHF) or South Tibetan Detachment System (STDS) and overridden by units of the ITSZ to the north.
c) The Higher Himalaya is overthrusted on the Lesser Himalaya along the Main Central Thrust (MCT); gneisses and migmatites of the Higher Himalaya or Higher Himalayan Crystallines

(HHC) are separated from the sedimentary cover of the Tethyan margin (Tethys Himalaya) by the STDS.

d) The Lesser Himalaya is overthrusted on the Siwaliks along the Main Boundary Thrust (MBT) and is overridden by the Higher Himalayan Crystallines along the MCT. The Lesser Himalaya

e) shows mostly a Proterozoic series (2,400-540 Ma), with locally younger sequences that are almost all continentals, except for the Eocene, which has some marine intercalations. These Proterozoic sequences have been described using local classification in numerous and various formations. This does not facilitate regional correlations because these series form a pile of polymetamorphosed sheets with several superimposed deformations.

f) The Siwaliks are limited to the north by the MBT and Main Frontal Thrust (MFT) or Himalayan Frontal Thrust (HFT) to the south.

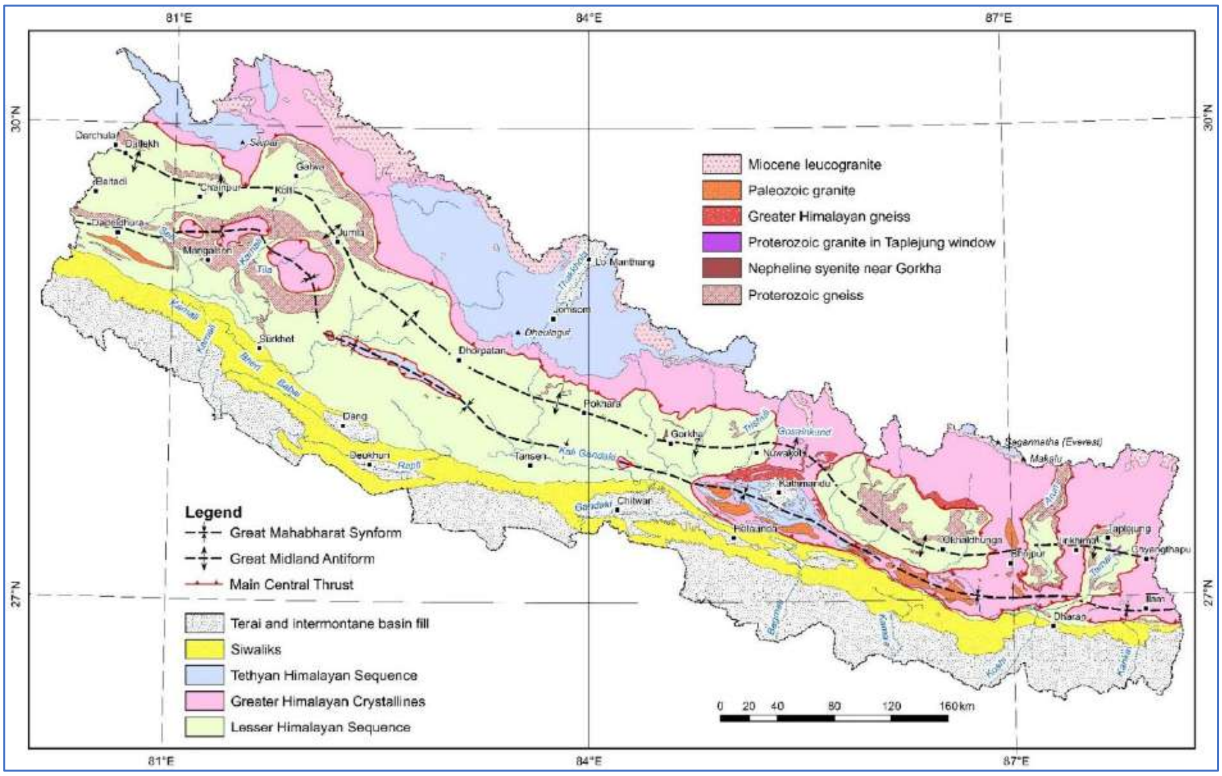


Figure 3-2 Geological Map of Nepal Himalaya (Dhital, 2015)

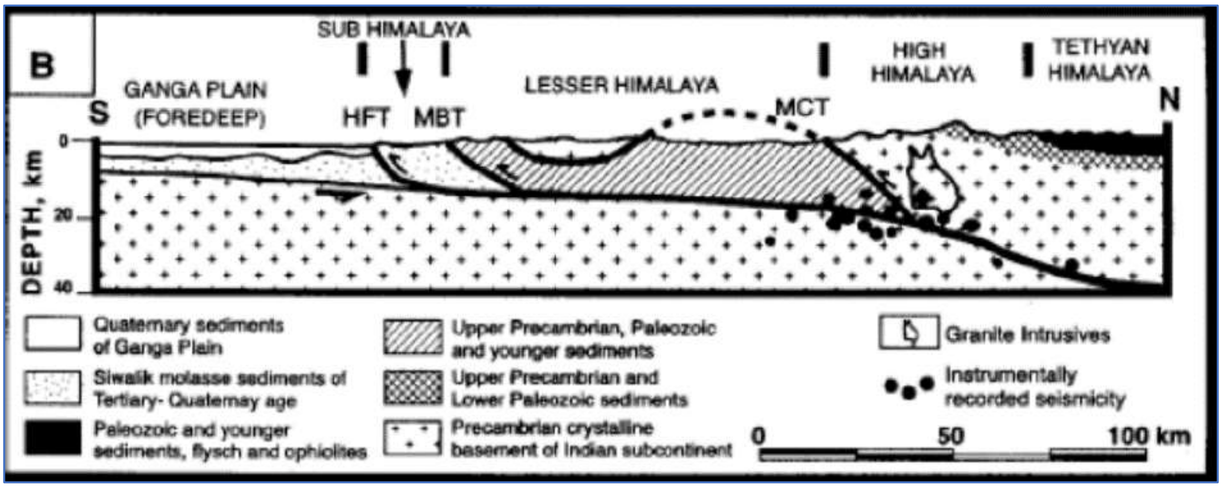


Figure 3-3 Generalized North-South Geologic Section across the Himalayas

Table 3-2 Geological Division of Nepal Himalaya

Tectonic Unit	Geological Unit	Geological Age
Tethys Himalayas	Tibetan Tethys Sedimentary zone	Cambrian to Cretaceous (570 - 65 MY.)
STDS (South Tibetan Detachment Slab)		Tertiary
Higher Himalayas	Higher Himalayan Crystalline Zone	Pre-Cambrian (> 540 MY.)
MCT (Main Central Thrust)		Miocene
Lesser Himalayas	Kathmandu Complex	Precambrian to Paleozoic (540 – 251 MY.)
	MT (Mahabharat Thrust)	Miocene
	Nawakot Complex	Pre-Cambrian (> 540 MY.)
MBT (Main Boundary Thrust)		Pliocene
Sub Himalayas	Siwalik zone	Middle Miocene to Early Pleistocene (16 – 2.6 MY.)
HFT (Himalayan Frontal Thrust)		Pleistocene
Ganga Plain (Terai)	Gangatic Alluvium	Quaternary (2.6 MY. – Recent)

3.1.2.3 Properties of Rock and Their Effects to Rock Excavation

In this section, the word rock refers to the intact rock portion excluding any geological structures of the rock mass, and only the physical and mechanical properties of the rock are discussed. The main physical properties such as density, porosity, hardness, abrasivity, permeability, and wave velocity of different rock types found in Nepal has been mentioned in the Table 3-3.

The main mechanical properties of rock material include compressive strength, tensile strength, shear strength, Young's Modulus, Poisson's ratio, and other engineering properties of rock materials. However, only the strength of the rock based on the point load index test and unconfined compressive strength tests of various hydropower projects has been considered for the preparation of this guideline.

A. Point Load Index (PLI) Test

Point load index is a simple index test of rock. It gives the standard point load index, $Is_{(50)}$, calculated from the point load at failure of core samples of different sizes collected from the core drilling.

B. Unconfined Compressive Strength (UCS) Test

The uniaxial compressive strength (UCS) of rock is a critical rock parameter in drilling and blasting operation. UCS measures the maximum axial compressive strength that a rock can withstand under unconfined conditions. Understanding UCS and its effect on blasting is essential for designing the efficient and effective drilling and blasting operation in hydropower projects. The powder factor based on the density and UCS proposed by Gokhale (2010) has been presented in Table 3-4.

C. PLI and UCS Values of different rocks from various Geological Units of the Nepal Himalaya

An attempt has been made to collect all the laboratory test results of PLI and UCS tests from various infrastructure projects especially HPPs throughout the country that represent all the major geological units of the Nepal Himalaya. The list of the project from the data has been collected is presented in the Annex 5. From all the collected PLI test results and UCS test results from the rock core samples, the average compressive strength of major rock types in the major geological units have been presented in the Table 6-1.

Table 3-3 Physical Properties of some fresh rock materials (Zhou, 2017)

Rock	Dry density (g/cm3)	Porosity (%)	Schmidt Hardness Index	Cerchar Abrasivity Index	P-wave velocity (m/s)	S-wave velocity (m/s)	Coefficient of permeability (m/s)
Igneous							
Granite	2.53–2.62	1.02–2.87	54–69	4.5–5.3	4500–6500	3500–3800	10^{-14}-10^{-12}
Rhyolite	2.40–2.60	0.40–4.00					10^{-14}-10^{-12}
Basalt	2.21–2.77	0.22–22.1	61	2.0–3.5	5000–7000	3660–3700	10^{-14}-10^{-12}
Sedimentary							
Conglomerate	2.47–2.76			1.5–3.8			10^{-10}-10^{-8}
Sandstone	1.91–2.58	1.62–26.4	10–37	1.5–4.2	1500–4600		10^{-10}-10^{-8}
Shale	2.00–2.40	20.0–50.0		0.6–1.8	2000–4600		
Mudstone	1.82–2.72		27				10^{-11}-10^{-9}
Dolomite	2.20–2.70	0.20–4.00			5500		10^{-12}-10^{-11}
Limestone	2.67–2.72	0.27–4.10	35–51	1.0–2.5	3500–6500		10^{-13}-10^{-10}
Metamorphic							
Gneiss	2.61–3.12	0.32–1.16	49	3.5–5.3	5000–7500		10^{-14}-10^{-12}
Schist	2.60–2.85	10.0–30.0	31	2.2–4.5	6100–6700	3460–4000	10^{-10}-10^{-8}
Phyllite	2.18–3.30						
Slate	2.71–2.78	1.84–3.64		2.3–4.2			10^{-14}-10^{-12}
Marble	2.51–2.86	0.65–0.81			5000–6000		10^{-14}-10^{-11}
Quartzite	2.61–2.67	0.40–0.65		4.3–5.9			10^{-14}-10^{-13}

Table 3-4 Powder factor based on intact rock properties based on density and UCS (Gokhale, 2010)

Powder factor in kg/m^3		Mean distance between natural fractures in rock in m	Uniaxial Compressive Strength	Density of rock kg/m^3	Recoomended Range as per DoR norms (2077)
Range	Average value				
0.12-0.18	0.15	<0.10	10-30	1400-1800	0.14-0.36
0.18-0.27	0.225	0.10-0.25	20-45	1750-2350	
0.27-0.38	0.32	0.20-0.50	30-65	2250-2550	
0.38-0.52	0.45	0.45-0.7 5	50-90	2500-2800	
0.52-0.68	0.6	0.70-1.00	70-120	2750-2900	
0.68-0.88	0.78	0.95-1.25	110-160	2850-3000	
0.88-1.10	0.99	1.20-1.50	145-205	2950-3200	
I. I 0-1.37	1.235	1.45-1.70	195-250	3150-3400	
1.37-1.68	1.525	1.65-1.90	235-300	3350-3600	
1.68-2.03	1.855	>1.85	>285	>3550	

3.1.2.4 Properties of Rock Mass and Their Effects to Rock Excavation

Rock mass property is governed by the properties of intact rock materials and the discontinuities present within the rock mass. The behavior of rock mass is also influenced by the in-situ such as the in-situ stress and groundwater condition among others. The major factor governing the rock mass properties have been mentioned in the Figure 3-4.

When it comes to blasting, the properties of the rock mass are of greater importance than rock specimen properties. This is due to the fact that in drilling, only a small portion in the alignment of the blasthole is to be fragmented into very small pieces, whereas in blasting a very large mass of rock is to be fragmented into relatively large pieces.

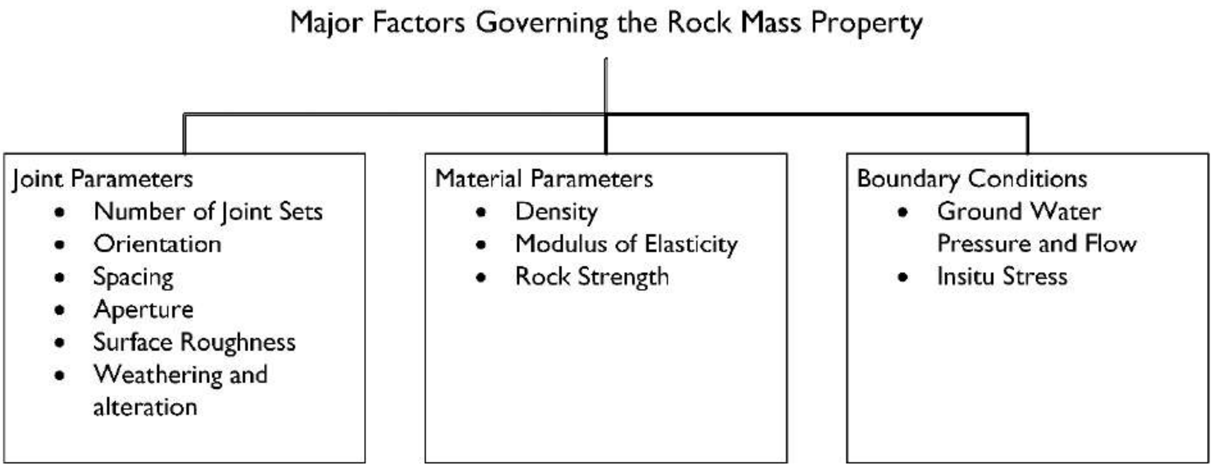


Figure 3-4 Major factors governing the rock mass properties

3.1.2.5 Classification of Rock Masses

Rock masses are generally classified by visual observations or indices based on diverse parameters of the rock mass. The major findings of the literatures regarding classification of rock masses based on visual observation have been summarized in Table 3-5. Similarly, major findings of the literatures regarding classification of rock masses based on rock mass classification have been summarized in Table 3-6. In addition, major findings of the literatures regarding classification of rock masses based on blastability index have been summarized in Table 3-7.

Table 3-5 Various Rock mass classification based on visual observation

S.N.	Classification by Visual Observation	Rock Mass Parameters/ Description
1	Terzaghi (1946) rock mass classification	Intact Rock
		Stratified Rock
		Moderately Jointed Rock
		Blocky and Seamy Rock
		Crushed and Chemically Intact Rock
		Squeezing Rock
		Swelling Rock
2	Deere (1963) Rock Quality Designation index (RQD)	Provide a quantitative estimate of rock mass quality from drill core logs. RQD is defined as the percentage of intact core pieces longer than 100 mm (4 inches) in the total length of core.

Table 3-6 Various Rock mass classification base on the field measurement and laboratory results

S.N.	Classification of Rock Masses	Rock Mass Parameters/ Description
1	Rock Quality Designation index (RQD) based classification	RQD 25-50%, Poor Quality Rock Class
		RQD 50-75%, Fair Quality Rock Class
		RQD 75-90%, Good Quality Rock Class
		RQD 90-100%, Excellent Quality Rock Class
2	Rock Mass Rating (RMR) based classification	RMR < 20, Very Poor Rock (Class-V)
		RMR 21-40, Poor Rock (Class-IV)
		RMR 41-60, Fair Rock (Class-III)
		RMR 61-80, Good Rock (Class-II)
		RMR 81-100, Very Good Rock (Class-I)
3	Rock Tunneling Quality Index (RTQI) based classification	Q value 400-1000, Exceptionally Good Rockmass Quality (Class-A)
		Q value 100-400, Extremely Good Rockmass Quality (Class-A)
		Q value 40-100, Very Good Rockmass Quality (Class-A)
		Q value 40 - 10, Good Rockmass Quality (Class-B)
		Q value 10 - 4, Fair Rockmass Quality (Class-C)
		Q value 4 - 1, Poor Rockmass Quality (Class-D)
		Q value 1 - 0.1, Very Poor Rockmass Quality (Class-E)
		Q value 0.1 - 0.01, Extremely Poor Rockmass Quality (Class-F)
		Q value 0.01 - 0.001, Exceptionally Poor Rockmass Quality (Class-G)

Table 3-7 Various Rock mass classification based on blastability index

S.N.	Blastability Index based Classification of Rock Masses	Proposed Equations/Parameters
1	Index proposed by Hansen (1968)	Proposed an equation for estimating the quantity of explosive required for optimum fragmentation
2	Index proposed by Hainen and Dimock (1976)	Proposed co-relation between powder factor lb/tonne and the velocity of sound wave in rock mass (i.e. sonic velocity feet/sec)
3	Index proposed by Ashby (1977)	Proposed an empirical equation for powder factor using friction angle, roughness angle, and fracture frequency within the rock mass
4	Index proposed by Langerfors (1978)	Proposed that the every rockmass has certain powder factor (C_o) and the Powder Factor (Co) ranges from 0.17-0.35 kg/m^3
5	Index proposed by Lilly (1986)	Developed an equation for blastablility index (BI) based on five parameters namely, rock mass description, joint plane spacing, joint plane orientation, specific gravity influence, and rock hardness in Moh's scale
6	Index proposed by Ghose (1988)	Developed an equation for blastablility index (BI) based on six parameters namely, density ratio, discontinuity spacing ratio, point load index strength ratio, adjustment factor1 and adjustment factor 2
7	Index proposed by Gupta (1990)	Suggested an equation for charge factor based on effective burden and Protodyakonov strength index

S.N.	Blastability Index based Classification of Rock Masses	Proposed Equations/Parameters
8	Index proposed by Julius Kruttschnitt Mineral Research Center (JKMRC 1996) in Australia	Factors taken into consideration while calculating the powder factor include: strength, density and Young's modulus of the rockmass, average in situ block size, influence of structure, target fragment size, heave desired, confinement provided, scale of operation and groundwater.
9	Index proposed by Han, Weiya and Shouvi (2000)	Used an Artificial Neural Network approach for determining rockmass blastability through a computer program.

3.1.2.6 Geological Structures of Rock Mass and their Effects to Rock Excavation

During rock excavation in a large area, the rock mass is hardly ever homogeneous. Different portions of rock mass have varying mineral contents. Rock masses also have inconsistencies like voids, folds, unconformities, bedding planes, faults and joints. All these defects result in the rock mass are subjected to various volcanic, plutonic and tectonic activities, and other processes at the surface of the earth during its formation.

A. Voids

Two types of voids can be found in rock masses. First type of voids are very small size voids are homogeneously spread over a very large area and found in some types of rocks, particularly in the softer varieties. These voids make the rock mass very weak – so weak that there is no necessity of blasting. In other words, such type of rocks can be excavated mechanically. However, if such a rock mass contains a layer of hard rock or some very large boulders, blasting may be unavoidable.

On the other hand, second type of void have large volume which are formed in a rock mass during volcanic or tectonic activities, or by erosion. In such circumstances, the gases formed in the explosion rush into the void. During blasting, these voids absorb quite a bit of energy. Thus, the energy left for fragmentation of rock mass is reduced and large pieces of rocks are formed.

B. Folds, unconformities and bedding planes

Sedimentary rock masses cover a considerable part of the earth's surface. When formed, they are in layers lying one upon another. These layers are called beds or strata. The thickness of these beds varies from a few millimeters to several meters. The bounding planes of a bed are called bedding planes. During the deposition of the sediments that give rise to the beds, often there is a time interval during which no deposition takes place. Therefore, a surface formed during this time interval separates the old beds from new beds. On many occasions, due to a change in the mode of deposition or a change in the type of sediment, such an interface is very distinct and is called an unconformity. The properties of the rock mass on two sides of an unconformity can differ considerably.

Horizontal beds of sedimentary rocks are often distorted by physical forces exerted on them. Such geological activities are termed tectonic activities. Tectonic i.e. structural activities are mainly caused by plutonic activities taking place in the earth's crust and mantle. In tectonic activities, beds are often compressed and distorted in such a way that they take the shape of a waveform. Such structures are called folds.

The orientation of bedding planes with respect to the blasthole alignment can have considerable influence on the outcome of blasting because the bedding planes are weak, and parting of the rock mass along these bedding planes is rather easy. Based on the relationships between the orientations of bedding planes and blastholes, three cases, as under, are usually considered.

a) Shooting with the dip
b) Shooting against the dip
c) Shooting along the strike

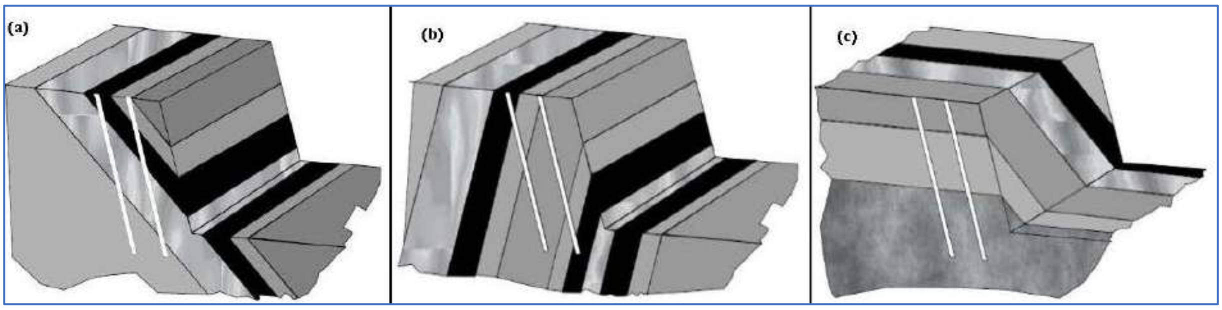


Figure 3-5 Shooting with (a) with dip, (b) against dip and (c) along the strike

a) Shooting with the dip

In this situation, the lines of intersections of the bedding planes and bench floor or bench top are parallel to the bench crest as shown in Figure 3-5(a). This is the most favourable excavation / tunneling condition as mentioned in the Table 3-8.

b) Shooting against the dip

In this situation, also the lines of intersections of the bedding planes and bench floor or bench top are parallel to the bench crest as shown in Figure 3-5(b). This is the unfavorable to fair excavation / tunneling condition as mentioned in the Table 3-8.

c) Shooting along the strike

In this situation, the lines of intersection of the bedding planes and bench floor or bench top are perpendicular to the bench crest, as illustrated in Figure 3-5(c). This is the very unfavorable to fair excavation / tunneling condition as mentioned in the Table 3-8.

Table 3-8 Effect of discontinuity orientation in tunneling/excavation

Effect of Discontinuity Strike and Dip Orientation in Tunneling/Excavation	Shooting with the dip	Shooting/Drive with dip - Dip 45 - 90°	Shooting/Drive with dip - Dip 20 - 45°
		Very Favorable	Favorable
	Shooting against the dip	Shooting/Drive against dip - Dip 45-90°	Shooting/Drive against dip - Dip 20-45°
		Fair	Unfavorable
	Shooting along the strike	Dip 45 - 90°	Dip 20 - 45°
		Very Unfavorable	Fair
		Dip 0-20° - Irrespective of strike°	
		Fair	

C. Faults, joints, and intrusions

Both faults and joints are fractures in the ground mass. They are essentially planes of separation formed during plutonic or tectonic activities. When there has been observable movement of the rock mass on the two sides of the fracture plane, they are termed as faults, otherwise they are called joints. Joints are usually small in thickness and may have intrusion of fine clayey particles. Faults are usually much thicker.These fracture surfaces can be found in almost any inclination and direction. The frequency of their occurrence is often very high. However, there is a possibility of blind fault/thrust, which is not observed directly in the ground. Similarly, igneous intrusions due to plutonic or tectonic activities are also present in the ground mass. For example, higher Himalaya granites and lesser Himalaya granites of Nepal Himalaya. Fracture surfaces i.e. joints, require to be given great attention, not only in the realm of blasting but also in other type of excavation and construction in or above the ground.

3.1.3 Explosives

This guideline covers commercial explosives/ industrial explosives only. According to the explosive act 2018 (1961) the explosives have been defined as any material whether or not of same category which are produced or used with the objective of bringing about the practical affect through explosion or the effect of a fire-cracker nature. There are three kinds of explosion: physical (mechanical) explosion, chemical explosion, and nucleus explosion as mentioned in the Table 3-9 and Figure 3-6. In reality, the explosion of the explosive is the chemical explosion but not the mechanical or nucleus explosion. Since no gases are evolved although there is a very high temperature (3000° C) during the explosion. So, the definition proposed in the explosive act 2018 (1961) does not categorized the type of explosion but only recognizes the act of explosion.

Types of chemical decomposition of the explosives and the detonation process

The chemical decomposition process of the explosive may be the thermal decomposition, combustion, deflagration, and detonation. Detonation is the fullest form of the chemical reaction of the explosive, and the reaction releases the most energy. The basic characteristics of these reactions is that they are initiated and sustained by a supersonic shock wave-detonation wave. Thus, the detonation process consists of propagation of chemical reaction that moves through the explosive at supersonic speed transforming into a new chemical compound.

Table 3-9 Characteristics of different type of explosion

Character of Explosion	Type of Explosion		
	Physical or Mechanical Explosion	Chemical Explosion	Nucleus Explosion
Temperature	High	Very High	Extremely High
Gas formation	Rapid	Instantaneous	None
Noise Level	Loud	Very Loud	Extremely Loud
New substance production	None	Yes	Yes
Radioactivity	No	Probably not	Yes

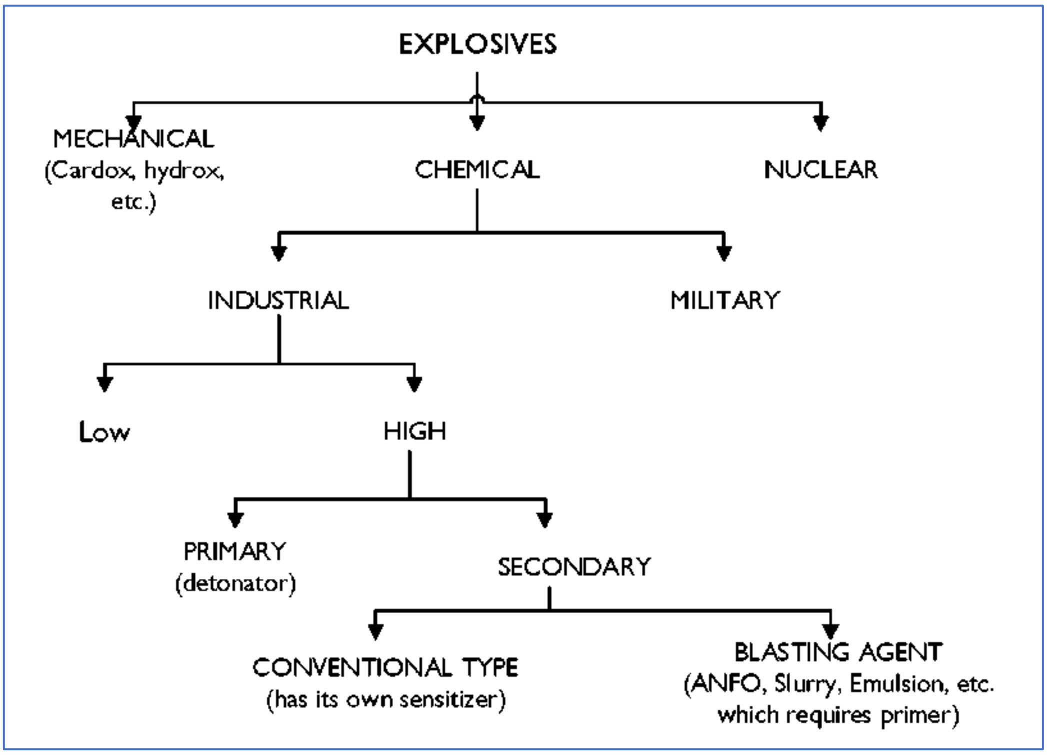


Figure 3-6 Family tree of explosives

The commercial explosives for industrial use are divided into two large groups:

a) **Cartridge (conventional) explosives**; These explosives usually have a cap sensitivity and are made up in various sizes of diameter and length for convenient use. They include Nitroglycerin (NG)-based explosives, AN-TNT-based explosives—ammonite, Water-based explosives (water gel/slurry and emulsion), and Permissible explosives; and
b) **Blasting agents**; These mixtures do not contain ingredients classified as explosive. The most common blasting agents are ANFO, ALANFO, Bulk slurries or water gels, Bulk emulsions, and Heavy ANFO.

3.1.3.1 Properties of Explosives

In commercial blasting, explosives and blasting agents are characterized by various properties that define how they will perform under field conditions. These properties include fume class, density, water resistance, temperature effects, detonation velocity, detonation pressure, borehole pressure, sensitivity, and strength.

A. Density

The density of a material is defined as its weight per unit volume for blasting. Explosive density is expressed in grams per cubic centimeter (g/cc). The specific gravity of commercial explosives ranges from 0.6 to 1.7 g/cc. With few exceptions, denser explosives give higher detonation velocities and pressure, but for any explosive, there is a critical density, above which it cannot reliably detonate, for example, for TNT—1.78 g/cc and ANFO—above 1 g/cc. Density is an important consideration when choosing an explosive. For difficult blasting conditions or when fine fragmentation is required, a dense explosive is usually necessary. In easily fragmented rock or where fine fragmentation is not needed, a low-density explosive will often suffice. Low-density explosives are particularly useful in the production of riprap or other coarse products. The density of the emulsion explosives manufactured worldwide have been tabulated in Table 3-10 for comparison.

B. Detonation Velocity

Velocity of detonation (VOD) is the velocity of the detonation waves formed during the explosion that move through the column of explosives. The factors that affect VOD are charge density, diameter, confinement, initiation, and aging of the explosive. In general, the larger the diameter is, the higher is the VOD until a steady velocity is reached. For every explosive, there is a minimum critical diameter at which the detonation process once initiated, will support itself in the column. The VOD of the emulsion explosives manufactured worldwide has been tabulated in Table 3-10 for comparison.

C. Strength And Energy

Explosive contains a huge amount of chemical energy. Energy is released from the explosive as a potential energy in the form of heat and transforms in the surrounding medium (i.e. into the soil or rock) making them fracture. The heat energy released is one of the most important performance parameters of the explosive. Detonation heat is defined as the heat released by unit mass of explosive (1 kg or 1 mol) during detonation. The detonation reaction of explosive is extremely rapid and the detonation process is considered in a constant volume condition. Generally, the detonation heat is expressed in Q_V. The energy of the explosive is the amount of the energy that is available to do useful work as some of the energy is always lost in the form of heat and other energy forms. There are different terms to express the strength of an explosive but the most useful indication of the strength is the relative effective energy. The relative weight strength (RWS) and relative bulk strength (RBS), referring to the strength of an explosive in so much percentage of another explosive that is taken as a standard, usually the standard ANFO (i.e., 94 % AN, 6 % fuel oil, density = 0.8 g/cc) which has the assigned value of 100. The RWS and RBS of the emulsion explosives manufactured worldwide has been tabulated in Table 3-10 for comparison.

D. Sympathetic Detonation

Sympathetic detonation is an explosion caused by the transmission of a detonation wave through any medium from another explosion. The initiating explosive is called donor explosive, and the initiated one is known as receptor explosive. In the case of a chain detonation, a receptor explosive can become a donor one. The shock sensitivity, also called gap sensitivity, which influences the susceptibility to sympathetic detonations. The gap value of sympathetic detonation is affected by some factors, such as the density of the receptor explosives, the diameter and quantity of tested explosives, package materials of explosives, confined situation and the firing direction and layout of tested explosives.

For engineering application, the sympathetic detonation value has an instructive reference to the spacing of borehole-segmented charges, misfire handling, and the reasonable blasting parameters.

E. Sensitivity

Sensitivity of explosives is the degree to which an explosive can be initiated by external actions, such as shock wave, impact, heat, or friction. All explosive compounds have a certain amount of energy required to initiate. Factors like particle size, density, chemical composition, and environmental conditions also influence sensitivity. Finely powdered explosives are more sensitive to shock and friction than larger particles, and compounds with unstable bonds or reactive groups are particularly sensitive. If an explosive is too sensitive, it may go off accidentally. A safer explosive is less sensitive and will not explode if accidentally dropped or mishandled. However, such explosives are more difficult to initiate intentionally. Sensitivity is one of the most important indexes not only for blasting works but also for the safety of storage, transportation, and application. When choosing the correct explosives, detonator or cap sensitivity along with sensitivity to heat, impact and friction need to be considered.

F. Water Resistance

An explosive's water resistance is a measure of its ability to withstand exposure to water without deteriorating or losing sensitivity. The scale of classification generally accepted goes from null, limited, good, very good, and excellent. In dry work, water resistance is of no consequence. If water is standing in the borehole, and the time between loading and firing is fairly short, an explosive with a water-resistant rating of "good" is sufficient. If the exposure is prolonged, or if the water is percolating through the borehole, "very good" to "excellent" water resistance is required. Among the commercial explosives which are widely used in the world at present, water gels and emulsion explosives have a very good water resistance. Ammonium nitrate/fuel mixtures (ANFOs) have no inherent water resistance, as ammonium nitrate is very soluble in water. The thin film of fuel oil offers little protection. The blended emulsion/ANFO explosives have a range of water resistance, which varies from very good to a little resistance according to the emulsion percentage blended. The water resistance of the emulsion explosives manufactured worldwide has been tabulated in Table 3-10 for comparison.

G. Fumes and Fume Classification

Understanding fumes and their classification is essential for ensuring safety during explosive usage in hydropower projects. Fumes, consisting of gases and airborne particles produced during detonation, can pose health risks to personnel. These fumes are categorized into toxic, nuisance, and inert types based on their composition and potential hazards. Toxic fumes, containing harmful substances like nitrogen oxides and sulfur dioxide, can cause respiratory issues, while nuisance fumes may cause irritation but are not usually harmful. Inert fumes, such as nitrogen and carbon dioxide, are generally non-toxic but can lead to asphyxiation risks in confined spaces. Implementing safety measures like providing personal protective equipment, ensuring ventilation, monitoring air quality, and offering proper training can mitigate these risks and safeguard personnel involved in blasting operations.

Ideally, detonation of a commercial explosive produces water vapor, carbon dioxide, and nitrogen. In addition, undesirable poisonous gases such as carbon monoxide and nitrogen oxides are usually formed. These gases are known as fumes, and the fume class of an explosive indicates the nature and quantity of the undesirable gases formed during detonation. So, understanding fumes and their classification is essential for ensuring safety during explosive usage in hydropower projects. Better ratings are given to explosives producing smaller amounts of fumes.

For open work, fumes are not usually an important factor. In confined spaces, however, the fume rating of an explosive is important. In any case, the blaster should ensure that everyone stays away from fumes generated in a shot. Details of the operational health and safety regarding the fumes have been discussed in Section 4.3.4 of this guideline. The gas formation of the emulsion explosives manufactured worldwide has been tabulated in Table 3-10 for comparison.

Some factors that increase fumes are poor product formulations, inadequate priming, insufficient water resistance, lack of confinement, and reactivity of the product with the rock or other material being blasted. Irrespective of the fume classification adopted worldwide, this guideline recommends the uses of explosive in which gas formation is less than 1000 liter per 1 kilogram of explosive for both surface and underground drilling and blasting operation.

H. Desensitization

For any explosive, there is a critical density, above which it cannot reliably detonate. The increase of an explosive's density can be caused by some external pressures and the sensitivity of the explosive can be diminished to the point that it cannot detonate or has only weak detonation. This kind of phenomenon is called "desensitization." The desensitization of an explosive can be caused by a hydrostatic pressure or a dynamic pressure. The first one is usually only present in very deep blast holes and is not common for this reason. In dynamic desensitization, the following situations are usually observed.

a) Desensitization by using in-hole detonating cord
b) Desensitization by channel effect due to which detonation of the explosive charge self-suppresses—energy gradually decays until the detonation extinguishes

Appropriate blasting design which mainly include blast hole pattern and delay timing to suit the actual condition of rock mass should be adopted to prevent desensitization of explosives during blasting.

I. Stability and Shelf-Life for Storage

Stability and shelf-life are crucial aspects of explosive storage, ensuring their integrity and performance over time. Stability is the ability of an explosive to be stored without deterioration. The factors affecting the stability of an explosive are chemical composition of the explosive, temperature of storage, exposure to sunlight, and electrical discharge due to improper electrical grounding during explosive handling and storage.

Shelf-life indicates the duration for which explosives can be stored while retaining their properties. Proper storage conditions, including temperature control and moisture prevention, are essential for maintaining stability and extending shelf-life. Regular monitoring and compliance with regulatory standards further ensure safe storage practices, minimizing risks to personnel and infrastructure while maximizing the effectiveness of explosives in hydropower projects. The shelf-life after the Date of Manufacture (DoM) of the emulsion explosives manufactured worldwide has been tabulated in Table 3-10 for comparison.

3.1.3.2 Technical Specification of the Explosives Available

The technical specifications of explosives encompass details such as chemical composition, detonation velocity, pressure, energy release, sensitivity, density, water resistance, storage requirements, environmental impact, and regulatory compliance. These specifications are crucial for understanding an explosive's properties, performance, safety considerations, and suitability for specific applications. They guide users in safely handling, storing, and transporting explosives while ensuring compliance with relevant regulations and minimizing environmental impact. Manufacturers provide detailed technical data sheets to aid users in making informed decisions and implementing appropriate safety measures during usage. The properties of commercial explosive from different manufactures around the world has been presented in the Table 3-10.

Table 3-10 Comparative table showing the explosive properties from different explosive manufactures worldwide

Explosive Parameters		Orica India (Powergel 801)	SBL Energy(Neo Gel 901)	IDL Explosives	Emultex PG (Chile)	Nitroerg (EMULINIT 2)- Poland	Enaline Chile	EPC Group-Explus TSR(France)	EPC Group-Explus TSR(UK)	Austin Powder Austrogel P-Austria	Dyno Powermite Pro-Australia
Density (g/cc)		1.15±0.05	1.2±0.05	1.15 to 1.20	1.22±3%	1.10-1.30	1.0-1.2	1.27±0.008	1.27	1.4	1.16-1.23
Velocity of Detonation (VOD) in m/s		3500	4400±200	4800±200	4200-5500	>4000	3500	5500	5500	5500-6000	3400
Relative weight strength		122%	119%	105%	89%	53%	89%		130%	112% (ANFO @100)	121%
Relative bulk strength	to ANFO@ 0.8 g/cc to ANFO @ 0.95 g/cc	175%	168%	156% (ANFO @ 0.85 g/cc)	139%		127%		206%	176% (ANFO @ 0.85)	183%
Detonation pressure					7625 Mpa		6900 Mpa	13200 Mpa			
Energy (KJ/kg)					3370	3364	3371	4700±200		4135	2720-2780
Waterproof					Excellent		Excellent		Very good		
Gas volume (L/kg)					997		997	708	708	892	
Shelf life (after DoM)									1 year	1 year	

3.1.3.3 Recommended Technical Specification of All Explosive

The technical specification of the explosives materials recommended by this guideline has been presented in Table 3-11.

Table 3-11 Recommended technical specification of the explosive materials and initiation systems.

S.N.	Explosive Parameters		Recommended Range
1	Density		1.1 - 1.27 g/cc
2	Velocity of Detonation (VOD)		3400 - 5500 m/s
3	Relative weight strength		105 - 130 %
4	Relative bulk strength	*to ANFO@ 0.8 g/cc*	156 - 183%
		to ANFO@ 0.95 g/cc	139 - 206%
5	Detonation pressure		6900 - 13200 MPa
6	Energy (KJ/kg)		2720 - 4700
7	Waterproof		Excellent - Very good
8	Gas volume (L/kg)		708- 997
9	Shelf life (after DoM)		Up to 1 year
S.N.	**Initiation System Parameters**		**Recommended Range**
1	Plain Detonators and Safety Fuses		Not recommended as an initiation system in drilling and blasting operation for hydropower project in Nepal.
2	Electric detonator	Millisecond delay detonators	with 20 - 30 delay numbers
		Long-period delay detonators	delay series of 1/4 s delay (or 200 ms delay), half second delay, and second delay
		Coal mines delay detonators	Not recommended as an initiation system in drilling and blasting operation for hydropower project in Nepal.
3	Non electric detonator	Millisecond delay system	delay time of 25 ms between each interval
		Long-period delay system	delay time ranging from 100 to 1000 ms between each interval
		Unidet system	delay time ranging from 0 to 200 ms between each interval
4	Electronic detonators		delay time ranging from 1 to 10000 ms between each interval
5	Detonating Cord	Core load (g/m)	1.5 - 10
		Outside diameter (mm)	2.8 - 7.6
		Tensile strength (kgf)	68 - 90.7
		VOD (m/s)	6500 - 7000
		Core explosive	PETN

3.1.4 Initiation System

According to the functions, the initiation system includes three categories. They are detonators, detonating cords, and boosters or primers. All the three categories of the initiation system have been discussed in the following sub sections.

3.1.4.1 Detonators

Detonators are initiating devices for generating a detonation. They are specifically designed to safely and efficiently initiate and control the performance of larger explosive charges. They contain relatively sensitive high explosives, which are initiated by a signal or energy from an external source. The different types of detonators available in the market have been discussed in the following sections.

A. Plain Detonators and Safety Fuses

The plain detonator (also called ordinary detonator) and safety fuse is the oldest explosive initiation system. After the detonating explosives were introduced, and until electric methods became widespread, the plain detonator and fuse system was the dominant initiation method for small-diameter holes. Due to economics, this method remains in wide use in many areas of the world. However, at present, this system has fallen into disfavor due to its high accident potential and the fact that better breakage and higher productivity are possible with modern electric and non-electric methods.

Thus, this guideline does not recommend the use of plain detonators and safety fuses during any drilling and blasting operations in any hydropower project of Nepal.

B. Electric Detonators

Electric detonators are such kind of detonators which are ignited with an electrical igniting element and utilize electrical current as their initial energy source. In the electric detonators, the electrical current to the detonator is supplied from the power source through the circuit wiring to the detonator by means of two leg wires that are internally connected by a small length of high-resistance bridge wire. The electrical energy is converted into heat energy on passing the firing current through bridge wire. The heat energy ignites the pyrotechnic that surrounds the bridge wire on the match head assembly (called fusehead). The resulting flash or flame ignites the primary charge or the delay element, and these in turn set off base charge. Electric detonators are classified as instantaneous and delay detonators which have been depicted in Figure 3-7.

a) Instantaneous detonators; and
b) Delay Detonators

Instantaneous detonators

In instantaneous detonators, the fuse head directly ignites the primary charge of the detonator. Instantaneous detonators fire within a few milliseconds (<5 ms) after they receive the current. Instantaneous detonators are used when all the holes are to be fired simultaneously. At present, instantaneous electric detonators are usually used as a starter to ignite some non-electrical initiation systems, detonating cord system and Nonel (shock tube) system.

Delay Detonators

In delay detonators, a delay element is inserted between the electrical fusehead and the primary charge. This delay element consists of a column of slow-burning composition contained in a thick-wall metal tube. The length and composition determine the amount of delay time introduced into the detonator. Three basic delay series have been mentioned below.

a) Millisecond delay detonators;
b) Long-period delay detonators such as delay series of 1/4 s delay (or 200 ms delay), half second delay, and second delay; and
c) Coal mines delay detonators

The delay times of millisecond delay detonators of some products, and the timing series of some long-period delay detonators for reference have been presented in Table 3-12 and Table 3-13 respectively. For most blasting operations, it is an advantage to have the various holes fired in a predetermined sequence with specific time intervals between detonators. The most notable advantages of delay detonators are mentioned below.

a) Reduced vibration, airblasts, and flyrocks;
b) More predictable throw (amount and direction);
c) Reduced backbreak and overbreak, with working faces left in an improved condition;

d) Improved the excavation results for tunneling due to the fresh free faces for the subsequently firing holes are offered by the holes previously fired in a proper time interval.

It is often required that detonation events and/or explosive weight per time interval be separated by a certain specified minimum time. This is often considered to be 8 ms. Considering the rock breakage and movement caused by the detonation of explosive charge of each blasthole, long firing time intervals between blastholes are often necessary, especially in tunnel and shaft drilling and blasting operation.

Table 3-12 Nominal delay times of some products of millisecond delay electric detonators

Delay no.		0	1	2	3	4	5	6	7	8	9	10	11	12
Dyno Nobel	Super SP	9	25	50	75	100	125	150	175	200	225	250	275	300
Austin Powder	Rock Star I	0	25	50	75	100	125	150	175	200	225	250	275	300
Orica	Electric MS	9	25	50	75	100	125	150	175	200	225	250	275	300
China	Series 3	0	25	50	75	100	125	150	175	200	225	250	275	300
Delay no.		**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**22**	**24**	**26**	**28**	**30**
Dyno Nobel	Super SP	325	350	375	400	425	450	475	500	550	600	650	700	750
Austin Powder	Rock Star I	325	350	375	400	425	450	475	500	600	700	800	900	1000
Orica	Electric MS	325	350	375	400	425	450	475	500					
China	Series 4	325	350	375	400	425	450	475	500					

Table 3-13 Nominal delay times of some products of long-period delay electric detonators

Delay no.	Austin Powder (ms)			Dyno Nobel (ms)	Orica (ms)	China GB/T 803 (s)		
	Timestar I 250	Timestar I 500	DEM-F-80	Super LP	Electric LP	1/4 second	1/2 second	Second
0			0					
1	250	500	80	25	25	0	0	0
2	500	1000	160	200	200	0.25	0.50	1.0
3	750	1500	240	400	400	0.50	1.00	2.0
4	1000	2000	320	600	600	0.75	1.50	3.0
5	1250	2500	400	800	800	1.00	2.00	4.0
6	1500	3000	480	1000	1000	1.25	2.50	5.0
7	1750	3500	560	1200	1200	1.50	3.00	6.0
8	2000	4000	640	1400	1400		3.50	7.0
9	2250	4500	720	1600	1600		4.00	8.0
10	2500	5000	800	1900	1900		4.50	9.0
11	2750	5500	880	2200	2200			10.0
12	3000	6000	960	2500	2500			
13	3250		1040	2900	2900			
14	3500		1120	3300	3300			
15	3750		1200	3800	3800			
16	4000		1280	4400	4400			
17	4250		1360	5100	5100			
18	4500		1440					
19			1520					
20	5000		1600					
21			1750					
22	5500		2000					
23			2250					

Delay no.	Austin Powder (ms)			Dyno Nobel (ms)	Orica (ms)	China GB/T 803 (s)		
	Timestar I 250	Timestar I 500	DEM-F-80	Super LP	Electric LP	1/4 second	1/2 second	Second
24	6000		2500					
25			2750					
26			3000					
27			3250					
28			3500					
29			3750					
30			4000					

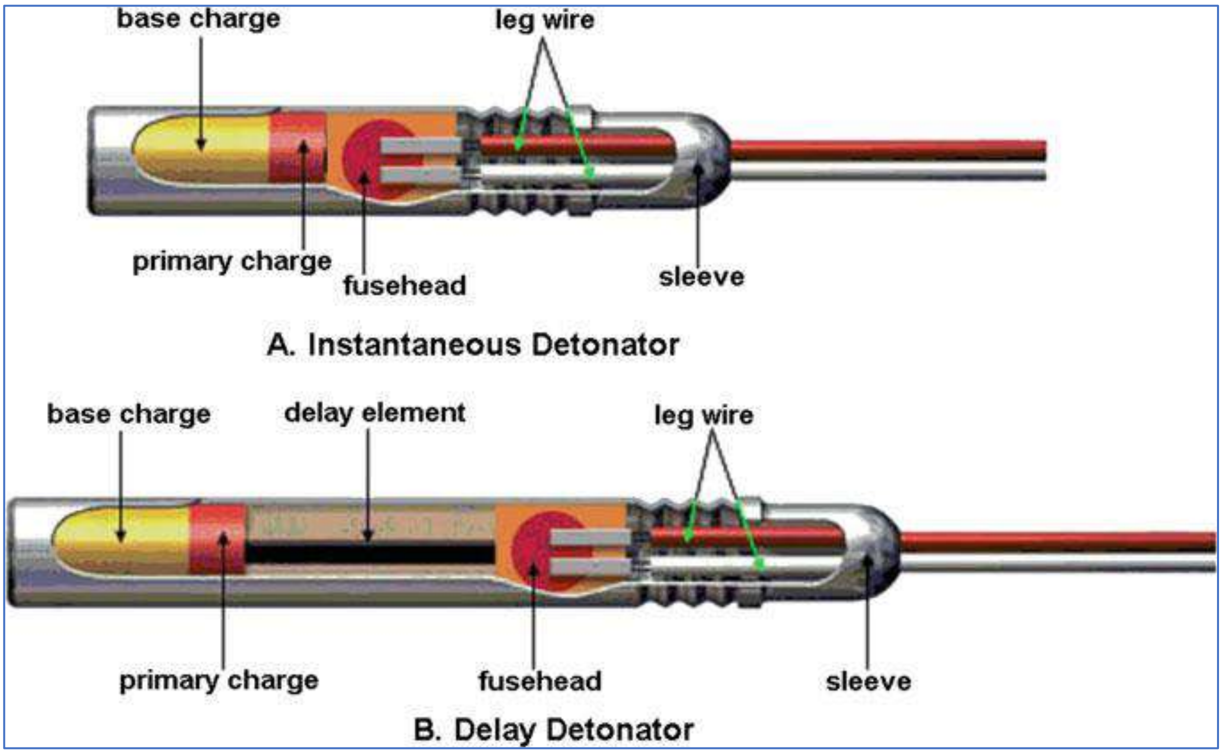


Figure 3-7 General assembly of electric detonator (Source: Zhou, 2017)

C. Shock Tube Detonators (Non Electric Detonator)

A shock tube detonator is a non-electric detonator in the form of small-diameter hollow plastic tubing used to transport an initiating signal to initiate the primary explosive or delay element in a detonator by means of a shock wave traveling the length of the tube (Figure 3-8). It was invented by Nitro Nobel AB in 1971, and sold under the registered trademark Nonel (the contraction of non-electric). It is the most commonly used initiation system.

The plastic shock tube is composed of one or more layers of plastic which are designed to enhance the physical properties (tensile strength, flexibility, and abrasion resistance) (Figure 3-9). The inner wall of the tube is covered with a fine dust of explosives (usually composed of HMX and aluminum powder) which reacts chemically to support the air shock wave by heating and by the explosion of the gaseous reaction products. The explosive load of the shock tube is <20 mg/m of tubing, sufficient to propagate the shock wave indefinitely through the tube, or until the conventional cap delay element is reached. The propagation velocity of the shock wave is about 2000 m/s (1980–2130 m/s), and the shock wave travels through the tube without affecting the outside surface of the tube.

Figure 3-8 Photograph of Shock tube detonator (Non electric detonator) taken during UT-1 HEP Field Visit

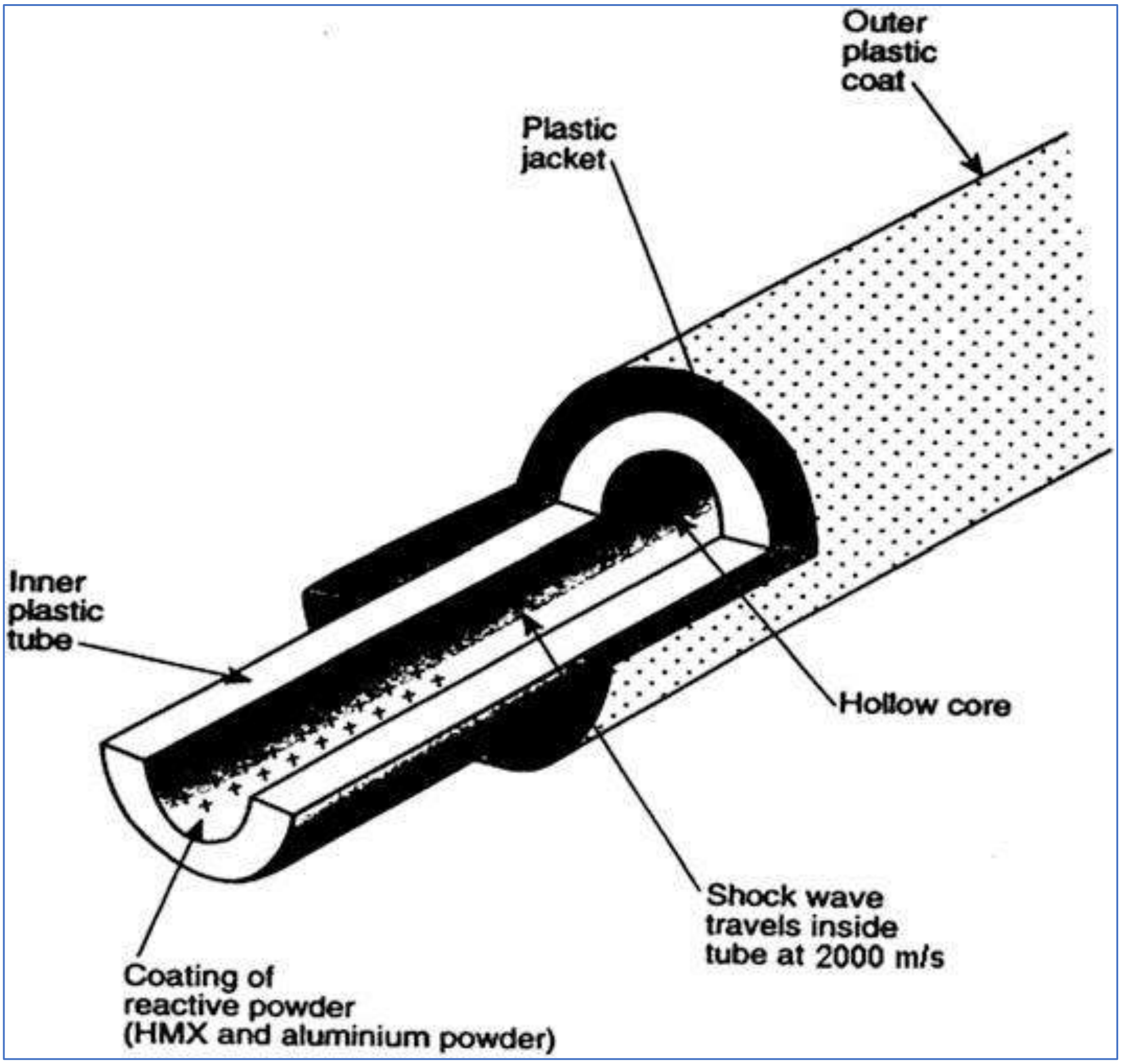


Figure 3-9 Structure of Plastic Shock tube of non-electric detonator (Source: Zhou, 2017)

A variety of shock tube system configurations are available for specific applications. Usually, there are three configurations that are widely used in rock blasting:

a) Millisecond delay system;
b) Long-period delay system; and
c) A combination of high-precision long-period in-hole detonators and a number of short-delay surface connector units (Unidet system).

1) Millisecond delay system

Millisecond delay system of shock tube detonators is a conventional initiation system with a delay time of 25 ms between each interval. The nominal delay times of millisecond delay systems provided by several manufacturers has been presented in Table 3-12 .

2) Long-period delay system

Long-period delay system is an initiation system intended for underground use. The delay times between intervals in the system are generally longer in order to give enough time for blasted rock to be properly displaced in the confined space and single free face typical in tunneling. The nominal delay times of long-period delay systems provided by several manufacturers has been presented in Table 3-13.

3) Combination of high-precision long-period in-hole detonators and a number of short-delay surface connector units (Unidet system).

This system (Unidet) is an initiation system that employs a uniform delay time in the in-hole detonators and variable delay times in the connector units on the surface. The delay time in the drillhole usually has a longer delay time which normally enables most of the in-hole detonators to be initiated on the surface before any rock displacement begins. This is then supplemented by delay times in the surface connector units, which give the desired initiation sequence. Surface delays from 0 to 200 ms are available, which gives great flexibility in adapting the initiation sequence to suit the burden and rock characteristics.

Table 3-14 The nominal delay times of millisecond delay systems provided by several manufacturers

Austin Powder		Dyno Nobel		Orica		China	
Shock Star MS		Nonel MS Series		Excel MS		Series 3	
No.	Time	No.	Time	No.	Time	No.	Time
0	0	1	25	1	25	1	0
1	25	2	50	2	50	2	25
2	50	3	75	3	75	3	50
3	75	4	100	4	100	4	75
4	100	5	125	5	125	5	100
5	125	6	150	6	150	6	125
6	150	7	175	7	175	7	150
7	175	8	200	8	200	8	175
8	200	9	225	9	225	9	200
9	225	10	250	10	250	10	225
10	250	11	275	11	275	11	250
11	275	12	300	12	300	12	275
12	300	13	325	13	325	13	300
13	325	14	350	14	350	14	325
14	350	15	375	15	375	15	350
15	375	16	400	16	400	16	400

Austin Powder		Dyno Nobel		Orica		China	
Shock Star MS		Nonel MS Series		Excel MS		Series 3	
No.	Time	No.	Time	No.	Time	No.	Time
16	400	17	425	17	425	17	450
17	425	18	450	18	450	18	500
18	450	19	475	19	475	19	550
19	475	20	500	20	500	20	600
20	500	21	550	22	550	21	650
22	600	22	600	24	600	22	700
24	700	23	650	26	650	23	750
26	800	24	700	28	700	24	800
28	900	25	750	30	750	25	850
30	1000	26	800	32	800	26	950
15	375	27	900	34	850	27	1050
16	400	28	1000	36	900	28	1150
				40	1000	29	1250
				48	1200	30	1350
				56	1400		
				64	1600		
				72	1800		
				80	2000		
				90	2250		

Table 3-15 The nominal delay times (ms) of long-period delay systems provided by several manufacturers

Austin Powder		Dyno Nobel		Orica		China					
Shock Star LP detonators		Nonel LP series		Excel LP		1/4 second delay series 1		1/2 second delay series 2		Second delay series 2	
No.	Time	No.	Time	No.	Time	No.	Time	No.	Time	No.	Time
0	0	0	25	1/4	100	1	0	1	0	1	0
1	200	1	500	1/2	200	2	250	2	500	2	1000
2	400	2	800	3/4	300	3	500	3	1000	3	2000
3	600	3	1100	1	400	4	750	4	1500	4	3000
4	800	4	1400	1-1/4	500	5	1000	5	2000	5	4000
5	1000	5	1700	1-1/2	600	6	1250	6	2500	6	5000
6	1200	6	2000	2	800	7	1500	7	3000	7	6000
7	1400	7	2300	2-1/2	1000	8	1750	8	3500	8	7000
8	1600	8	2700	3	1200	9	2000	9	4000	9	8000
9	1800	9	3100	4	1400	10	2250	10	4500	10	9000
10	2000	10	3500	5	1600						
11	2500	11	3900	5-1/2	1800						
12	3000	12	4400	6	2000						
13	3500	13	4900	7	2250						
14	4000	14	5400	8	2500						
15	4500	15	5900	9	3000						
16	5000	16	6500	10	3500						
17	5500	17	7200	11	4000						
18	6000	18	8000	12	4500						

Austin Powder		Dyno Nobel		Orica		China					
Shock Star LP detonators		Nonel LP series		Excel LP		1/4 second delay series 1		1/2 second delay series 2		Second delay series 2	
No.	Time	No.	Time	No.	Time	No.	Time	No.	Time	No.	Time
19	6500			13	5000						
20	7000			14	5500						
21	7500			15	6000						
22	8000			16	6500						
23	8500			17	7000						
24	9000			18	8000						
25	9600			19	9000						

Initiation Methods for Shock Tube Detonator System

A shock tube detonator system can be initiated either by using electrical detonator or by using plain detonator with safety fuse or by using a special blasting machine or shock tube starting device.

a) **Initiation using an electric detonator**

A shock tube detonator round can be initiated with an electric detonator. The electric detonator is taped to the shock tube with the detonator bottom pointing opposite to the direction of the shock wave starting propagation in the tube (Figure 3-10). The electric detonator should be well covered with earth, drill cuttings, etc., as the strength of this detonator is considerably greater than that of the surface connection unit.

b) **Initiation using a plain detonator with safety fuse**

Shock tube detonator system can also be initiated by plain detonator with safety fuse, and the length should be long enough to ensure master blaster evacuating to a safe place after igniting the fuse and detonating cord. However, this guideline does not recommend initiation using a plain detonator with safety fuse in any drilling and blasting operation of hydropower projects of Nepal.

c) **Initiation using a special blasting machine or shock tube starting device**

The simplest and safest way of initiating shock tube detonator rounds is using along shock tube with a length long enough to ensure the master blaster can evacuate to a safe place to fire the round. The ultrasonic seal at the ends of both starting connection unit and the long shock tube is cut off and connected together by pushing at least 1 cm into an approx. 4 cm long outer plastic connecting sleeve, and then the long shock tube is extended to the chosen safe firing point. When the round is ready to be blasted, connect the long shock tube to the blasting machine, by inserting the tube into the chuck as far as possible, then starting the machine, and firing the round (see Figure 3-11). Some blasting initiation devices for shock tube detonator system (or by means of remote firing devices have been presented in Figure 3-12 and Figure 3-13 for reference.

The advantage of shock tube detonators as a kind of non-electric initiation system versus electric initiation system is principally perceived to be their lack of susceptibility to premature activation by extraneous electrical energy, such as static electricity, stray currents, strong radio or radar signals, or lightning. The principal shortcoming of most non-electrics including shock tube initiation system is the lack of a circuit test capacity.

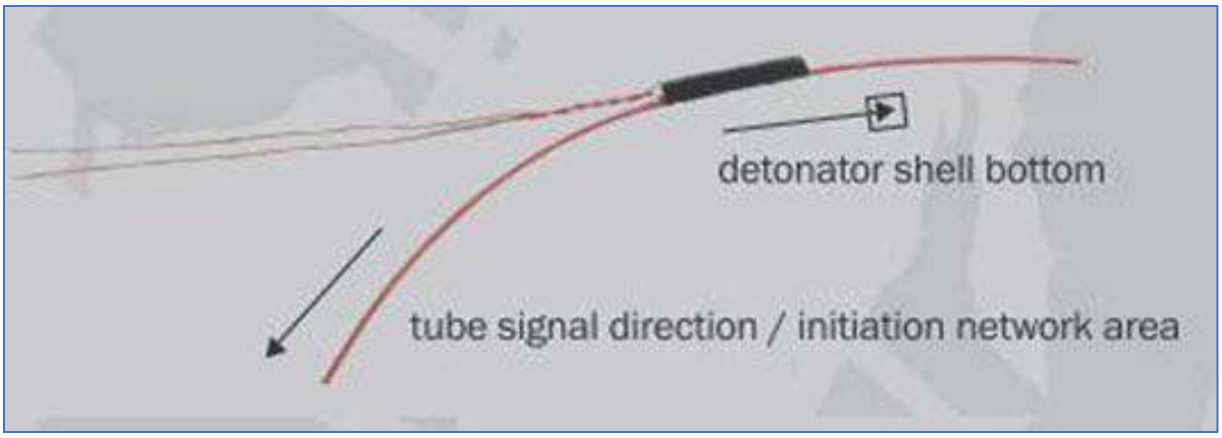


Figure 3-10 Initiation by means of an electric detonator (Source: Zhou, 2017)

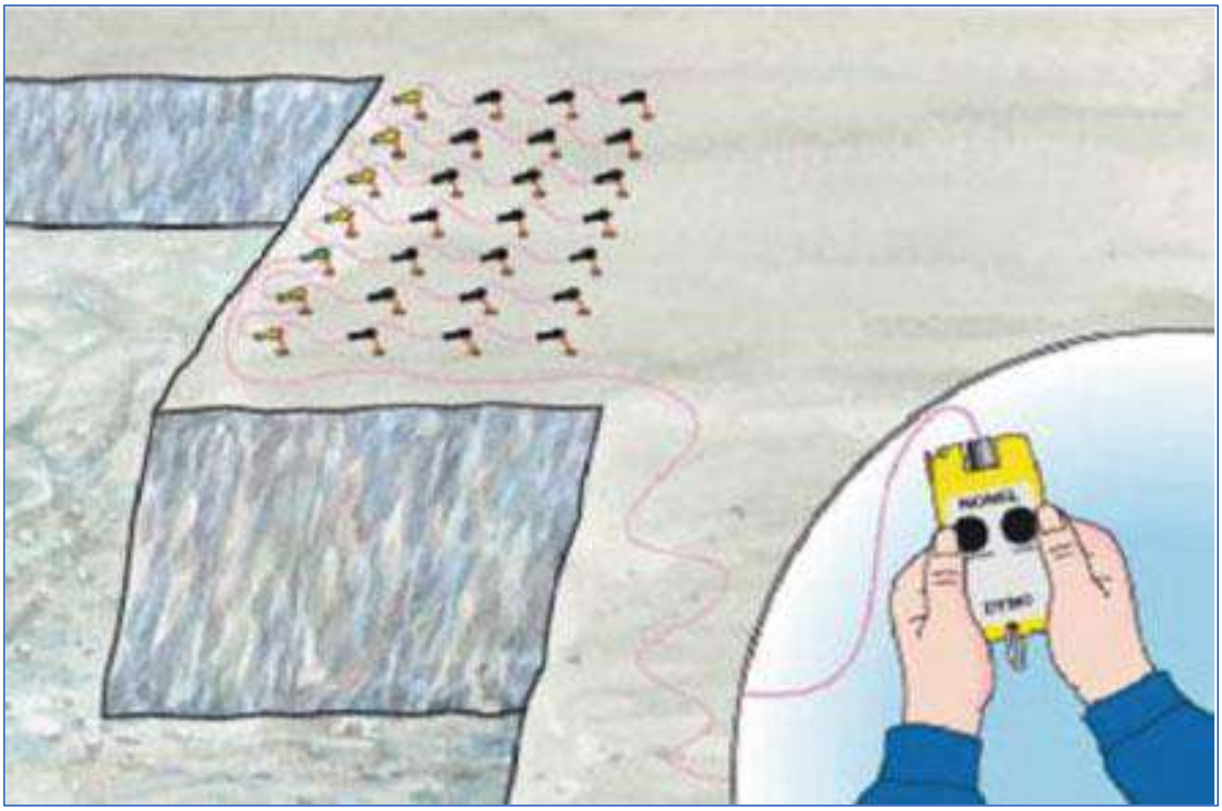


Figure 3-11 Firing a blasting round using a blasting machine (Source: Zhou, 2017)

Figure 3-12 Blasting machine for shock tube detonator - Dyno Nobel

Figure 3-13 Blasting machine for initiation of both electric and shock tube detonator-Austin Power

D. Electronic (Digital) Detonators

Since the last years of the twentieth century, more advanced initiation devices, such as laser detonators, electronic (or digital) detonators, and sound control detonators, came to the world and promoted the development of blasting technology. Especially, the digital detonators can offer great advantages of accurate timing, safety and reliability although they are more expensive than the normal electrical and Nonel systems but the cost difference has been and will be further reduced along with the development of electronic technology.

In electronic detonator, there is an integrated circuit chip and a capacitor internal to each detonator control the initiation time. A specially designed blasting machine transmits a selectable signal that is identified by each detonator and determines the detonation timing sequence. The structure of the electronic detonator and its integrated circuit board produced by Dyno Nobel and DetNet South Africa (DSA) have been presented in Figure 3-14. The SmartShot detonator and its control and firing devices have been presented in the Figure 3-15. The features of some electronic detonator systems in the international market have been presented in Table 3-16 for reference.

Although the cost of electronic detonator is higher than electric and shock tube detonators, the electronic detonator system has the following advantages:

a) Multiple verification of detonators prior to each blast and 100 % verification of reliability of connections in initiation network.
b) Delay range of 1 up to 20,000 ms with an increment of 1 ms.

c) Precision of 0.01 % of nominal delay time and up to 1000 times more accurate than pyrotechnics.
d) Safe and reliable initiation of up to 20,000 units in one blast. It cannot be initiated by foreign energy, i.e., thunder, static electricity, and stray current, only by the specified blasting machine.
e) There is a unique ID in each detonator. The ID number is not removable and is readable by the specified logger.

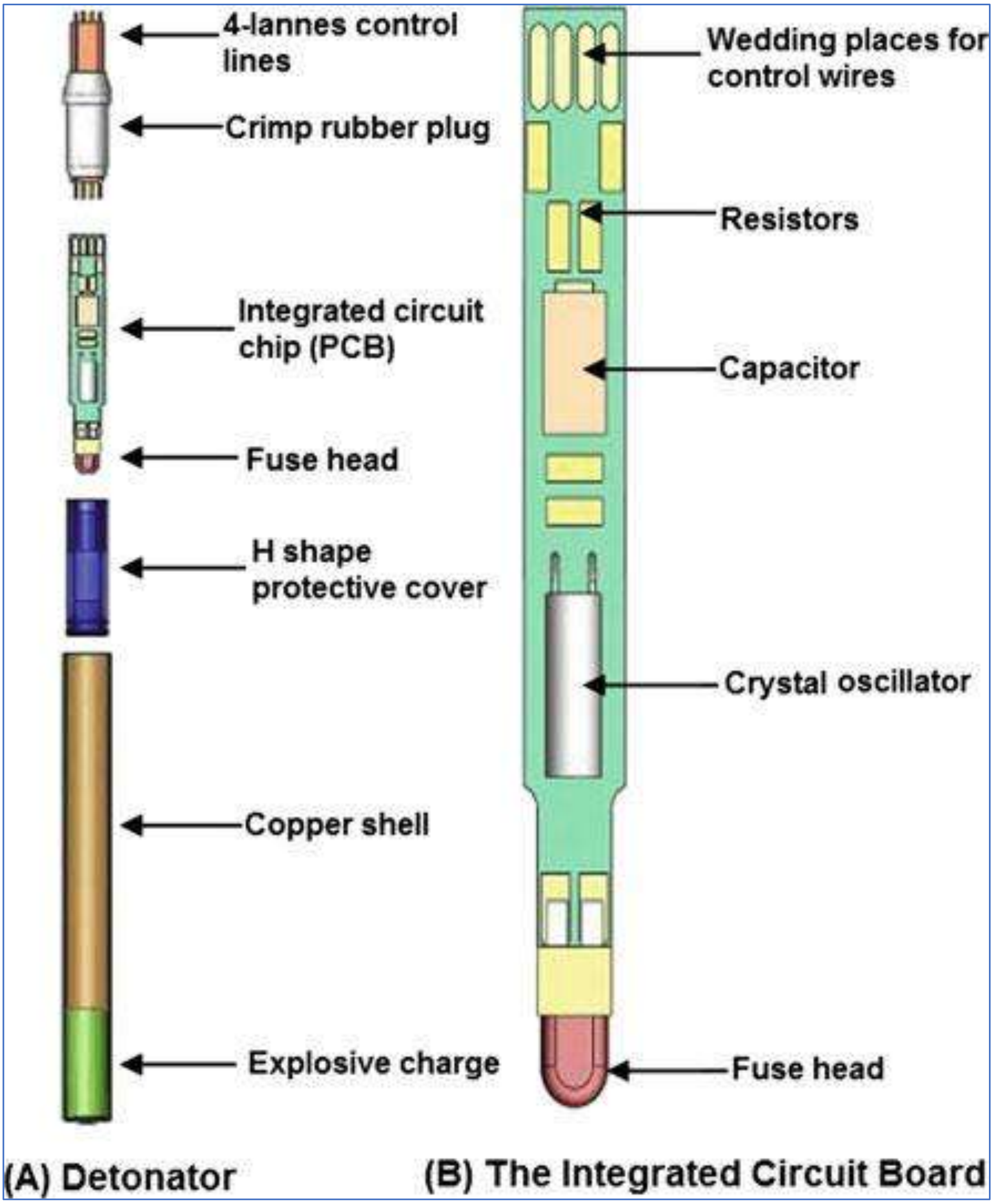


Figure 3-14 Structure of electronic detonator (Source: Zhou, 2017)

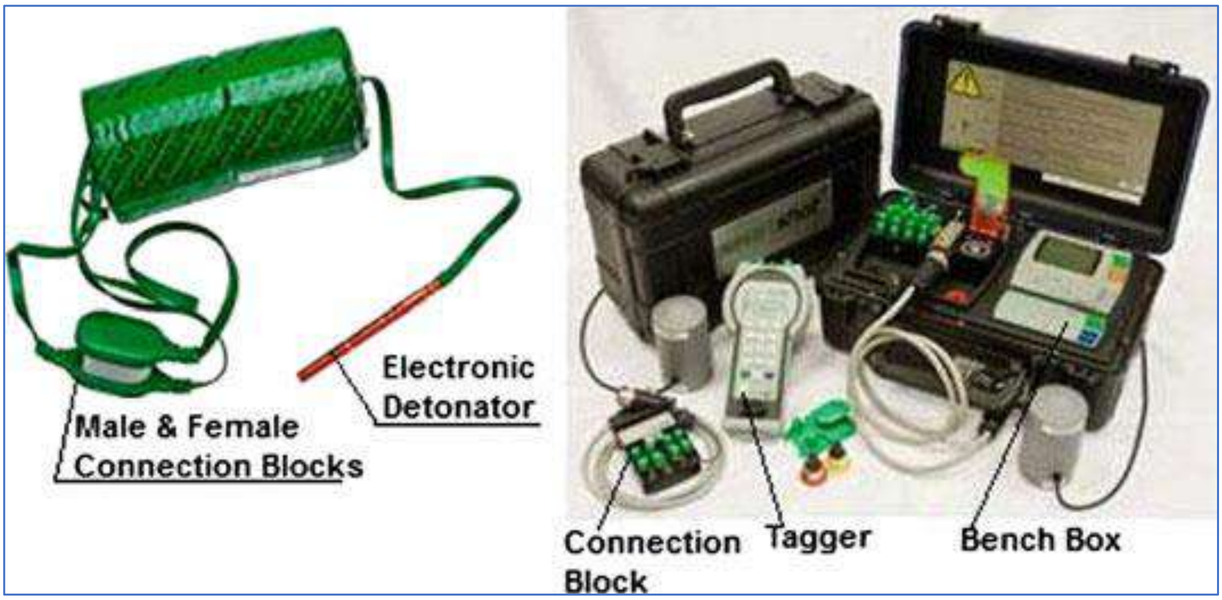


Figure 3-15 SmartShot electronic detonator and control system (Dyno & DSA)

Table 3-16 Features of some electronic detonator systems

Manufacturer	Austin Powder	Dyno Nobel	Dyno Nobel/DetNet	Orica		
Brand	E*Star	DigiShot Plus	SmartShot	i-Kon II	Uni Tronic 600	eDev II
Max. delay (ms)	10,000	20,000	20,000	30,000	10,000	20,000
Min. delay interval (ms)	1.0	1.0	1.0	1.0	1.0	1.0
Precision (%)	0.005			0.005	0.03	0.01
Max. detonators per blast	1,600	7,200	2,400	400–4800	800	800
Detonator strength	Base: 720 mg	#12	#12	Base: 780 mg	Base: 780 mg	Base: 780 mg
Equipment (exclude detonator)	Tester LM-1 Logger DLG1600-2-K Blasting Machine DBM1600-2-k	Tagger Blast Box	Bench Box Base Box String Starter End Plug Tagger	i-Kon Logger i-Kon Blaster CEBS SURBS	Scanner 120/125 Test Box Blast Box 310/310RAU	Blast Box 610 Tester Scanner 125 CEBS Blast Design Software

3.1.4.2 Detonating Cord

Detonating cord (also called detacord, detonation cord, or detonating fuse) is round, flexible cord containing a core of PETN in varying amounts (1.5, 3, 5, 11…,40 and 100 g/m) wrapped in a plastic jacket that gives adequate flexibility, waterproofing, tensile strength, and resistance to humidity (Figure 3-16). The detonation velocity is around 7000 m/s. Due to the strong directionality of the detonating cord during propagating detonation, care should be taken when connecting two or more detonating cords. Some recommended connection methods for detonating cords have been presented in Figure 3-17.

Detonating cord is relatively insensitive and requires intimate contact with a detonator of at least No. 6 strength to assure initiation. Detonating cord should be cut by a specially made cord cutter for safety as shown in Figure 3-18 for reference. Although the primary application of detonating cords is to propagate the detonation to an explosive charge, they also have other uses. Some typical applications and the technical information of detonating cords from some manufacturers have been presented in the Table 3-17 and Table 3-18 respectively for reference.

Figure 3-16 Photographs showing detonating cord taken during site visit of UT-1 HEP

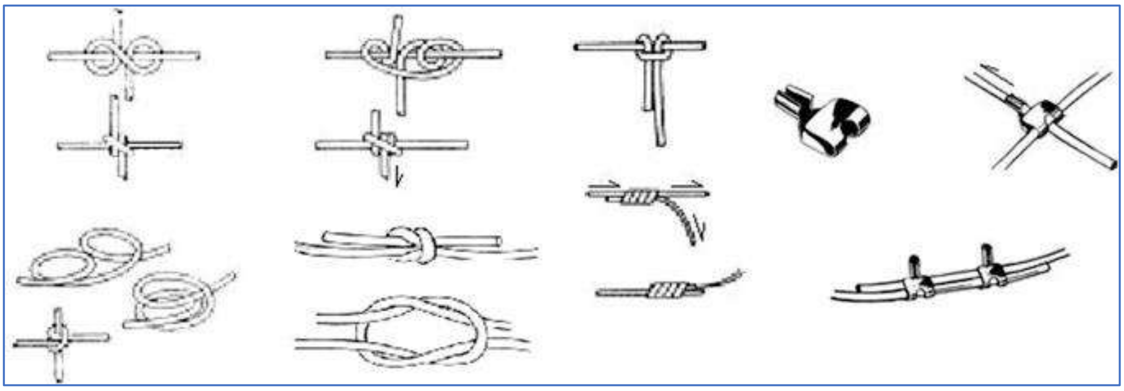


Figure 3-17 Recommended knots for connection of detonating cords (Source: Zhou, 2017)

Figure 3-18 Cord cutter

Table 3-17 Application of detonating cord

Core rate (g/m)	Application
1.5–3	Initiation of primers and very sensitive explosives
5, 6	Trunk lines connecting blast (presplitting) holes Used in bunch connecters for initiating shock tube detonators in tunneling
11–20	Initiation of conventional and less sensitive explosives
40	Seismic explosion and also used for lineal charge (double lines) for presplitting
100	Contour blasts and demolition

Table 3-18 Technical information of detonating cords

Manufacturer	Brand	Core load (g/m)	Outside diameter (mm)	Tensile strength (kgf)	VOD (m/s)	Core explosive
Austin Power	Lite Line	3.2	3.94	104	6500–7000	PETN
	A-Cord	5.3	4.19	104	6500–7000	PETN
	50 Reinforced	10.6	5.0	90.7	6500–7000	PETN
	Heavy Duty 200	42.5	8.5	113.4	6500–7000	PETN
Dyno Nobel	Primacord 1	1.5	3.18	68	7000	PETN
	Primacord 2.5	2.4	2.8	27	7000	PETN
	Primacord 3	3.2	3.66	113	7000	PETN
	Primacord 4Y	3.6	3.61	68	7000	PETN
	Primacord 5	5.3	3.99	68	7000	PETN
	Primacord 8	8.5	4.47	90	7000	PETN
	Primacord 10	10.8	4.7	90	7000	PETN
Orica	Cordtex 3.6 W	3.6	4.0	90	6500–7000	PETN
	Cordtex 5P	5.0	3.7	70	6500–7000	PETN
	40 RDX LS[a]	8.5	4.4		6700	RDX
	Cordtex 10P	10.0	4.6	70	6500–7000	PETN
	Cordtex 40	40.0	7.6	70	6500–7000	PETN
China	Low Energy	5.0	4.2	>50	>6000	PETN
	General	11.0	6.0	>50	>6500	PETN
	Seismic	40.0	9.5	>50	>6500	PETN

3.1.4.3 Cast Booster

Cast boosters are explosive units designed to act as primers, comprising a mixture of PETN (or RDX) and TNT, which are inexpensive military high explosives released to the commercial market during the late 1950s through the 1960s and other minor ingredients. Their high energy, high strength, and high VOD (above 7000 m/s) make them suitable for priming the above-said bulk blasting agents. An additional advantage is their lower sensitivity to shock, friction, and impact than NG explosives. This guideline does not recommend the use of cast boosters in any drilling and blasting operations of any hydropower projects of Nepal since it is used in most site-mixed and loaded bulk blasting agents, such as ANFO, bulk emulsion, and heavy ANFO among others.

3.1.5 Blasting Assessment Report

Rock excavation by blasting can adversely affect the stability and integrity of slopes, retaining walls, structures, buildings, services, and utilities through ground vibration and other effects. The transport, storage, and use of explosives for blasting also pose a safety hazard to the public. A blasting assessment should be undertaken in the design stage to assess such adverse effects and hazards and to propose measures to demonstrate the practicality of safely carrying out of blasting works. Thus, this guideline recommends preparing a Blasting Assessment Report (BAR) regarding estimation, usage, handling, storage, transportation, and procurement of the explosive materials.

The concerned developer/promoter of the hydropower project must provide the detail Blasting Assessment Report (BAR) to DoED for getting the recommendation regarding the procurement of the explosive materials. The generalized table of content for the blasting assessment report has been presented in the Table 3-19 for reference purpose only.

Table 3-19 Table of content of the Blasting Assessment Report (BAR) with the details required

Chapter	Content	Details required	Remarks
1	Introduction	Purpose of the Report	
		Scope of the Assessment	
		Agreement or contract details for the procurement of explosive materials with the manufacturers or suppliers or main civil contractors	
2	Project Overview	Project Description including salient features mentioned in Section 3.1.5	
		Issued construction drawings of every project components and project facilities requiring rock excavation by drilling and blasting method	
		Location and Site Details of every project components and project facilities including its geological conditions	
3	Drilling and Blasting Operations	Drilling Methodology with details of equipment and materials to be employed	
		Blasting Methodology with details of equipment and materials to be employed	
		Technical specification of the explosive materials including initiation systems to be procured	Check whether the given technical specification of explosive materials lies within the recommended technical specification presented in Table 3-28
		Blast Design Parameter • Hole Diameter, Depth, and Spacing • Recommended blasting pattern along with parameters recommended by this guideline	
4	Explosive Materials Estimation	Quantity estimate of rock excavation volume and explosive materials in pursuant to Table 3-1 presented in this guideline	Check whether the (1) rock excavation volume and (2) geological condition mentioned in the salient feature of the project complies or not.
			Check whether the estimation of explosive materials for underground excavation has been carried out by using any two typical curves recommended by this guideline or not as mentioned in Section 7.1.1.
			Check whether the contingency provision mentioned in Table 6-11 is applied during estimation of explosive materials for underground excavation by using any two typical curves recommended by this guideline or not.

Chapter	Content	Details required	Remarks
5	Explosive Materials Usage	Daily Blasting Work Sheet of the hydropower project	Check whether it is pursuant to Table 3-29 or not
		Typical format of record keeping of the data related to the drilling and blasting operations of the hydropower project	Check whether it is pursuant to Table 3-30 or not
6	Explosive Materials Handling	Overall responsibilities of authorized personnel regarding different activities associated with explosive material handling	Compare with Table 3-31
		Specific TARP of the hydropower project	Check whether the plan is in pursuant to Table 3-32 or not
		Work planning procedure and control requirement in any drilling and blasting operation by any hydropower project in Nepal	Check whether the procedures are in pursuant to the Section 3.3.5 or not
		Disposal plan for surplus, defective and expired explosives, and used packing material	Check whether it is in pursuant to Figure 3-43 or not
		Misfire handling procedures	Check whether the procedures are in pursuant to the Section 3.3.11.1 or not
7	Explosive Materials Transportation	Elimination measures to be adopted during explosives transportation	Check whether the measures are in pursuant to the Section 4.4.1 and Section 4.4.3 or not
		Typical format of Request for Information (RFI) for delivery and acquisition of the explosive materials of the hydropower project	
		Typical format of inventory records of used explosive quantity of the hydropower project	
8	Explosive Materials Storage	Proper planning and siting of bunker facilities	Check whether it is in pursuant to Section 7.1.5 or not
		Detail drawings of Bunker facilities	
9	Explosive Materials Procurement	Company profile of the hired main civil contractor or explosive manufacturer or explosive supplier	Refer to Section 7.1.6 for reference
10	Operational Health and Safety Regarding Explosive Materials	General requirement for drilling and blasting operation	Refer to Section 4.2 for reference
		Major hazards and risks and its elimination measures	Refer to Section 4.2 for reference
		Blasting safety for surface blasting	Refer to Section 4.3 for reference
		Explosive stored in site magazine and site transportation	Refer to Section 4.4 for reference
11	Formalizing Inspection and Monitoring of Explosive Materials	Framework for formalized inspection and inventory process of the explosive material	As presented in Table 3-34 of Section 3.4.1 for reference
		Typical format of checklist for the inspections of the bunker site and the explosive material of the hydropower project	Refer to Annex 10 for reference
12	Conclusion and Recommendations	Summary of Findings including estimation of explosive materials	
		Recommendation for future blasting operation (if any)	
13	Appendices	Maps and Diagrams (e.g., site layout, blast area, issued construction drawings, engineering geological maps of every project components and project facilities)	Refer to Annex 13
		Engineering geological plan and profile of the hydropower project	
		Checklists	
14	References		

3.1.6 Explosive Material Estimation for Surface Excavation

This guideline discusses the estimation of explosive materials for three types of surface excavation namely bench blasting, trench blasting, and boulder blasting in the following sub sections. The details of explosive materials estimation and ignition system estimation for surface excavation have been discussed in Section 6.1.

3.1.6.1 Bench Blasting

Bench blasting is the most common and basic method for the surface excavation. It is carried out by drilling blastholes from the upper surface to the downward into rock, a drill hole may be vertical or inclined along the rock surface. Then, charging is done to break the rock mass into muckable size. For the estimation of explosive materials, this guideline identifies the following parameters and its computation methods.

a) Geometrical parameters related to blasting pattern
b) Rock parameters
c) Drilling parameters
d) Explosive parameters

In the following sections, the identified parameters are discussed.

A. Geometrical parameters related to blasting pattern

For the bench blasting, the important geometrical parameters related to blasting pattern are blasthole inclination, blasthole diameter, height of bench, burden, spacing, subdrilling, stemming, and blasthole pattern among others. These parameters are discussed in the following sub sections accordingly.

1) Blasthole inclination (β)

This guideline recommends vertical or inclined blastholes instead of horizontal blasthole for bench blasting. Since, horizontal blastholes are very rarely used due to difficulty with drilling and charging as well as the greater potential risk of flyrock in surface rock blasting. However, this guideline recommends the vertical blasthole instead of inclined blasthole because during inclined blasthole there is an increase in difficulty of explosives charging especially in blastholes with water. Moreover, inclined blastholes also have high potential risk of flyrock especially in the case of rugged bench face as there is an upward component of rock movement. But, inclined holes should be drilled in parallel with the front face of the bench as shown in Figure 3-19 for getting better fragmentation, displacement of the muck pile, and less backbreak to the newly formed slope.

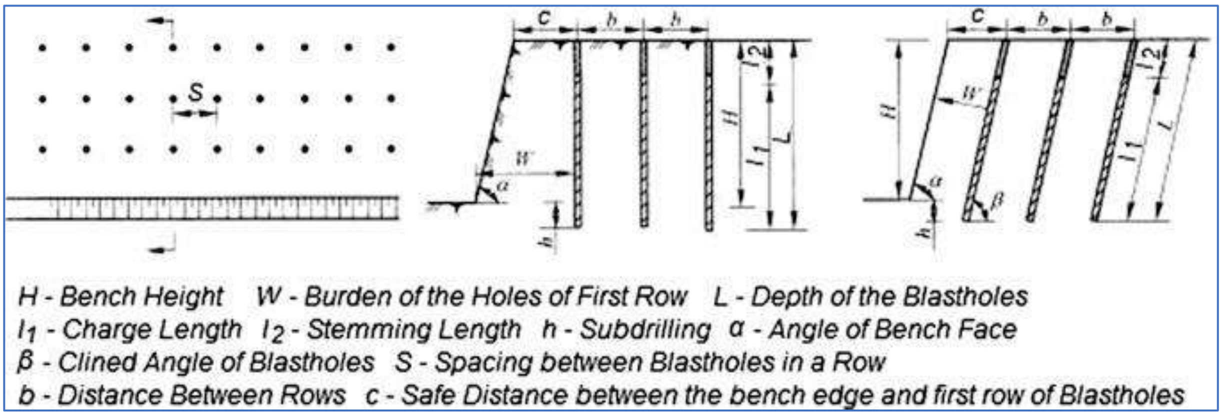


Figure 3-19 Geometrical parameters related to blasting pattern for bench blasting, (Zhou, 2017)

2) Blasthole diameter (D)

Generally, the blasthole diameter (D) used for rock blasting in construction excavation projects ranges from 38 mm to 150 mm. The blasthole diameter should be selected for a given hydropower project depending upon the following factors: such as (1) blasting scale and productivity, (2) Degree of fragmentation required to suit the loading and transportation equipment, and (3) height of bench and configuration of charges. Thus, this guideline recommends the application of blasthole diameter (D) ranging from 38 mm to 50 mm for hydropower projects in Nepal in order to lower the bench height (H), and get optimum distribution of explosives for better blasting fragmentation.

3) Burden (W)

Burden is one of the most critical geometrical parameters related to blasting pattern in bench blasting. The burden is the minimum distance from the axis of a blasthole to the free face of the bench. For vertical blastholes the burden should be measured from the toe of the bench to the axis of blasthole as shown in Figure 3-19. The value of the burden is controlled by the rock blastability, the diameter of the blasthole, and the performance of explosive charge. There are numerous formulas that have been suggested to calculate the burden. Most formulas utilize charge volume, charge weight, or hole diameter as the basic parameter to calculate the burden. This guideline recommends the following four common methods for the calculation of burden during estimation of explosive materials in bench blasting.

a) Burden (W) calculated based on relative density
b) Burden (W) calculated based on relative bulk strength
c) Burden (W) calculated based on Langefors and Kihlstrom, 1973
d) Burden (W) calculated based on Tamrock's method

a) Burden (W) calculated based on relative density

The burden (W) of the blasting pattern can be calculated based on the relative density of the rock mass present in any given drilling and blasting location. The burden is calculated based on relative density as given below:

$$\boldsymbol{Burden\ (W)} = \left(\frac{\boldsymbol{2SG_e}}{\boldsymbol{SG_r}} + \boldsymbol{1.5}\right)\boldsymbol{D_e}$$

Where,
W = Burden (ft)

D_e = Diameter of explosive (in)

SG_e= Specific gravity of the explosive used

SG_r= Specific gravity of the rock at the given drilling and blasting location

b) Burden (W) calculated based on relative bulk strength

The burden (W) of the blasting pattern can be calculated based on the relative bulk strength (ANFO=100) of the explosive used. The burden is calculated based on relative bulk strength as given below:

$$\boldsymbol{Burden\ (W)} = \boldsymbol{0.67D_e}\sqrt[3]{\frac{\boldsymbol{St_v}}{\boldsymbol{SG_r}}}$$

Where,

W = Burden (ft)

D_e = Diameter of explosive (in)

St_v = Relative Bulk Strength (ANFO=100) of the explosive used

SG_r= Specific gravity of the rock at the given drilling and blasting location

c) Burden (W) calculated based on Langefors and Kihlstrom, 1973

The burden (W) of the blasting pattern can be calculated based on Langefors and Kihlstrom, 1973. The burden is calculated as given below:

$$W_{max} = \frac{D}{33}\sqrt{\frac{\rho PRP}{\bar{c}f\left(\frac{S}{W}\right)}}$$

Where,

W_{max} = Maximum burden (m);

D = Diameter in the bottom of blasthole (mm);

ρ = Loading density of explosive, (kg/dm^3);

PRP = Weight strength of the explosive, (for dynamite: PRP = 1.0, for ANFO: PRP = 0.84, and for TNT: PRP = 0.97;

$\bar{c}$ = $\bar{c}$ + 0:75 kg/m^3 for Wmax 1.4–15.0 m and c is the rock constant, normally in surface blasts and with hard rock c ¼ 0:40 kg/m^3;

f = Degree of fixation, 1.0 for vertical holes and 0.95 for holes with inclination 3:1;

S/W = Ratio of spacing and burden.

d) Burden (W) calculated based on Tamrock's method

The burden (W) of the blasting pattern can be calculated based on Tamrock's method. According to this method the burden(W) is calculated 24-40 times of blasthole diameter(D) in mm (Table 3-20). Since, this guideline recommends, the blasthole diameter ranging from 38 mm to 50 mm, the calculated burden (W) ranges from 912 mm to 2000 mm based on Tamrock's method.

4) Spacing (S)

The distance between adjacent blastholes, measured perpendicular to the burden, is defined as the spacing. Usually, spacing of blastholes is calculated as a function of burden, but it is also affected by the initiation timing between blastholes and the initiation sequence. This guideline recommends the ratio K_S (relationship of Spacing – Burden) as mentioned in the Table 3-20 for the calculation of spacing for the blasting pattern in bench blasting.

Moreover, this guideline recommends the calculation of spacing (S) of the blasting pattern in the bench blasting by the calculation of burden (W) based on either relative density of the rock or relative bulk strength of the explosive used or Langefors and Kihlstrom (1973) or Tamrock's method while using the same ratio K_S (relationship of Spacing – Burden).

5) Subdrilling (h or J)

In bench blasting, the blastholes are drilled below the floor level in order to avoid leaving a hump or toe in bench floor after blasting, This excess drill length is termed as subgrade drilling or subdrilling. This guideline recommends an optimum subdrilling of roughly 0.3 times the burden (W) based on the ratio K_H (relationship of Subdrilling – Burden) as mentioned in Table 3-20. If the rock structural formation and strength is in favor of blasting, subdrilling should be decreased (even to 0 for the horizontal stratification) and vice versa.

Moreover, this guideline recommends the calculation of Subdrilling (H) of the blasting pattern in the bench blasting by the calculation of burden (W) based on either relative density of the rock or relative bulk strength of the explosive used or Langefors and Kihlstrom (1973) or Tamrock's method while using the same ratio K_H (relationship of Subdrilling– Burden).

Table 3-20 Recommended relationship ratios for calculation of different geometrical parameters of bench blasting

S.N.	Name of Relationship	Equation	Range of values
1	Burden -Diameter	$W = K_W \times D$	K_W = 25-40 (Tamrock's Method)
2	Spacing-Burden	$S = K_S \times W$	K_S=1-1.5
3	Subdrill-Burden	$J = K_J \times W$	K_J = 0.3
4	Stemming-Burden	$T = K_T \times W$	K_T = 0.7-1.2
5	Bench Height-Budren	$H = KH \times W$	$KH \geq 1.6$

6) Stemming (T)

Stemming is the portion of blasthole which has been packed with inert material above the charge in order to confine and retain the gases produced by the explosion, thus improving the fragmentation process. The type and length of stemming have no significant effect on the characteristics of the explosion generated strain wave. But, a stemming column of suitable length and material can reduce premature venting of high-pressure explosion gases to the atmosphere; hence, it always enhances fracture and displacement of bench rock by gas energy. This guideline recommends that the size of granular particle materials used for stemming should range between 1/17 of D (blasthole diameter) and 1/25 of D (blasthole diameter) for effective stemming as they exhibit high frictional effects and free flowing when stemming. Moreover, the drill cuttings or sand of above mentioned size is recommended as a stemming material rather than the soil due to its low friction and may cause heavy dust during blasting.

This guideline recommend an optimum stemming of about 0.75 to 1.2 times the burden (W) based on the ratio K_T (relationship of Stemming – Burden) as mentioned in Table 3 19. Moreover, this guideline recommends the calculation of Stemming (T) of the blasting pattern in the bench blasting by the calculation of burden (W) based on either relative density of the rock or relative bulk strength of the explosive used or Langefors and Kihlstrom (1973) or Tamrock's method while using the same ratio K_T (relationship of Stemming – Burden).

7) Bench Height (H)

In the context of bench blasting, benches refer to the levels or platforms created within an open pit or quarry where blasting operations are conducted. These benches serve several purposes, including providing stable platforms for drilling, loading, and blasting activities. The height of the bench usually depends on the scale of the excavation project and the equipment used for drilling and loading. Sometimes, it is also limited by the design requirements of the project. Usually, lower height of bench (equal or less than 5 m) is suitable for small blastholes and 10–15 m high bench is used for moderate to large-scale rock blasting.

In bench blasting, the ratio of the bench height to the burden (H/W) is an important concept—the stiffness of the bench, and it has great influence on the results of blasting (Figure 3-19). When the stiffness of bench, H/W, is large, it is easy to displace and deform rock in front of the blastholes. For example, if H/W < 1, the fragmentation will be bad and the rock body in front of the blastholes, especially in the lower part of the bench, is difficult to be pushed forward and may cause vertical flyrock. If H/W = 1, the fragmentation will be large, with overbreak and toe problems. When H/W = 2, these problems are attenuated, and are completely eliminated when H/W = or >3. Thus, this guideline recommends ratio of the bench height to the burden (H/W)—the stiffness of the bench ranging from 1.6 to 4.0 for bench blasting in any hydropower project of Nepal.

8) Blasting pattern

In bench blasting, there are two types of blasthole patterns, quadrangular pattern (including square and rectangular) as presented in the Figure 3-20 (a), and (b) respectively and staggered pattern as presented in the Figure 3-20(c). The quadrangular pattern is often used in bench blasting. However, the most effective is staggered pattern, especially those drilled on an equilateral triangular grid, as they give optimum distribution of explosive energy in the bench rock, hence result a better fragmentation, especially in hard and integral rock mass.

This guideline recommends some additional small charges (satellite or pocket charges) to be used together with the main blasting charges in two different ways as shown in Figure 3-21 when blasthole pattern is larger than 2.5 × 2.5 m in a hard rock in order to improve bench top fragmentation.

B. Rock parameters

For the estimation of explosive materials, this guideline identifies the rock parameters which has been discussed in Section 3.1.2 in detail.

C. Drilling parameters

For the estimation of explosive materials, this guideline identifies the following drilling parameters.

a) Numbers of charged holes
b) Blasthole diameter (mm)- This guideline recommends the appropriate blasthole diameter ranging from 38 mm to 50 mm as discussed in Section 3.1.6.1A (2).
c) linear Charge Concentration (kg/m) - This guideline recommends the appropriate linear charge concentration as per the stemming requirements as discussed in Section 3.1.6.1 J.

D. Explosive parameters

For the estimation of explosive materials, this guideline identifies the explosive parameters which has been discussed in Section 3.1.3 in detail.

E. Charge Configuration

This guideline recommends three charge configurations for bench blasting namely (1) Continuous Charge (2) Continuous Decking Charges and (3) Isolated Decking Charges as shown in Figure 3-22 and as discussed in the Table 3-21.

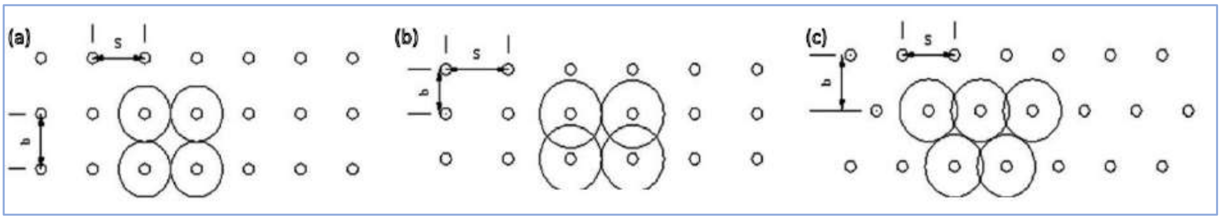


Figure 3-20 Comparison of three types of blasthole patterns: (a) Square Pattern (S=b); (b) Rectangular Pattern (S>b), Staggered (equilateral triangle) Pattern (Source: Zhou, 2017)

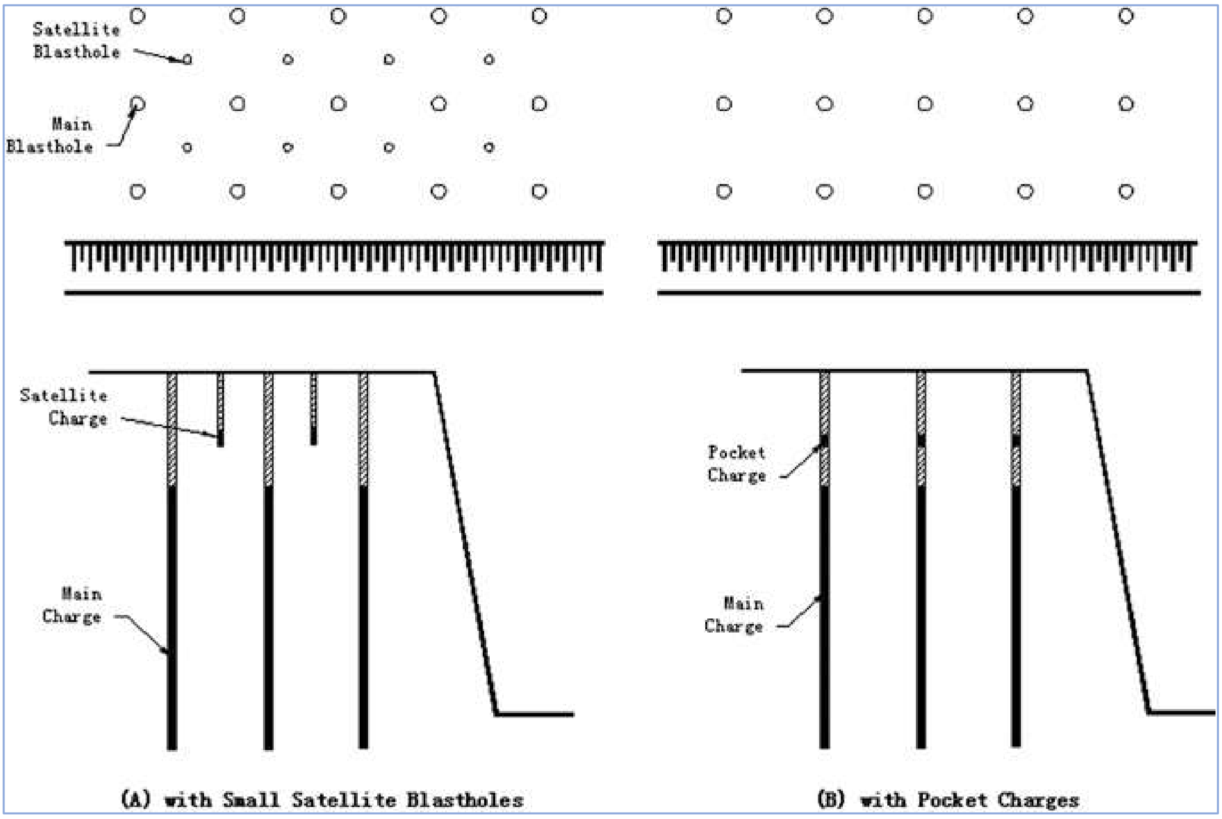


Figure 3-21 Improving bench top fragmentation with additional small charge (Source: Zhou, 2017)

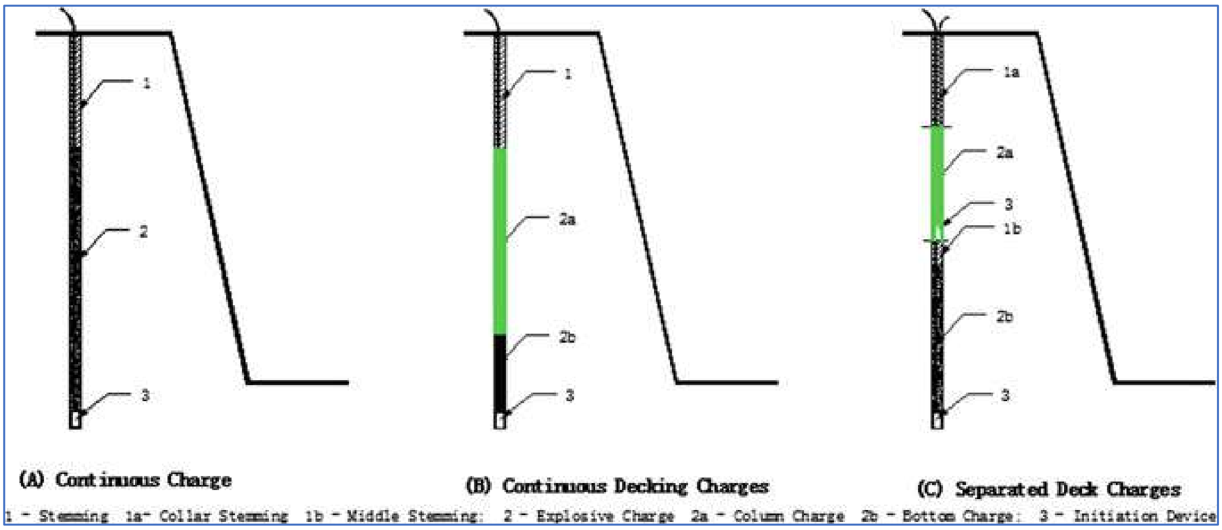


Figure 3-22 Charge Configuration (Source: Zhou, 2017)

F. Firing Method and Firing Sequence

1) Electric Detonator Initiation System

In bench blasting, millisecond delay detonators should be used with multi-row blastholes as it results a better fragmentation, smaller ground vibration, and high productivity. However, this guideline does not recommend the use of electric detonator as mentioned in the Section 3.1.4.1 B. The firing sequence design for drilling and blasting operation with one free face for square and staggered pattern has been presented in Figure 3-23. Similarly, the firing sequence design for drilling and blasting operation with two free faces for square and staggered pattern has been presented in Figure 3-24. The connection of the detonator wires between themselves or to the buswire should be done in accordance with the recommended pattern as presented in Figure 3-25.

Table 3-21 Different types of Charge Configuration

S.N.	Charge Configuration	Definition
1	Continuous Charge	In this configuration, charge is placed continuously in the blasthole
2	Continuous Decking Charges	In this configuration, explosives of different density and strength is placed in the blasthole. This configuration is not recommended by this guideline because of the limitation of bench height (H) as mentioned in Section 3.1.6.1A 7)
3	Isolated Decking Charges	This configuration is usually used in the deep hole bench blasting where the charge configuration of two or three decks which are isolated by a middle section of stemming and have different firing times is often used. The length of middle stemming should be not shorter than 10d. This configuration is not recommended by this guideline because of the limitation of bench height (H) as mentioned in Section 3.1.6.1A 7)

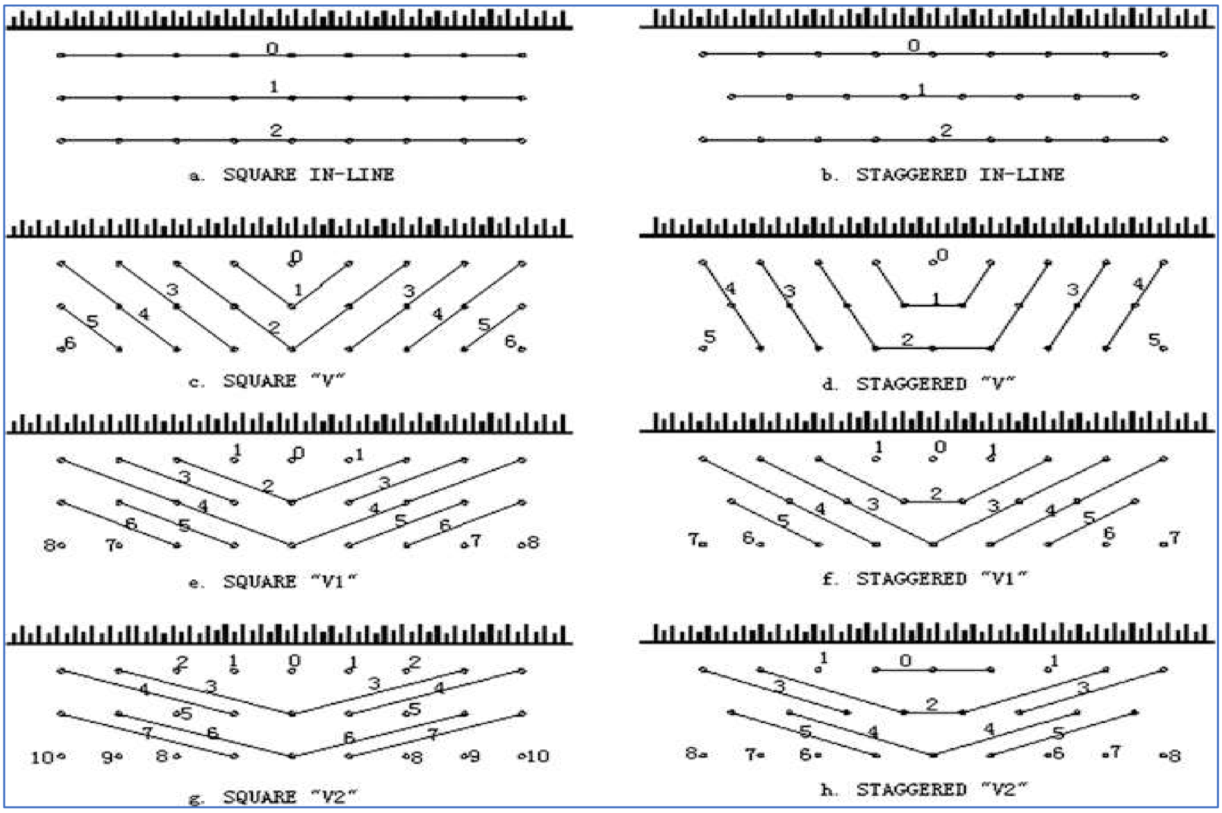


Figure 3-23 Firing sequences for square and staggered pattern with electric MS delay detonators for drilling and blasting operation with one free face (Source: Zhou, 2017)

G. Shock Tube Detonator Initiation System

This guideline recommends the firing circuit of a millisecond delay system of shock tube detonators similar to the electric ms delay detonator which is discussed in above Section 3.1.6.1F1). In order to connect all shock tubes of each blasthole the connector blocks (0 ms delay) as presented in Figure 3-26 (a) or a trunk line of low load detonating cord as presented in Figure 3-26 (b) should be used.

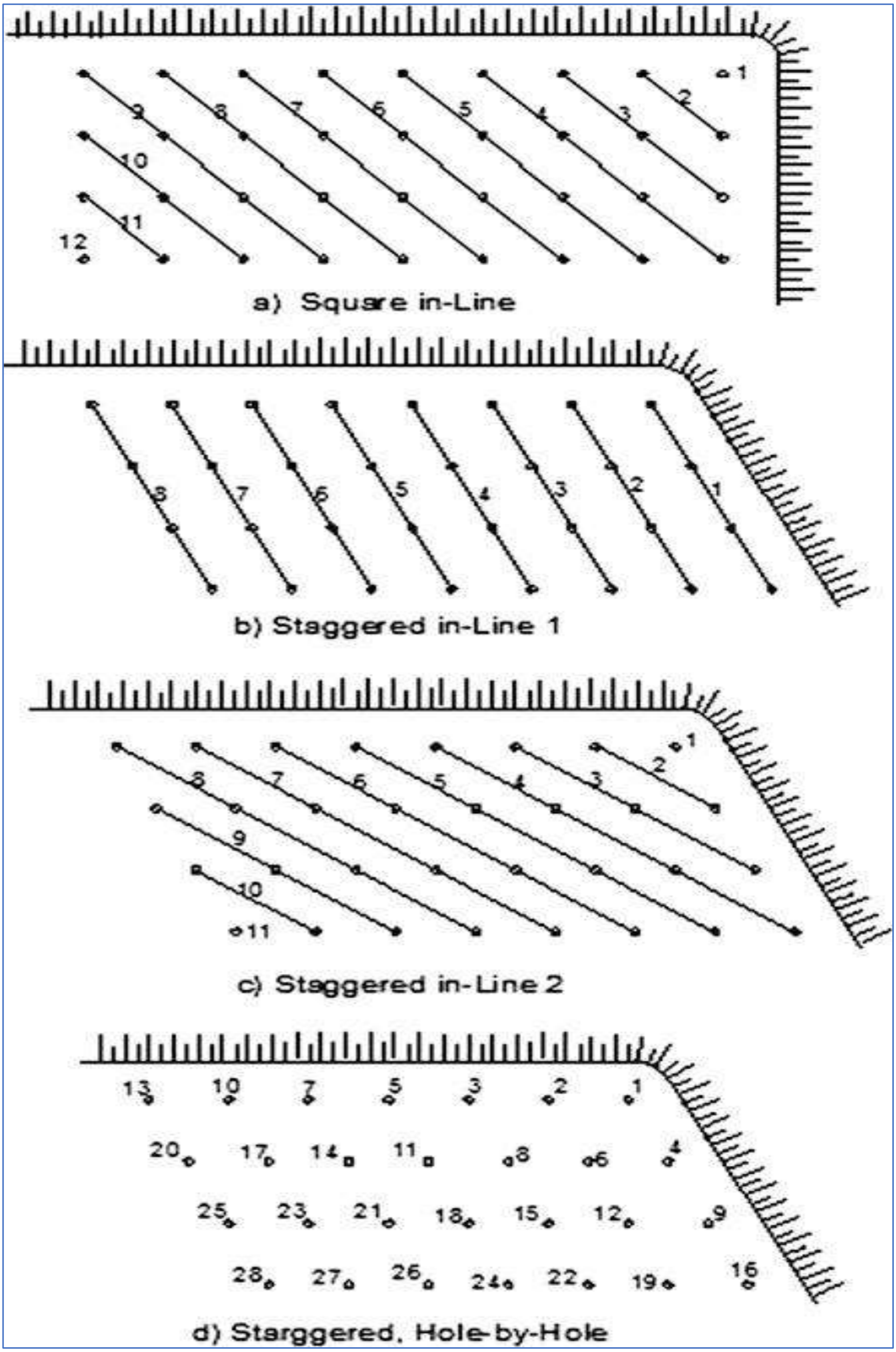


Figure 3-24 Firing sequences for square and staggered pattern with electric MS delay detonators for drilling and blasting operation with one free face (Source: Zhou, 2017)

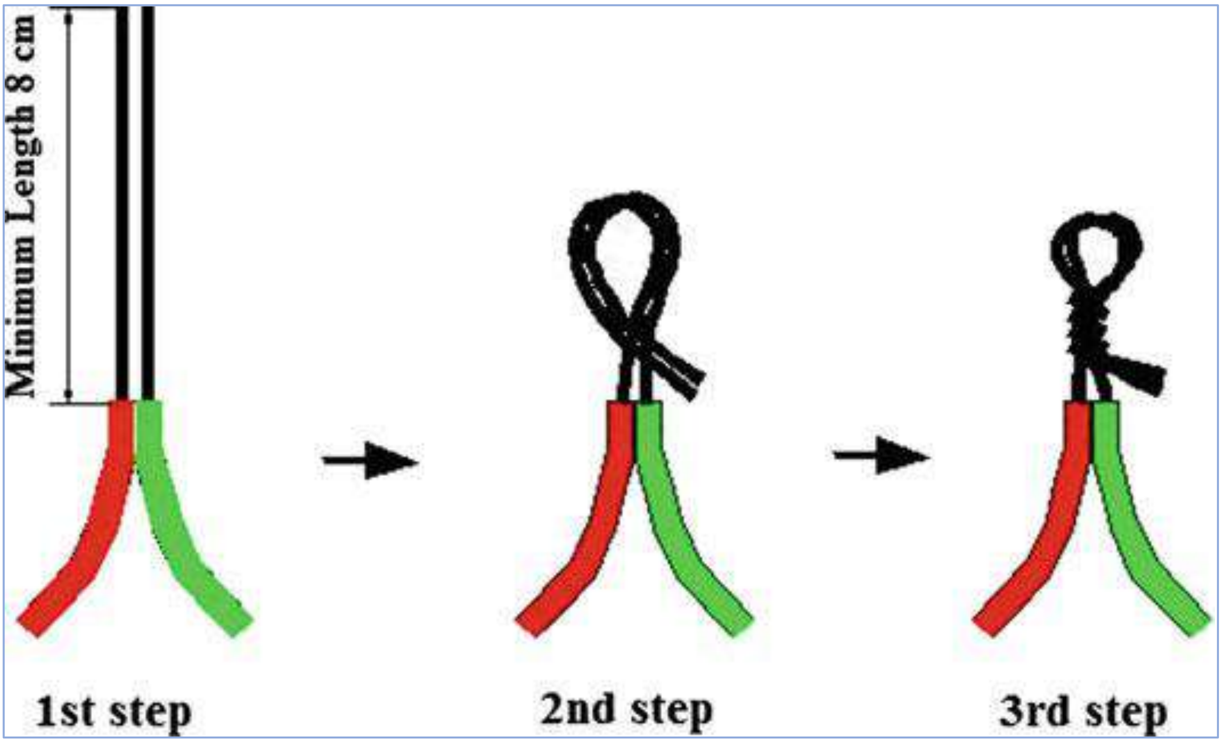


Figure 3-25 Recommended wire splices (Source: Zhou, 2017)

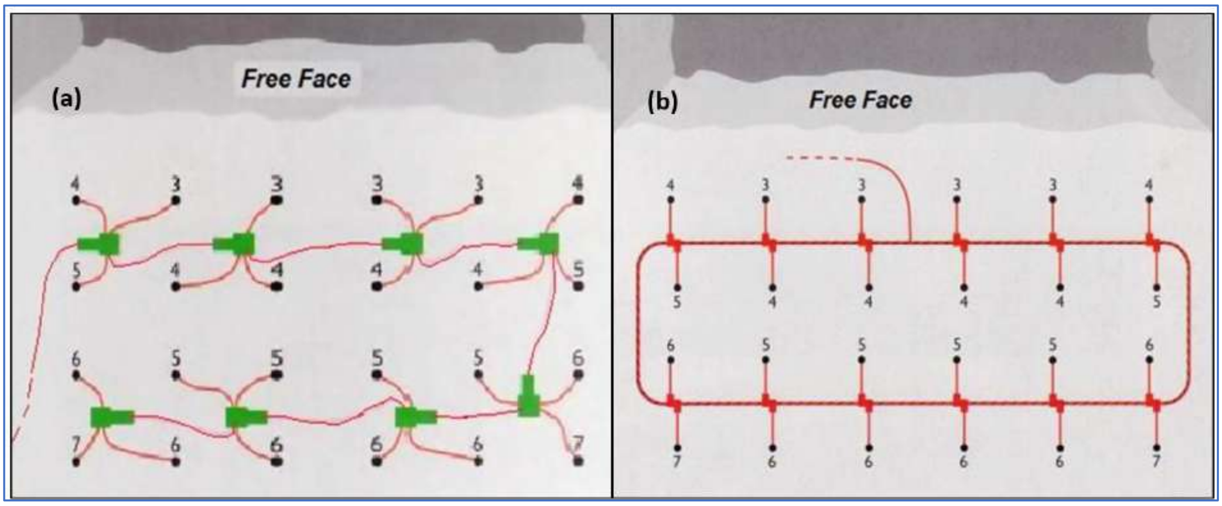


Figure 3-26 Connection using (a) connector (0 ms delay) blocks and (b) detonating cord (Source: Zhou, 2017)

H. Electronic Detonator Firing Sequence Design

This guideline recommends the firing sequence design of electronic detonators is similar to the electric detonators which is discussed in above Section 3.1.6.1F1) and without any surface delays. The number of delay period is almost unlimited from 1 to 20,000 ms, and the delay time should be arbitrarily set at the blasting site with an increment of 1 ms according to the requirement of any given drilling and blasting operation in bench blasting.

I. Delay Timing

A long delay time between rows can offer enough time to move broken rock of the previous fired rows forward to accommodate space for broken rock from subsequent rows. The long delay time also reduces the potential flyrock risk due to the tendency of later firing rows to move upward and the backbreak to the newly formed bench (slope) face. So, this guideline recommends an adequate delay timing as mentioned below.

a) Delay between adjacent holes in a row should be 5.5–8.3 ms/m of spacing of adopted blasting pattern;
b) Delay between rows should be 14–28 ms/m of burden of adopted blasting pattern for medium to hard rocks and a little longer for soft rock.; and
c) Delay between rows should be about 2–3 times of the delay between adjacent holes in a row.

J. Specific Charge (Powder Factor) and Explosive Charging Calculation

Specific Charge (Powder Factor)

Specific charge or powder factor (PF) is defined as the quantity of explosive (in kg) necessary to fragment 1 m^3 of rock, and expressed as kg/m^3. This guideline recommends the unit of specific charge (powder factor) as kg/m^3. Specific charge is one of the important parameters of bench blasting. The specific charge or powder factor varies between 0.12 and 1.37 kg/m^3 for normal bench blasting in various rock type and rock class of different geological units of Nepal Himalaya as presented in Figure 6-1. For the quick assessment of the explosive material estimation for bench blasting, this guideline has developed a powder factor calculation sheet attached in the CD of this guideline.

The value of powder factor is affected by the following factors:

a) Blastability of rock
b) Required fragmentation
c) Swelling and throwing (cast) distance
d) Performance of explosive
e) Distribution of explosive in the blastholes and rock mass
f) Degree of fixation of the rock mass to be blasted

Calculation of Explosive Charging

According to the definition of specific charge or powder factor:

$$PF = Q/V \ kg/m^3$$

Where,

Q is the explosive weight and

V is the solid volume of the rock blasted.

Charge Weight for a Blasthole

For the blast of single row of blastholes or the first row of blastholes of a multiple row blast, the explosive charge of one hole, Q_1, is calculated according to the following formula:

$$Q_1 = q \times S \times W \times H$$

Where,

q = specific charge, in kg/m^3;

S = spacing between two adjacent holes, in m;

W = burden at the toe of the bench face, in m; and

H = height of the bench, in m.

For multiple row blast, the explosive charge weight per hole of all blastholes from the second row is calculated as:

$$Q_2 = k \times q \times S \times b \times H$$

Where,

k = coefficient for considering the resistance of blasted rock of front rows,

k = 1.1–1.2;

b = Distance between rows, in m.

Linear Charge Concentration (L_e)

Linear charge concentration (L_e) is often used in blasting terminology especially when dealing with any type of perimeter blasting. The term loading density is equivalent to linear charge concentration. For a fully coupled charged blasthole, the expression of linear charge concentration Le simply gives the amount of explosive used per 1 m loaded blasthole:

$$L_e = \frac{\pi d^2 \rho_e}{4} \; kg/m$$

Where,

d = blasthole diameter, in m;

ρ_e = loading density (or called degree of packing) of explosive, in kg/m^3

For a decoupling charged blasthole, the expression of linear charge concentration L_e should include a coefficient of decoupling:

$$L_e = k_d \frac{\pi d^2 \rho_e}{4} \; kg/m$$

Where,

k_d = coefficient of decoupling, $k_d = d_e^2/ d^2$;

d_e = the diameter of the explosive column (or cartridge).

3.1.6.2 Boulder Blasting

Boulder blasting refers to the process of using explosives to break apart large rocks or boulders into smaller, more manageable pieces. For the boulder blasting, this guideline recommends to include a site assessment to determine the size and composition of the boulders and develop a blast design in the blasting assessment report as discussed in the Section 3.1.5. Strategic placement of explosives within or around the boulders should be done to create controlled fractures, which allow the boulders to be broken into smaller, more manageable pieces upon detonation. Once blasted, fragmented boulders should be inspected and further broken down using mechanical means if necessary.

For the estimation of explosive materials in boulder blasting, this guideline identifies the parameters and its computation method as mentioned in Section 3.1.6.1.

3.1.6.3 Trench Blasting

Trench blasting is also called ditch blasting. Trench excavation with explosives presents a series of particular characteristics which are different from bench blasting.

A. Blast Hole Pattern And Firing Sequence

1) Blasthole Diameter

This guideline recommends the blasthole diameter ranging from 38 mm to 50 mm for trench blasting which is similar to that of bench blasting and boulder blasting.

2) Drilling Pattern

The drilling patterns of trench blasting depend upon the size of the trench. The holes should be placed in rows with no slope at the sides. When blasting smaller trenches, the hole should have an inclination of 2:1–3:1 (26.5°–18.5° from the vertical) as shown in Figure 3-27. For the larger and longer trench, it is recommended to use vertical holes. Square or rectangular and staggered patterns should be used in trench blasting as presented in the Figure 3-27. If there is no free face for starting trench blasting, some cut holes should be drilled in order to form a free face for trench excavation. Figure 3-28 presents two types of cut-hole patterns for reference. When burn-cut pattern is used, one or more larger uncharged holes should be drilled for relief.

This guideline recommends the following geometrical parameter related to the blasting pattern in trench blasting for general rock conditions.

a) Blasthole diameter (D) ranging from 32 mm to 45 mm for trench depth (L_2) ≤ 1.5 m
b) Burden (W) should be 26D
c) Spacing, (S) = W when trench width < 0.75 m; S = W/2 when trench width = 0.75–1.5 m; S = W/(2–3) when trench width > 1.5 m;
d) Subdrilling (J) = 0.5W with minimum value of 0.2 m;
e) Stemming (T) ≥ W;

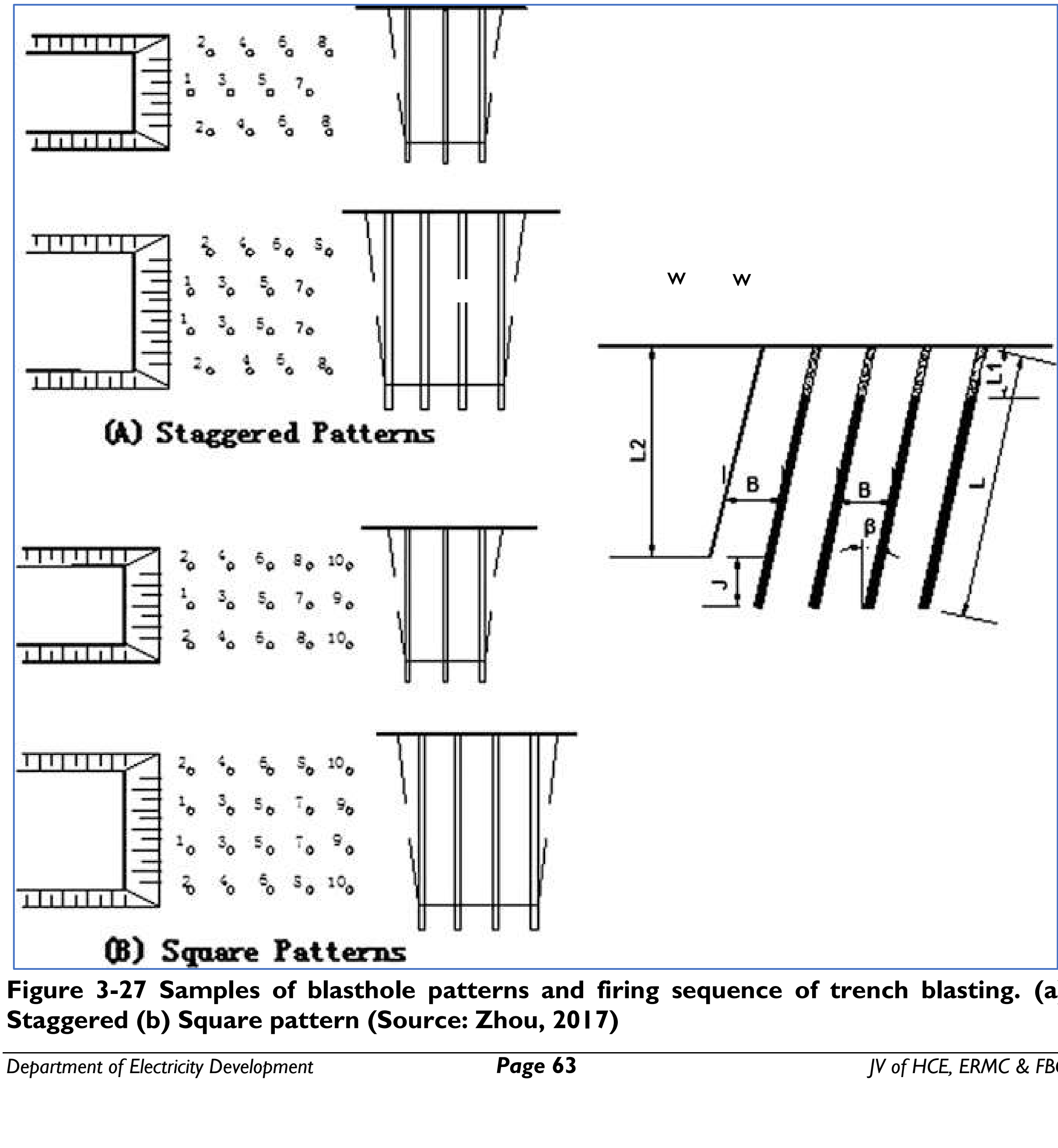


Figure 3-27 Samples of blasthole patterns and firing sequence of trench blasting. (a) Staggered (b) Square pattern (Source: Zhou, 2017)

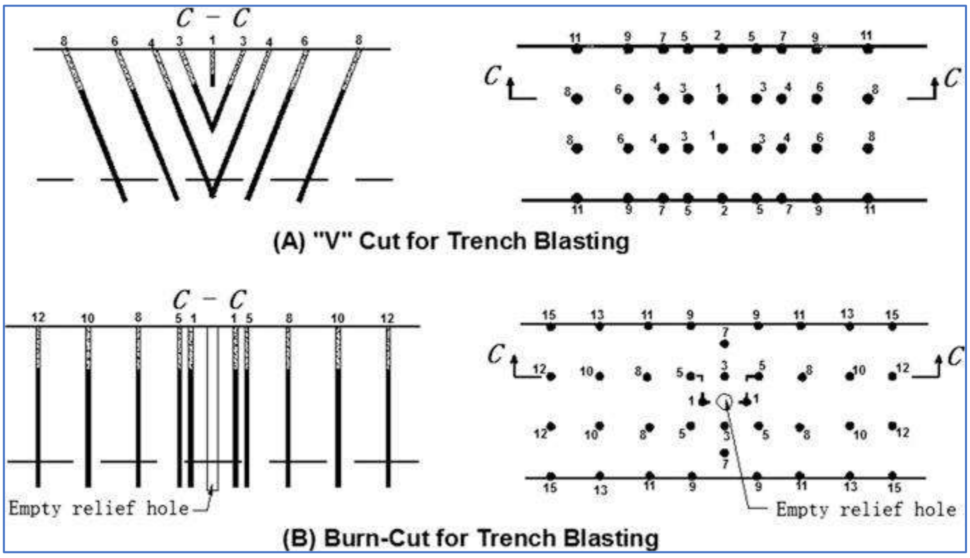


Figure 3-28 Cut-hole types for trench blasting. (A) "V" cut for trench blasting. (B) Burn-cut for trench blasting (Source: Zhou, 2017)

3) Firing Sequence

The firing sequence in trench blasting should be so designed that it can produce a good fragmentation and rock breakage while, at the same time, maintaining overbreak at a minimum. Usually, the millisecond delays electric or shock tube initiation system should be used in trench blasting and the central holes should always be fired earlier than the both sides' holes. Some examples of the firing sequences in trench blasting have been presented in Figure 3-27, Figure 3-28 and Figure 3-29.

4) Explosive Charging

As the rock is more confined in trench blasting, higher powder factors are used than with conventional bench blasting, and drilling patterns are closer. There are two types of trench blasting techniques to be used—the conventional and the controlled (or called smooth wall) techniques. The conventional one applies explosive charging, almost the same for all blastholes. The controlled technique has holes placed in rectangular pattern with the center holes charged more heavily and the side holes charged only lightly (Figure 3-30). If the surrounding environment is not very restricted and allows adequate throw, backbreak and ground vibration, some larger diameter blastholes, such as 50 mm, may be adopted to increase the productivity and reduce the cost. Blasting parameters for trench excavation with conventional blasting method using 50 mm blastholes, blasthole inclination 3:1, and 3 holes per row has been presented in the Table 3-22.

Table 3-22 Blasting parameters for trench excavation with conventional blasting method

No.	Trench depth (m)	Hole length (m)	Burden (m)		Bottom charge (kg/hole) Width of trench bottom (m)		Column charge (kg/hole) (charge concentration: about 0.4 kg/m)
			Maximum	General	1.0	1.5–2.0	
1	0.6	0.9	0.6	0.6	0.15	0.20	
2	1.0	1.4	0.8	0.8	0.20	0.25	0.20
3	1.5	2.0	1.4	1.1	0.30	0.40	0.35
4	2.0	2.5	1.4	1.1	0.40	0.55	0.50
5	2.5	3.1	1.4	1.1	0.50	0.65	0.75
6	3.0	3.6	1.4	1.1	0.60	0.75	0.90
7	3.5	4.1	1.4	1.1	0.75	0.95	1.10
8	4.0	4.6	1.4	1.1	0.9	1.15	1.30

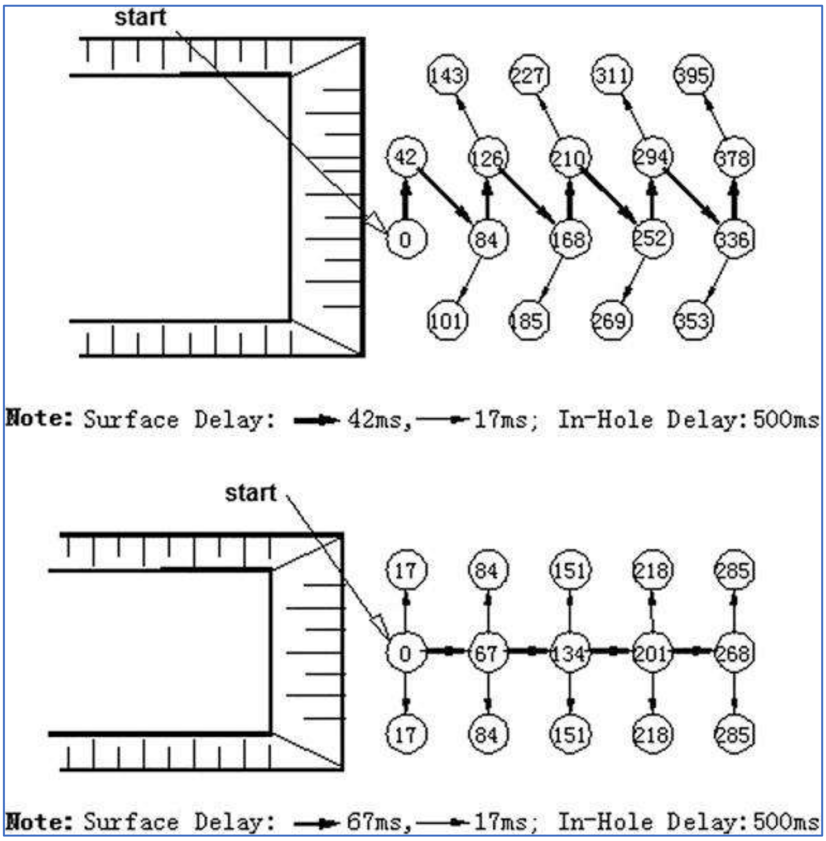


Figure 3-29 Firing sequence of trench blasting with shock tube detonator united system (Source: Zhou, 2017)

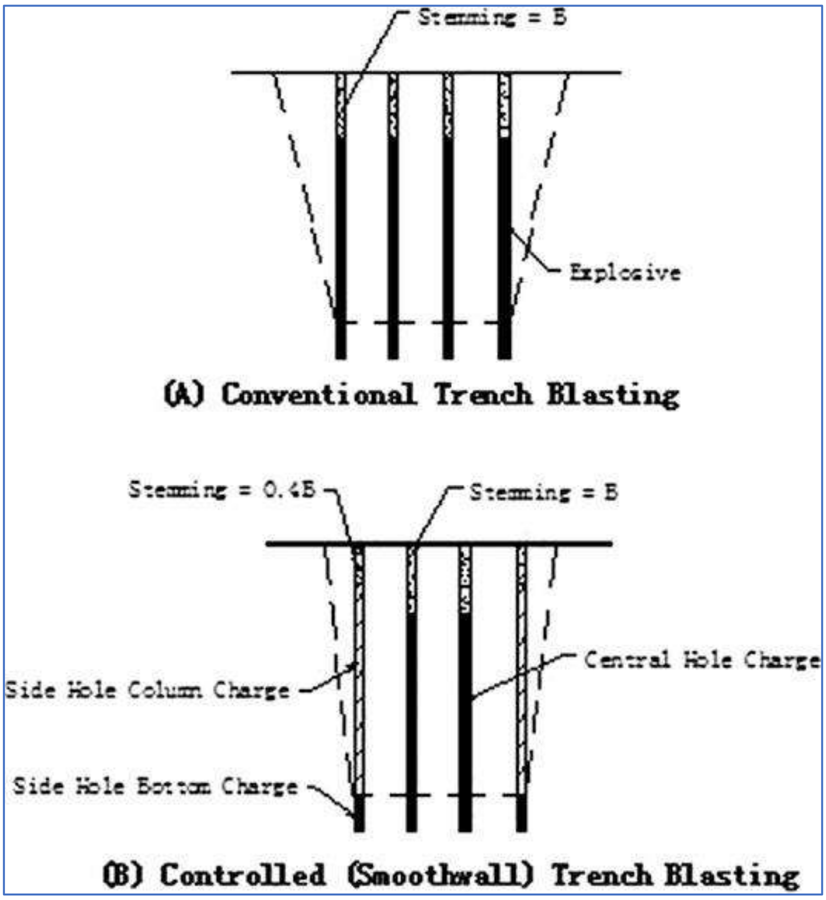


Figure 3-30 Explosive charging method for trench blasting. (A) Conventional trench blasting (B) Controlled Trench Blasting (Source: Zhou, 2017)

3.1.7 Explosive Material Estimation for Underground Excavation

This guideline discusses the estimation of explosive materials for underground excavation in the following sub sections. The details of explosive materials estimation for underground excavation have been discussed in Section 6.2. Similarly, the details of ignition system estimation for underground excavation have been discussed in Section 6.3.

3.1.7.1 Type and Features of Underground Excavation

Based on their function and utilities, underground excavations (tunnels and large openings) can be classified as mentioned in the following Table 3-23.

Table 3-23 Types of underground excavation based on their function and utilities

S.N.	Category	Function and utilities
1	Transportation/conveyance	Peoples and goods
		–Pedestrian and cycle subway
		–Railways and metros
		–Highways
		–Water and sewage
		–Tunnels and canals
		–Hydroelectric power stations
2	Storage and plants	Civilian function
		–Car parks
		–U/g commercial centers
		–Oil and gas storage caverns
		–U/g nuclear power stations
		–Disposal of radioactive waste
		–Military stocks and plants
3	Protection openings	Air raid shelters
		U/G hospitals
		Military shelters
4	Underground mining	

The features of underground excavation or the differences from the surface excavation are mainly as follows:

a) The ground condition surrounding the excavation space, including rock characteristics, geological structures, and stability;
b) For most underground excavation, groundwater is usually a serious problem.
c) Underground excavation is a more complicated and difficult operation than surface excavation because the only free face that initial rock breakage can take place toward is the excavating face. When drilling and blasting method is adopted, because of the high degree of constraints or fixation, larger charges will be required, leading to a considerably larger specific charge than in bench blasting.
d) Although the risk of flyrock to the public is eliminated due to the surrounding rock mass and blasting door at the tunnel portal, other risks, such as toxic fumes generated in blasting, ground settlement during or after excavation, rock fall from the roof and walls of the opening, water

flood when an unexpected water-bearing stratum is broken during excavation, may occur during the operation.

e) In practice, over-break along the planned outline of the excavation occurs after blasting a round. This results in higher cost for supports, more mucking, and generation of cracks in the surrounding rock and exceptionally into roof falls. For reducing the damage to surrounding rock beyond the excavation profile and also achieving a relative smooth surface of the roof and walls, smooth blasting asthe main contour blasting technique is usually used in underground excavations, and for large tunnels or caverns, presplitting may be adopted.

3.1.7.2 Working Cycle of Underground Excavation in a Drilling and Blasting Operation

Drilling and blasting are the most common methods for tunneling and underground excavation. The process begins with holes of predetermined diameter, depth, and spacing being drilled into the rock. Explosives are placed in the holes, and when detonated, the energy generated by the explosive reaction fractures the rock. A typical drilling and blasting cycle consist of following steps as shown in the Figure 3-31. The order of the last two steps may be reversed.

a) Drilling holes in the rock for the placement of explosives,
b) Charging/loading the explosives in the holes drilled,
c) Blasting and ventilation - detonation of the explosives and waiting for the dust and gases generated by the blast to clear,
d) Scaling by removing the loose rock in the crown and sidewalls,
e) Installing temporary support, and
f) Loading and transporting blasted rock (muck).

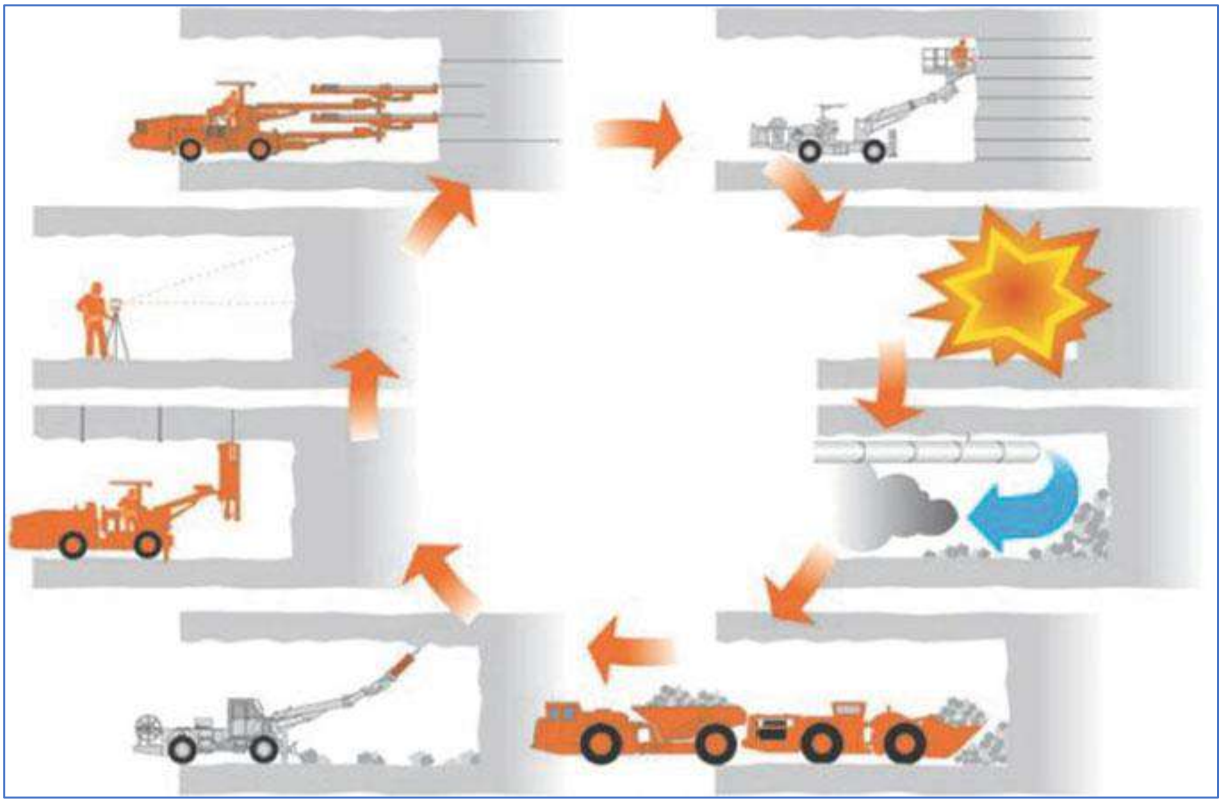


Figure 3-31 Drilling and blasting cycle for underground excavation (Source: Sandvik and Tamrock)

3.1.7.3 Excavation Methods for Tunnel and Caverns

There are mainly two excavation method for the tunnels and caverns namely full-face excavation and partial face excavation.

A. Full-Face Excavation

A full-face excavation should be done when the rock mass quality is good and when there is no limitation on the quantity of explosives discharged in a drilling and blasting operation given by vibration acceptance criteria mentioned in Section 4.2.6. It is normally more economical to excavate full face if the above two conditions permit.

B. Partial Face Excavation

A partial face excavation should be done when the conditions of full-face excavation do not fulfill. The partial excavation methods include top heading and benching, pilot heading, and sidewall drift.

1) Top Heading and Benching

The most common advance heading method is top heading. The crown is excavated before the bench. The temporary support of the crown with rock bolts and shotcrete gives safe working conditions for the excavation of the lower levels of the tunnel or cavern. Bench excavation is cheap because the large free surfaces allow the use of quarrying principles rather than tunneling technology. Bench excavation may be done with vertical drillholes as in a quarrying operation, or with horizontal drillholes for using the same drilling jumbo as the top heading.

2) Pilot Heading

Another method of partial advance is the pilot heading. A smaller pilot tunnel is driven in the top or center of the designed larger tunnel. The pilot tunnel can be driven a certain distance in advance of the whole size tunnel driving or through the entire length of the designed tunnel first before enlarging it. This guideline recommends this excavation method under the complex conditions and where the geological information of the ground along the tunnel alignment is insufficient.

3) Sidewall Drift

Under the condition of weak ground with low strength, sidewall drift method is usually used. The side galleries are excavated and supported first. They serve as abutment for the support of the crown, which is subsequently excavated.

3.1.7.4 Excavation Methods for Shaft

A. Shaft Sinking

Shaft sinking refers to the method of excavating a vertical or near-vertical tunnel from the top-down, where there is initially no access to the bottom. It is one of the most difficult of tunneling due to restricted space, gravity, groundwater, and specialized procedures make the task quite formidable. Shaft dimensions are determined by shaft purpose and geological and rock mechanical conditions. The collar for the head frame is installed after excavation has progressed a short distance. The head frame includes the hoisting system for the shaft sinking equipment. A sinking cycle includes the following operations:

a) Drilling, and blasting;
b) Mucking and hoisting;
c) Support or shaft lining; and
d) Auxiliary operations like dewatering, ventilation, lighting and illumination, and shaft centering.

B. Raise Driving

A raise is a vertical excavation proceeding from a lower elevation to a higher elevation, perhaps from one tunnel to another, or from a tunnel to the ground surface. Raises are one of the important structures in many civil and hydropower projects. Raise driving with drill and blast is classified into two large groups according to the drilling method used, either upward or downward:

a) Upward drilling by hand drill with the compartment method (raise building) , a Jora lift or the Alimak platform.
b) Downward drilling. Long holes with pilot hole cut, crater cut, "VCR" cut (vertical crater retreat), and the full-face method.

3.1.7.5 Explosive Charging

A. Manual Charging

When cartridge explosive is used for underground blasting, manual charging is the most common method. The details of explosive charging have been discussed in the Section 3.3.7.

B. Pneumatic Charging

There are two kinds of pneumatic charging machines: One is for cartridge charging, and another is for charging bulk ANFO. This guideline does not recommend the use of Pneumatic ANFO charging machine. Pneumatic cartridge charging machine was developed in Sweden during the 1950s for preventing the generation of static electricity which may accumulate in sufficient amount to cause premature detonation of the priming charge. These machines allow the charging of blastholes with diameters between 35 and 100 mm, obtaining a 15–20 % increase in loading densities comparing with manual tamping. The details of explosive charging have been discussed in the Section 3.3.7.

3.1.7.6 Blasting design for Underground Excavation

For the estimation of explosive materials using a typical blasting design, this guideline identifies the following parameters and its computation methods.

a) Geometrical parameters related to blasting pattern
b) Rock parameters
c) Drilling parameters
d) Explosive parameters

Based on the above-mentioned parameter, this guideline has adopted a typical blasting design for the estimation of explosive materials and ignition systems for underground excavation. The details of the typical blasting design have been presented in Section 6.2.

In the following sections, the identified parameters are discussed.

A. Geometrical parameters related to blasting pattern

For the underground blasting, the important geometrical parameters related to blasting pattern are mentioned below;

a) Hole layout and firing sequence
b) Cut hole pattern
c) Parallel hole cut design
d) Stoping holes
e) Lifter holes
f) Contour holes
g) Linear charge concentration of blastholes
h) General information on tunnel blasting design

1) **Hole layout and firing sequence**

This guideline recommends to divide the tunnel face into five separate zones, A–E (Figure 3-32) as mentioned for easy illustration of the blasting pattern for tunneling. The general firing sequence must be A > B > C > D > E. The most important operation in the blasting procedure of tunneling should be to create an opening in the face in order to develop another free face in the rock. This is the function of the cut holes. If this stage fails, the given drilling and blasting operation can definitely not be considered a success.

a) A denotes the cut section,
b) B denotes the stoping holes breaking horizontally,
c) C denotes the stoping holes breaking downward,
d) D denotes contour holes, and
e) E denotes the lifter holes.

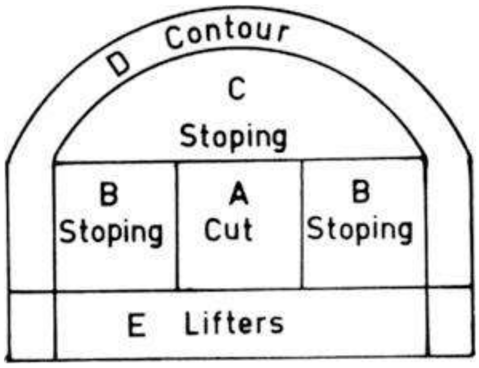


Figure 3-32 Different zones in tunnel blasting (Source: Zhou, 2017)

2) **Cut Holes**

Based on the pattern cut-hole can be classified in two large groups namely angled hole cuts and parallel-hole cuts. The most common angled cuts are V-cuts (Wedge cut) and Fan cut as shown in Figure 3-35 (A) and Figure 3-35 (B) respectively. Similarly, the most common parallel hole cut is burn cut as shown in Figure 3-35. The description, advantage and disadvantages of both angle hole cut and parallel hole cut has been discussed in Table 3-24 for comparison purpose.

As the cut holes are tightly spaced and overloaded, some of the problems that can rise in blasting with parallel-hole cuts are sympathetic detonation and dynamic pressure desensitization as discussed in Section D. Any one of these two problems can cause the cut to "freeze" and fail. The first phenomenon can appear in a hole that is adjacent to the detonating hole when the explosive used has a high degree of sensitivity, such as those with nitroglycerine in their composition. On the other hand, the dynamic pressure desensitization takes place in many explosives, and water-based emulsion or water gel explosives are most susceptible to dead-pressing failure when they are used in closely spaced holes because the shock wave of a charge can elevate the density of the adjacent charge above the critical or death density.

This guideline recommends following measures to be used in order to minimize cut "freezing":

a) Carefully align and drill all cut holes to ensure that they are parallel.
b) Provide more or large uncharged relief holes to accommodate the "swell" of broken rock.
c) Reduce the explosives energy per meter of blasthole in the cut (e.g., use smaller diameter packaged explosives in the cut holes).

d) Alter the geometry and spacing of the cut blastholes and relief holes, to allow for changes in ground conditions.
e) Ensure that blastholes in the cut area fire in a controlled sequence, with adequate time between successive detonations.
f) To pull a drilling and blasting operation deeper than 2.5 m, use parallel-hole cut designs with an adequate volume of uncharged relief holes. In a drilling and blasting operation exceeding 2.5 m, the relief-hole area should be at least 25 % of the total area in the immediate cut.
g) Use long-period delays to ensure that there is sufficient time for the rock from each hole, or group of holes, to break and be ejected from the cut, before subsequent holes fire.
h) Overdrill the cut holes by 15–30 cm (6–12 in.). If this extra drilling for a few holes returns an equal length of advance for the whole face, it is well worth the investment in extra drilling.

3) Stemming

Stemming refers to an inert material that is placed in the borehole between the top of the explosive column and the collar of the hole. Stemming material can consist of sand, drill fines, gravel, or pea stone; sandy clay is usually used. Sometimes, wet cardboard, wet paper, or hessian bags are used as the stemming material, but practice shows they are not effective. This guideline recommends using stemming of crushed rock granular with a blasthole-to-size ratio of 17:1 in thin plastic sausages in tunnel blasting in order to get the best result as the granular rock can "lock" in the blasthole due to its angular shape.

Generally, the amount of stemming material required should range from 0.7W to 1W, where W represents the burden or 10 times of the blasthole diameter (D). Since, the rock characteristics affect the amount of stemming material, it is recommended to use more stemming amount in a highly fractured rock mass.

4) Lookout Angle

To maintain the designed cross section from one round to another, the contour holes should be angled outside the designed cross section. This is to make sure that when drilling is done in the next drilling and blasting operation, there is required space for the rock drill. If the contour holes were drilled parallel to the designed line of the tunnel, the tunnel face would get smaller and smaller after each round. The lookout is depending on the equipment used. For example, modern drilling rigs have electronic or automatic lookout angle indicators that enable correct adjustment of the lookout angle relative to standard alignment and computerized drilling jumbos make setting, adjustment, and monitoring of the lookout angle even easier. Whatever drilling equipment is used in a drilling and blasting operation of a hydropower project in Nepal. This guideline recommends a lookout not less than 0.1–0.2 m as illustrated in the Figure 3-33.

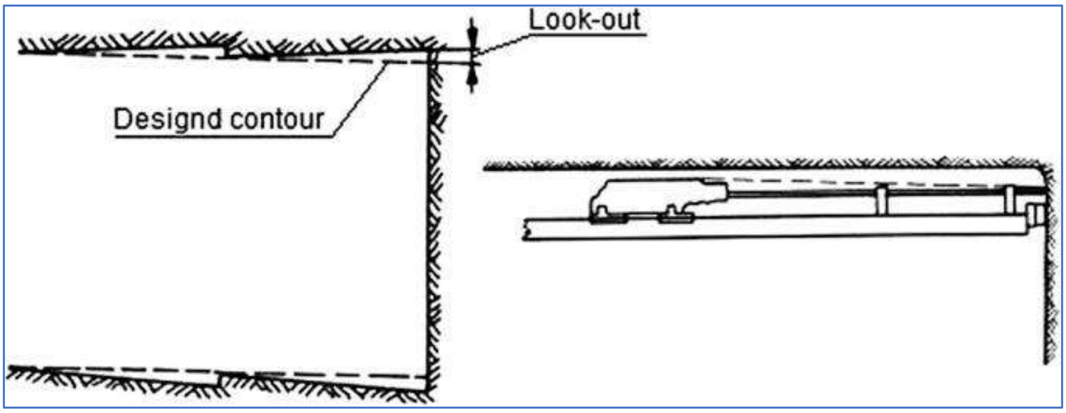


Figure 3-33 The lookout angle in tunnel blasting (Source: Zhou, 2017)

Table 3-24 Comparative table showing advantages and disadvantages of different type of cut holes in tunnel blasting

Type of cut	Description	Advantages	Disadvantages
Angled hole cut (V-Cut and Fan Cut)	The angled hole cut is the old type and is still occasionally used in construction. It is quite an effective type of cut for tunnels with a fairly large cross section, and it requires fewer holes than a parallel cut.	lower drilling length and explosive consumption than the parallel cut because there is better utilization of the free face surface and the possibility of orientation toward the visible discontinuities in the section	The angle at the bottom of the cut holes should not be less than 60°. Maintaining the right angle is the main difficulty in V-cut drilling
	It has lost some of its popularity with the widespread adoption of the parallel cut and longer rounds.		Tunnel width limits the use of the V-cut. In narrow tunnels, the advance per round can be less than one-third of the tunnel width.
	However, it is still commonly used in wide tunnels where the tunnel width sets no limitations on drilling.		t its biggest disadvantage is that it ejects rock violently, the rock is thrown a considerable distance resulting in services being destroyed, e.g., ventilation, power, air, and communications, and its use is banned in some places.
	The most common angled cuts are V-cuts (Wedge cut) and Fan cut as shown in Figure 3-33 (A) and Figure 3-33 (B) respectively.		
Parallel Hole Cut (Burn Cut)	Parallel-hole cuts are also called cylindrical cuts. The characteristic for this cut is that the drillholes are the same length and obviously parallel to each other.	The depth of the round is not dependent on the working space available for drilling holes at an angle.	If large relief holes are used, it requires reaming or larger drilling equipment.
		The cut allows a deep pull even in tough rock formations.	
	At the moment, this type of cut is the most frequently used in tunneling and cavern blasting, regardless of their dimensions.	It is relatively simple to drill, because all holes are parallel.	Drilling and explosives requirements (powder factor) are higher.
		There is generally less throw with better fragmentation.	
	This type of cut consists of one or several uncharged or relief blastholes toward which the charged holes break at intervals.	The resultant muckpile is higher, so it provides a better platform for scaling and bolting work.	Drilling must be accurate; otherwise, the results will be unfavorable.
		Round length may be shortened or lengthened without any difficulties.	

5) Parallel-Hole Cut Design

The parallel-hole cut has a large number of minor variations, but the basic layout always involves the drilling of one or several uncharged large diameter holes at or very near the center of the cut. These holes give empty space for the adjacent blasted holes to swell into. As the drilling equipment has become more and more powerful, this type of cut has become more and more used. This guideline recommends large diameter holes (65–175 mm) to be drilled with reamer bits. The parallel hole cut design parameters have been discussed in Table 3-25.

In order to reach an opening enough for stoping hole blasting, some cut spreader holes should be provided. For the convenience of arranging these spreader holes around the cut holes, a number of quadrants are arranged (Figure 3-36). Four-section cut is an empirical method for blasting design in underground excavations and tunnels. This method has often been used for excavating tunnels with cross-sectional area of more than 10 m². This guideline recommends the calculation of the parallel hole cut design parameters presented in Table 3-25 based on the experimental equation proposed by agnefors and Kihlström in 1978.

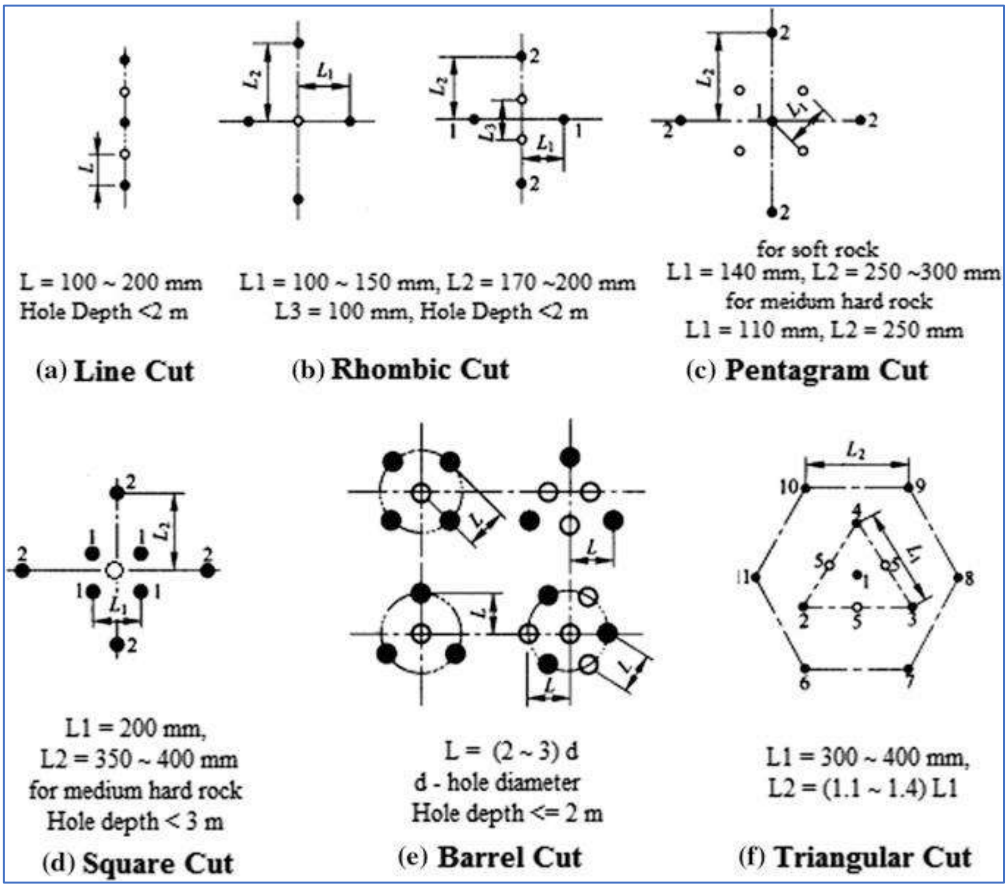


Figure 3-34 Examples of burn cut (Source: Zhou, 2017)

Table 3-25 Design parameters for parallel hole cut

S.N.	Parallel hole cut design parameters		Formula	Remarks
1	Large hole diameter		$d_f \approx (3.2 \times l)^2$	Where, d_f = equivalent hole diameter, in mm, l= Blasthole depth in m, n = number of large hole, B = Burden, X = Spacing, S= Stemming
2	Large hole number		$d_l = \frac{d_f}{\sqrt{n}}$	
3	Burden of cut holes	First Square Cut	$B_1 = 1.5 d_f$	
		Second Square Cut	$B_2 = B_1\sqrt{2}$	
		Third Square Cut	$B_3 = 1.5\ B_2\sqrt{2}$	
		Fourth Square Cut	$B_4 = 1.5\ B_3\sqrt{2}$	
4	Spacing of cut holes	First Square Cut	$X_1 = B_1\sqrt{2}$	
		Second Square Cut	$X_2 = B_2\sqrt{2}$	
		Third Square Cut	$X_3 = B_3\sqrt{2}$	
		Fourth Square Cut	$X_4 = B_4\sqrt{2}$	
5	Stemming of cut holes	First Square Cut	$S_{t1} = B_1$	
		Second Square Cut	$S_{t2} = B_1\frac{\sqrt{2}}{2}$	
		Third Square Cut	$S_{t3} = \frac{\sqrt{2}}{2}(B_1\frac{\sqrt{2}}{2}+B_2)+B_3$	
		Fourth Square Cut	$S_{t4} = \frac{\sqrt{2}}{2}(\frac{\sqrt{2}}{2}(B_1\frac{\sqrt{2}}{2}+B_2)+B_3)+B_4$	

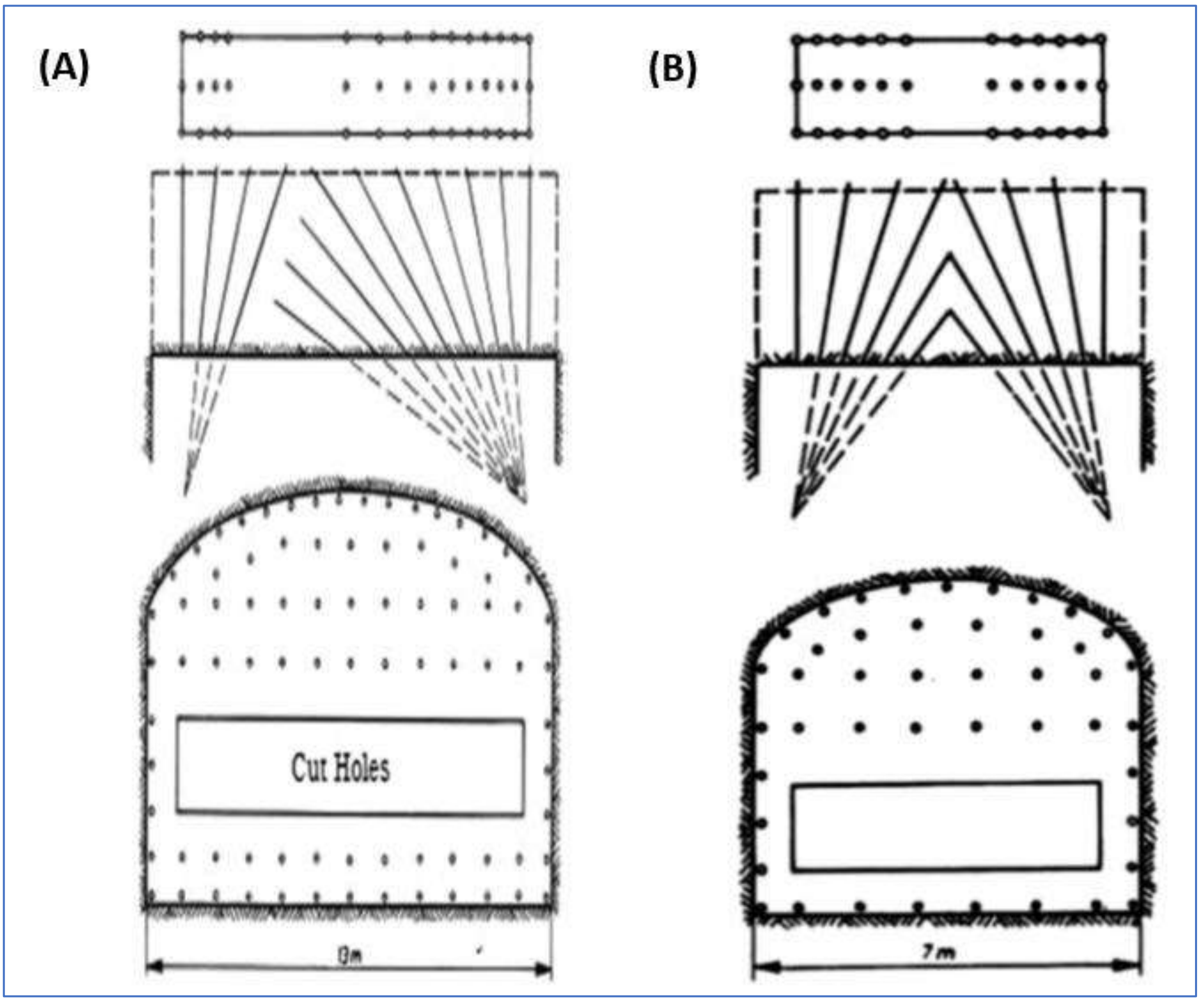


Figure 3-35 Types of angled cut holes; (A) V-Cut and (B) Fan Cut (Source: Zhou, 2017)

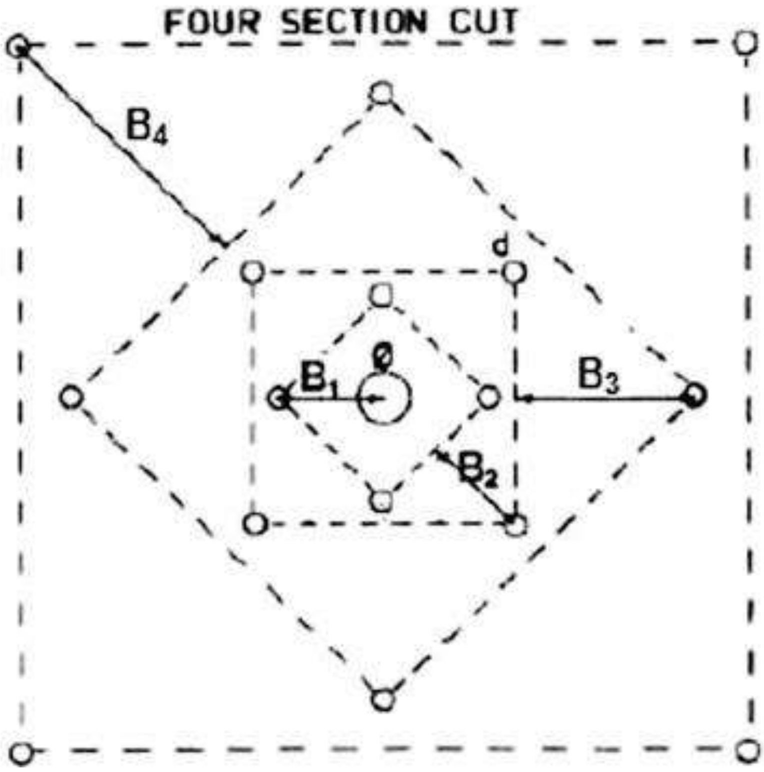


Figure 3-36 Four section cut design for parallel cut holes (Source: Zhou, 2017)

6) Stoping Holes

The object of the cut is to create a free surface toward which the rest of the blasting can be carried out. The purpose of stoping holes is to attain just as large an advance with the remainder of the round as created by the cut holes, to get a satisfactory fragmentation, and to get a suitable disposal of the broken rock. At the same time, the remaining rock face should also be left undamaged.

In this guideline, the blasting pattern of the stoping holes has been defined by the burden (W) - distance from the nearest cut hole and extension (B) – distance between the two stoping holes as presented in the Figure 3-37 Schematic diagram showing the measurement of burden and extension for stopping hole pattern for reference. This guideline recommends the burden (W) ranging from 100 mm to 500 mm as well as extension (B) ranging from 100 mm to 500 mm in any drilling and blasting operation of a hydropower project. It is recommended that during the preparation of the blasting pattern of the stoping holes, the value of extension (B) should not be greater than the value of burden (W).

The best way to decide the place of stoping holes is using the principle of rectangularity. Figure 3-38 Placement of stoping hole in a pattern (a) by not using the principle of rectangularity (b) by using the principle of rectangularity. This guideline recommends the stoping hole pattern by using the principle of rectangularity as shown in Figure 3-38 (b) and completely avoid stoping hole pattern by not using the principle of rectangularity as shown in Figure 3-38 (a).

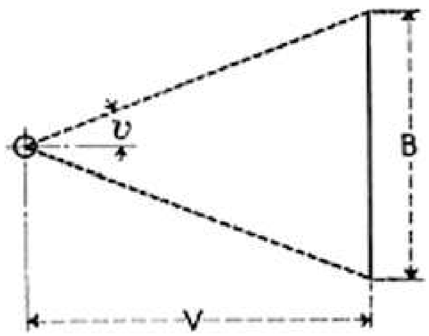


Figure 3-37 Schematic diagram showing the measurement of burden and extension for stopping hole pattern (Source: Zhou, 2017)

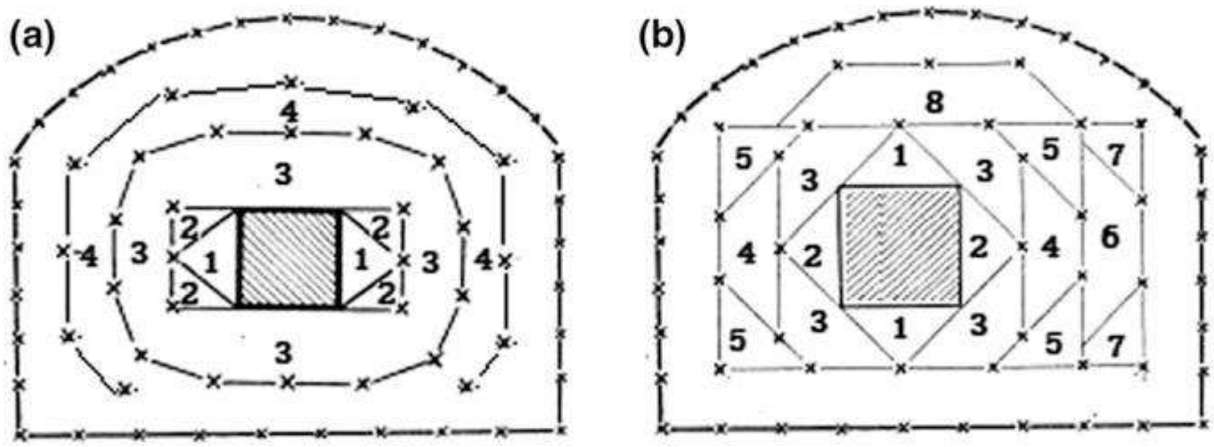


Figure 3-38 Placement of stoping hole in a pattern (a) by not using the principle of rectangularity (b) by using the principle of rectangularity (Source: Zhou, 2017)

7) Lifter Holes

This guideline recommends the calculation of the burden for the lifter holes same as the burden calculation done in the bench blasting by just taking the advance of the tunnel as the height of the bench height (Refer to Section 3.1.6.1). The stemming (T) should be fixed in T=10×D where, D is a blasthole diameter. The number of the lifter holes should be calculated by using the formula below and the notation in the formula has been illustrated in the Figure 3-39:

$$NB = integer\ of\ \left(\frac{B + 2L \times \sin\gamma}{B} + 2\right)$$

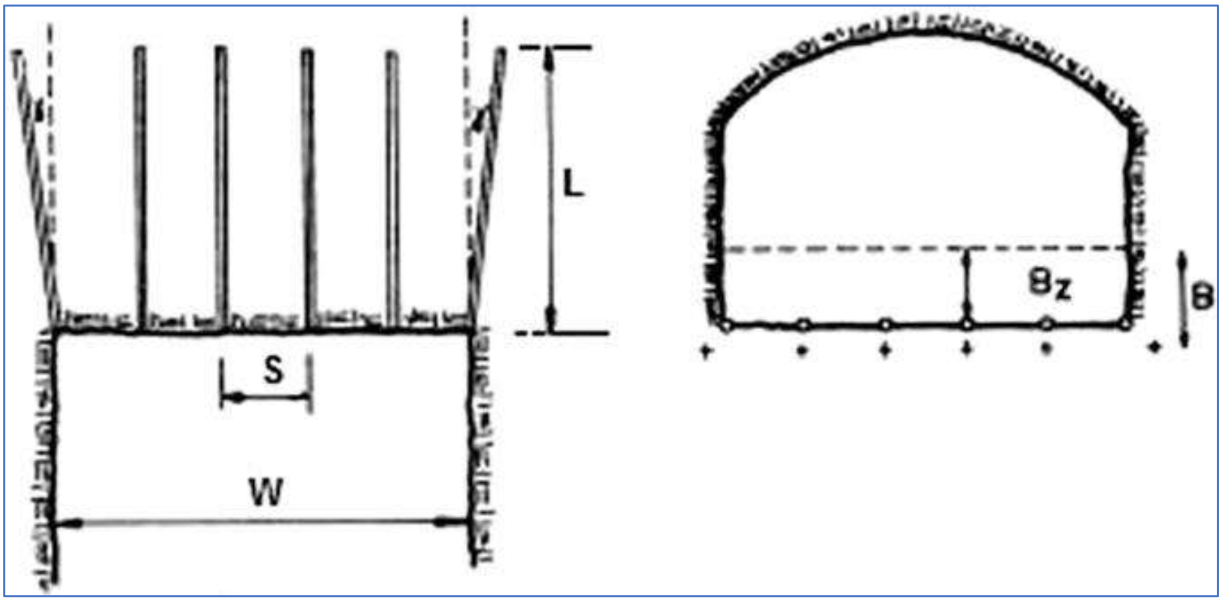


Figure 3-39 Geometry of the lifter holes (Source: Zhou, 2017)

8) Contour holes

The contour holes, also called perimeter holes, of tunnel blasting, especially the roof holes, are usually blasted using the smooth blasting method. If the blast does not need contour or smooth blasting, this guideline recommends that the calculation of the parameters should be calculated same as the parameter calculation of lifters holes as mentioned in the above sections with the with the following values.

a) fixation factor, f = 1.2;
b) S/B = 1.25;
c) column charge concentration, qc = 0.5qf, where qf is the bottom charge concentration.

9) Lineal Charge Concentration of Blasthole

For quick design of the drilling and blasting pattern in tunnel blasting, this guideline recommends the calculation of lineal charge concentration presented in the Table 3-26 for every type of blast holes presented in Figure 3-32 except for stoping holes. The recommended calculation of lineal charge concentration for stoping holes has been presented in Table 3-27.

B. Powder factor calculation

Specific charge or powder factor (PF) is defined as the quantity of explosive (in kg) necessary to fragment 1 m3 of rock, and expressed as kg/m3. This guideline recommends the unit of specific charge (powder factor) as kg/m3. Specific charge is one of the important parameters of tunnel blasting. The specific charge or powder factor for tunnel blasting in various rock type and rock class of different geological units of Nepal Himalaya as presented in Figure 6-11 and Table 6-9. For the quick assessment of the explosive material estimation for tunnel blasting, this guideline has developed a powder factor calculation sheet attached in the CD of this guideline. The powder factor versus cross-sectional area of the underground excavation prepared by ICI Australia Operations Pty Ltd (1980) has been presented in Figure 3-40 for reference.

Table 3-26 Lineal charge concentration for different types of blasthole in tunnel blasting (except stopping holes)

Type of blastholes	Burden (m)	Spacing (m)	Length of bottom charge (m)	Charge concentration (kg/m)		Stemming (m)
				Bottom	Column	
Lifters	*B*	1.1*B*	*L*/3	q_f	q_f	0.2*B*
Wall*	0.9*B*	1.1*B*	*L*/6	q_f	0.4q_f	0.5*B*
Roof*	0.9*B*	1.1*B*	*L*/6	q_f	0.36q_f	0.5*B*
Upwards	*B*	1.1*B*	*L*/3	q_f	0.5q_f	0.5*B*
Horizontal	*B*	1.1*B*	*L*/3	q_f	0.5q_f	0.5*B*
Downwards	*B*	1.2*B*	*L*/3	q_f	0.5q_f	0.5*B*

Table 3-27 Lineal charge concentration for stoping holes in tunnel blasting

Max. burden (V)	Extension (B) in m`						
	0.25	0.3	0.35	0.4	0.5	0.6	0.8
m	**Concentration of the charge, kg/m**						
0.25	0.3	0.26	0.22	0.18			
0.3	0.5	0.35	0.31	0.26	0.22	0.18	
0.35	0.65	0.45	0.4	0.35	0.3	0.25	
0.4	0.9	0.7	0.6	0.5	0.4	0.3	0.24
0.5	1.6	1.3	1	0.7	0.6	0.5	0.36
0.6	2.2	1.9	1.6	1.3	1	0.7	0.52
0.7		2.5	2.2	1.8	1.3	0.9	0.7
0.8			3.2	2.4	1.8	1.4	1

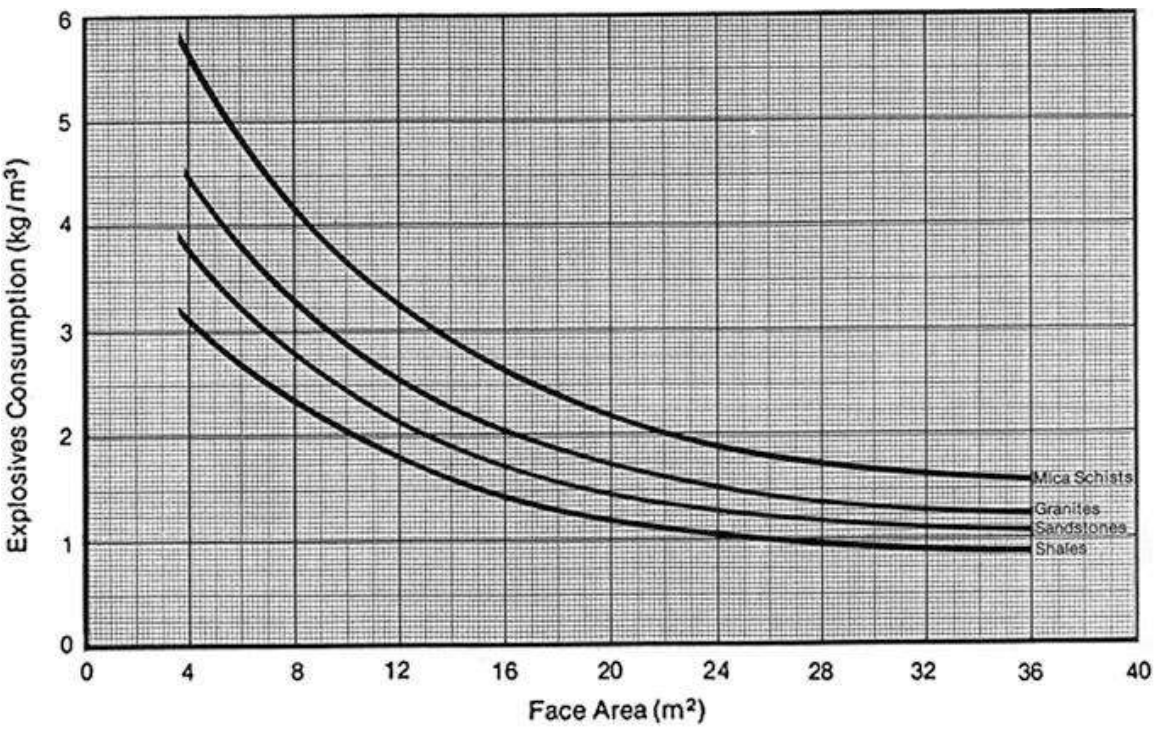


Figure 3-40 The powder factor versus cross sectional area of the underground excavation prepared by ICI Australia Operations Pty Ltd (1980)

C. Firing Sequence Designing For Underground Blasting

As there is only one free face in underground blasting (excluding benching), the blastholes should be fired in a certain sequence. The firing pattern must be designed so that each hole has free breakage. The angle of breakage is smallest in the cut area where it should be around 50°. In the stoping area, the firing pattern should be designed so that the angle of breakage does not fall below 90° (Figure 3-41). It is important in tunnel blasting to have a long enough time delay between the holes. In the cut area, it must be long enough to allow time for breakage and rock throw through the narrow empty hole.

It has been proven that the rock moves with a velocity of 40–70 m/s. A cut drilled to a depth 4–5 m would therefore require a delay time of 60–100 ms to be clean blasted. Normally, delay times of 75–100 ms are used. In the first two squares of the cut, only one detonator for each delay should be used. In the following 2 squares, two detonators may be used. In the stoping area, the delay must be long enough for the rock movement. Normally, the delay time is 100–500 ms. For contour holes, the scatter in delay between the holes should be as small as possible to obtain a good smooth blasting effect.

The general firing sequence is as follows:

For tunnel (cavern): Cut holes → Cut spreader holes → Stoping holes → Wall holes → Roof contour holes → Lifter holes.

For shaft: Cut holes → Cut spreader holes → Stoping holes → Wall contour holes.

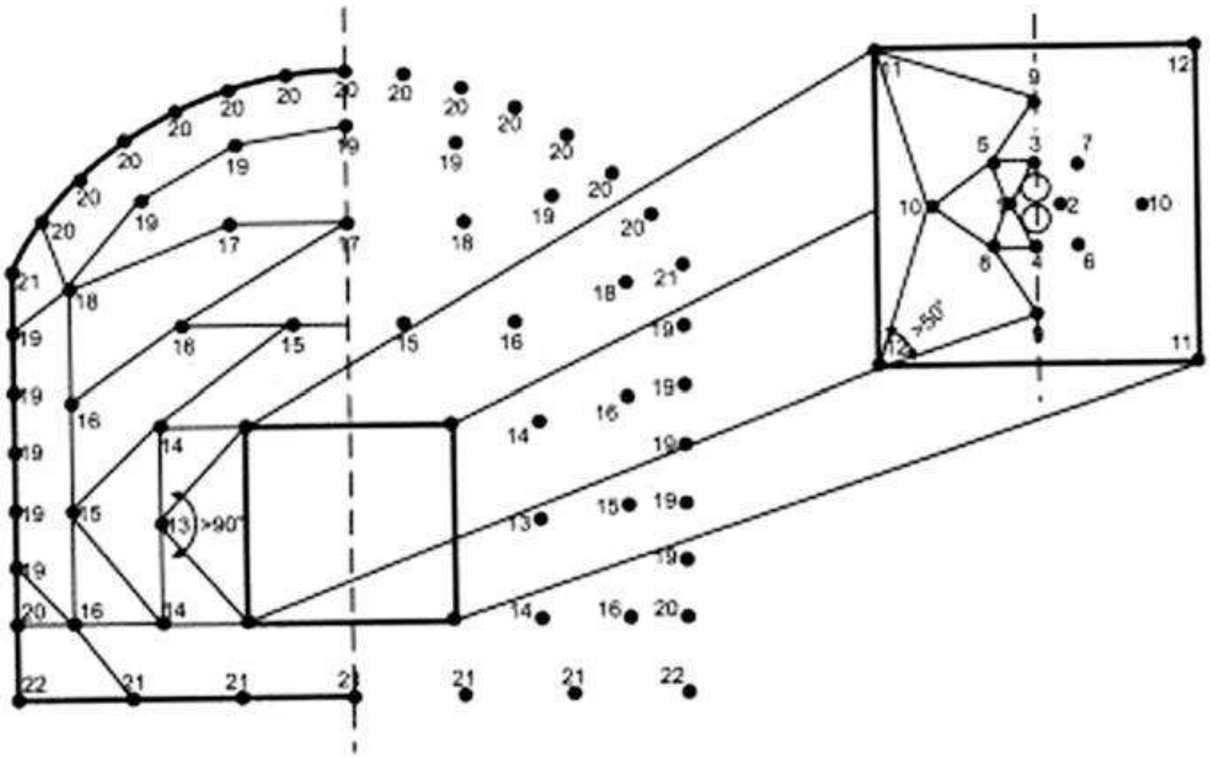


Figure 3-41 Firing sequence in a numerical order for tunnel blasting (Source: Zhou, 2017)

This guideline recommends some important principles that must be kept in mind when designing the firing sequence:

a. The firing sequence must start from the central cut holes and then progress outward to the tunnel contour gradually.
b. The minimal time interval of two adjacent holes must be no less than 25 ms, especially in shaft blasting with wet holes to avoid the "water hammer effect."

c. For the large tunnel or cavern, the blastholes on the working face should be divided into several groups. The shock tubes of all holes in each group should be bunched together and connected with a surface delay connector.

d. The delay time of the first firing in-hole detonator must longer than the longest delay time among all surface detonators; otherwise, the first fired blasthole will damage the initiation net for the tunnel blasting.

e. If there is a restriction of ground vibration, the maximum explosive charge weight per delay of any simultaneously fired holes must be no greater than the allowable charge weight per delay.

3.1.8 Recommended Technical Specification of All Explosive Materials (Blasting Agents and Methods)

This guideline recommends the technical specification of the explosives materials as mentioned in the following Table 3-11

Table 3-28 Recommended technical specification of the explosive materials and initiation systems.

S.N.	Explosive Parameters		Recommended Range
1	Density		1.1 - 1.27 g/cc
2	Velocity of Detonation (VOD)		3400 - 5500 m/s
3	Relative weight strength		105 - 130 %
4	Relative bulk strength	*to ANFO@ 0.8 g/cc*	156 - 183%
		to ANFO@ 0.95 g/cc	139 - 206%
5	Detonation pressure		6900 - 13200 MPa
6	Energy (KJ/kg)		2720 - 4700
7	Waterproof		Excellent - Very good
8	Gas volume (L/kg)		708- 997
9	Shelf life (after DoM)		Up to 1 year
S.N.	**Initiation System Parameters**		**Recommended Range**
1	Plain Detonators and Safety Fuses		Not recommended as an initiation system in drilling and blasting operation for hydropower project in Nepal.
2	Electric detonator	Millisecond delay detonators	with 20 - 30 delay numbers
		Long-period delay detonators	delay series of 1/4 s delay (or 200 ms delay), half second delay, and second delay
		Coal mines delay detonators	Not recommended as a initiation system in drilling and blasting operation for hydropower project in Nepal.
3	Non electric detonator	Millisecond delay system	delay time of 25 ms between each interval
		Long-period delay system	delay time ranging from 100 to 1000 ms between each interval
		Unidet system	delay time ranging from 0 to 200 ms between each interval
4	Electronic detonators		delay time ranging from 1 to 10000 ms between each interval
5	Detonating Cord	Core load (g/m)	1.5 - 10
		Outside diameter (mm)	2.8 - 7.6
		Tensile strength (kgf)	68 - 90.7
		VOD (m/s)	6500 - 7000
		Core explosive	PETN

3.2 Explosive Material Usage

For maintaining the proper usage of the explosive material, the hydropower project must devise a Daily Blasting Work Sheet. For this purpose, this guideline recommends a typical work sheet for every drilling and blasting operation in a hydropower project as presented in the Table 3-29. Similarly, this guideline recommends a typical format of record keeping of the data related to the drilling and blasting operations as presented in the Table 3-30 for reference.

There is currently a provision to provide monthly explosive material usage to the Nepal Army by the concerned hydropower project. Similarly, there is provision to provide the explosive material usage to the respective CDO in every 3 months duration. This guideline recommends to provide the explosive material usage in every 3 months duration notarized by the Nepal Army to DoED by including it in the regular trimonthly progress report which need to be submitted by every hydropower projects. However, the hydropower project must submit the explosive material usage record in the request application for procurement of explosive materials if additional explosive materials is required to complete the construction of hydropower project due to any reasons.

Table 3-29 A typical daily blasting work sheet recommended by this guideline

Typical Daily Blasting Work Sheet						
Name of the Hydropower Project:						
Chainage:						
Location:			Blast Time:		Date:	
S.N.	Description		Dispatch Quantity	Used	Remaining	Remarks
1	Explosives	25 mm				
		32 mm				
		40 mm				
		70 mm				
2	Detonating Cord					
3	Detonator					
4	Safety Fuse					
5	Electric Detonator					
a	#0					
b	#1					
c	#2					
d	#3					
e	#4					
f	#5					
g	#6					
h	#7					
i	#8					
j	#9					
k	#10					
6	Non-Electric Detonator					
a	25 ms					
b	50 ms					
c	75 ms					
d	100 ms					
e	125 ms					
f	150 ms					
g	175 ms					
h	200 ms					
i	225 ms					
j	250 ms					
k	275 ms					
l	300 ms					
m	325 ms					
n	350 ms					
o	375 ms					
p	400 ms					
q	425 ms					

Typical Daily Blasting Work Sheet					
Name of the Hydropower Project:					
Chainage:					
Location:		Blast Time:		Date:	
S.N.	Description	Dispatch Quantity	Used	Remaining	Remarks
r	450 ms				
s	475 ms				
t	500 ms				
u	525 ms				
v	550 ms				
w	575 ms				
x	600 ms				
	Total				
Civil Sub-Contractor		Blaster		Contractor	
Name:		Name:		Name:	
Designation:		Designation:		Designation:	
Signature:		Signature:		Signature:	
Nepal Army		Nepal Police		Owner Engineer	
Name:		Name:		Name:	
Designation:		Designation:		Designation:	
Signature:		Signature:		Signature:	

Table 3-30 A typical format of record keeping of the data related to the drilling and blasting operations

				Rock Class						**Excavation Dimension**								**Excavation Volume**							
										Rectangular		**Circular**	**D-Shaped**												
Project Name	**Project Component**	**Chainage**	**Stratigraphic Unit**	**RQD**	**Q-Value**	**Class**	**RMR**	**Class**	**Rock Type**	**Tunnel Height (m)**	**Tunnel Width (m)**	**Tunnel Diameter (m)**	**Tunnel Width (m)**	**Height of arc (m)**	**Cross-section m²**	**Drill Length**	**Pull Length**	**Projected**	**Actual**	**Total Explosive Consumption**	**Powder Factor (kg/m3)**	**Detonators (nos)**	**Detonators Nos/unit Kg explosive**	**Detonating Cord (m)**	**Detonating cord (m) per Kg of explosives**

3.3 Explosive Material Handling

Handling explosive materials requires careful planning, specialized knowledge, and adherence to strict safety protocols to prevent accidents and ensure the safety of personnel and property. Specific handling procedures must be followed to minimize the risk of accidents. This includes various activities such as proper packaging, labeling, and securing of explosive materials during storage, transportation, and usage. This section discusses about overall handling of explosive materials which requires meticulous attention to detail, rigorous safety protocols, and ongoing training and oversight to ensure the safety of both.

3.3.1 Responsibilities of Authorized Person regarding different activities associated with explosive material handling

All the personnel associated with the explosive material handling should strictly follow all the provisions mentioned in the Explosive Act (2018) and the Explosive Regulation (2020) of Nepal. This guideline recommends the overall responsibilities of authorized personnel regarding different activities associated with explosive material handling as mentioned in Table 3-31.

Table 3-31 Responsibilities of authorized person regarding different activities associated with explosive material handling

S.N.	Activities	Monitoring/observation parameters	Frequency	Responsibilities
1	Supplied Explosive	a) Amount of Magazines, b) Emulsion; Packing sealing; MSDS; Expiry date	Monthly	Nepal Army at the designated bunker site, master blaster
2	Carrier vehicle from custom office to bunker site	a) Placement of emulsion and detonator in different carrier vehicle b) Type of vehicle c) Review of vehicle service log book d) Electric line, firefighting arrangement, speed of carrier vehicle during transportation, e) Security	Regular during transportation duration	Nepal Army
3	Site Transportation	a) Placement of emulsion and detonator in different carrier vehicle b) Observation of containers c) Hazard control measures d) Fire protection measures e) Vehicle log books f) Speed during carrying duration	At a time of transportation	Magazine Keeper/ Nepal Army
4	Bunker Storage	a)Relative humidity, temperature, electric circuit, fire-fighting equipment	Weekly	OHS/Environmental Officer
		b) Visual observation on Lightening protection subsystem	Twice a year	Electrical Division
		c)Resistance (1 ohm)	Yearly	Electrical Engineer
5	Stock Packaging	a) Stacked height, b) Stacking type, c) Rotation of stack	Weekly	Magazine Keeper
6	Blasting Hole Preparation	Observation of number and position of drill holes as per the designated blasting pattern	Prior to charging	Drill Master/ Site Geologist
7	Explosive Charging	a) Drill factor b)Powder factor	Prior to blasting	Master Blaster/ Site Geologist
8	Accessibility during blasting	a) Personnel access b) Vehicle access c) Vehicle parking	Blasting Phase	Security Officer/ Safety Officer
9	Noise and Vibration measurement	a) PPV; b) L_{max}	Active blasting phase	Environmental/OHS officer
10	Misfire	a) Inspection of detonator, detonation cord, lead wires, or unfired signal tubes, cutoffs, bootlegs (butts),	Post blasting phase	Master Blaster

S.N.	Activities	Monitoring/observation parameters	Frequency	Responsibilities
		b) water ingress,		
		c) residual explosives		
11	Post Blasting	a) Monitoring on washing and wetting down	Post blasting phase	Environmental/OHS officer
		b) Scaling		
		c) Muck removal and disposal		
12	Stock Review	Log book review on stock of explosive and reporting to blasting and explosive team leader	Monthly	Magazine Keeper
13	Impact Monitoring	Overpressure and vibration	At a time of blasting	Environmental/OHS officer
14	Blast Fume	a) Visual monitoring of blast fume	At a time of blasting	Environmental/OHS officer
		b) Personal Protective Equipment for drilling and blasting operators		
		c) Gas analysers/ Particulate Matter (PM) monitors/ Data logging equipment / Environmental monitoring stations/ Sample collection equipments /Laboratory Analysis equipment		
15	Safety Measures	a) Observation on application of safety tools by workers	Post Blast	OHS Officer
		b) Muck segregation		
		c) Packaging		
16	Grievances	Complaint and grievances address	Trimonthly	Public Relation Officer
17	Inspection	a) Observation at magazine site	Trimonthly	Project Developer/Blasting and explosive team leader/Nepal Army/Magazine Keeper
		b) construction magazine,		
		c) method of storage and condition of explosive in magazine		
		d) cleanliness of magazine		
		e) fire prevention		
		f) signing and marking of magazines		
		g) Inventory record		

3.3.2 Blaster Requirement

This guideline recommends following requirements of a licensed Master Blaster and or Magazine Keeper regarding explosive material handling in any hydropower projects of Nepal.

a) All the drilling and blasting equipment must be checked for equipment for condition, capacity, etc. prior to loading the shot.
b) The master blaster should arrive at the blast site as early as possible which would allow him/her ample time to load and connect shots since misfires are generally caused by hurrying.
c) The formation and drill pattern must be observed prior to loading and look for mud seams, soft material, light burdens and spacing.
d) The loading of the explosive materials should be as per the drilling and blasting pattern. The firing of the explosive should be set using delay numbers, rather than cap numbers. The timings of the firing should be reviewed before caps are laid out.
e) Powder factors must be calculated prior to loading. Don't use the driller's measurements of burden, spacing, and depth during the calculation of the powder factor.
f) The number of people must be kept as minimum as possible when loading and connecting up. Since, idle people can be dangerous.
g) The duties should be assigned to specific people during loading and make sure that they carry out those duties during any drilling and blasting operations.

h) Loading of the charge should be done in a manner similar to the event of equipment failure.
i) When loading packaged explosives, one stick must be loaded prior to the primer. This ensures that the primer is not driven into cuttings at the bottom of the borehole.
j) The stemming is adequate or not should be insure. Avoid using wet or muddy stemming material. Crushed stone is recommended.
k) The drilling and blasting area should be always clean and cleared from any bags, wire, boxes, etc. prior to connecting up.
l) Adequate cover should be always provided at the drilling and blasting location
m) Make sure that the master blaster understands the signal to fire the shot. If in doubt, firing of charge should be stopped.
n) Drilling and blasting report/ assessment should be completed before leaving the site.
o) The drilling and blasting location must be evacuated when the blast area is threatened by electrical storms.
p) Master blaster should always use common sense during drilling and blasting operations.

3.3.3 Blasting and Explosives Management Plan

Any drilling and blasting operation in the hydropower project of Nepal should be carried out under the designated blasting plan which covers the hole preparation (Figure 3-42), charging, notification, blasting, cleaning, etc. as the major component. This guideline recommends that the blasting and explosive management plan must be prepared and included in the Blasting Assessment Report (BAR) as discussed in Section 3.1.5 by any hydropower project in order to ensure that the following minimum requirements are met in general.

a) The transportation, storage, processing, packaging, and the disposal of the explosive materials should comply with the Nepalese legislations on the use of explosives.
b) The access to the storage of explosives should be strictly controlled;
c) The explosives should be handled in accordance with the manufacturers' instructions and specifications;
d) No person should smoke, and no fires, lights or articles or substances of a flammable nature or liable to spontaneous ignition, or act to cause or communicate fire or explosion such as acids, petroleum, carbide of calcium, compressed gases or such other hazardous substances, or radio or cell phone or radio frequency operated device or any such communication system or devices should be allowed at any time within fifteen meters from the place where an explosive is stored or at any place where an explosive is handled during transport one hour before and during such handling;
e) Only suitably qualified and licensed master blaster or magazine keeper should handle or use explosives;
f) The blasting operations should be suspended during thunderstorms;
g) Primers should not be made near excessive quantities of explosives or in excess of immediate needs;
h) No attempt should be made to soften hard set explosives by heating over a fire or by rolling the explosives on ground;
i) No attempt should be made to use any explosives or detonators that have been water soaked.
j) Every hydropower project includes work planning procedure and control requirements discussed in Section 3.3.5 of this guideline in their specific blasting and explosive management plan.

3.3.4 Trigger Action Response Plan (TARP)

In order to identify alert level for surface and underground blasting activities, a specific trigger (TARP) should be proactively developed to address escalating levels of risk by every hydropower project in Nepal. For alerting purpose, at least one handheld personal lightning detector/monitor should be utilized during the handling of any explosive material on the surface. A typical TARP to identify alert level for surface and underground blasting activities has been presented in Table 3-32 for reference.

Table 3-32 A typical TARP to identify alert level for surface and underground blasting activities

<table>
<tr><th>S.N.</th><th>Status</th><th>Surface</th><th>Underground</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Blue Alert (30-50 Km)</td><td>Off-loading explosive materials shall not be started.</td><td>Use of explosive materials is permitted when initiation systems are independent and isolated from surface power source.</td></tr>
<tr><td>When in the process of off-loading explosive materials for transport underground or into magazines, those activities may continue without undue delay.</td><td rowspan="2">Connection of electrical initiation systems is not permitted when initiation systems are dependent on and not isolated from surface power source.</td></tr>
<tr><td>Surface loading and blasting activities are prohibited.</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Yellow Alert (15-30 km)</td><td>All handling of explosive materials on surface to cease and personnel to be withdrawn from magazines.</td><td>Explosive materials laden shaft conveyances shall proceed underground and immediately be off loaded</td></tr>
<tr><td>Explosive materials laden shaft conveyances shall proceed underground and immediately be off-loaded.</td><td>Connection of electrical initiation systems is permitted when initiation systems are isolated from the facility electrical systems.</td></tr>
<tr><td rowspan="4">3</td><td rowspan="4">Red Alert (<15 km)</td><td>All personnel to seek shelter indoors</td><td rowspan="2">Personnel handling explosives are prohibited from entering onto a shaft conveyance from any level including the surface.</td></tr>
<tr><td>All handling of explosive materials on surface to cease and personnel shall be withdrawn from magazines</td></tr>
<tr><td>All hoisting activities relating to the movement of explosives shall cease</td><td rowspan="2">Connection of electrical initiation systems is permitted when initiation systems are isolated from the facility electrical systems.</td></tr>
<tr><td>Personnel are prohibited from entering onto a shaft conveyance from any level, including the surface.</td></tr>
</table>

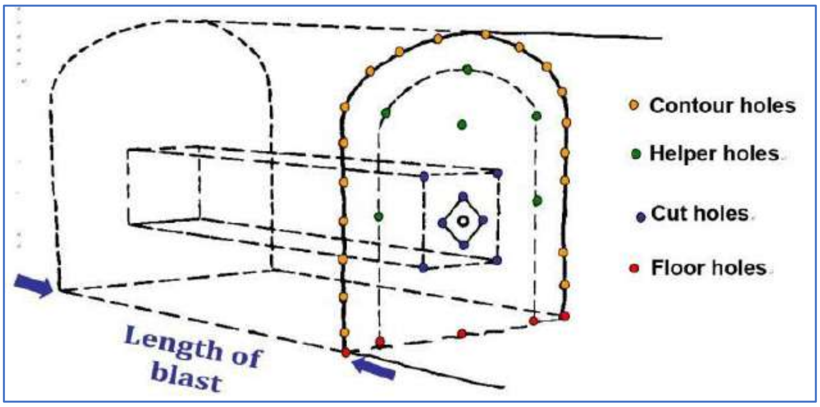


Figure 3-42 Blasting hole preparation (Source: UT-1 HEP Blasting and Explosive Management Plan)

3.3.5 Work Planning Procedure and Control Requirement

Any drilling and blasting operation in the hydropower project of Nepal should be carried out in a controlled environment under the specific work planning procedure as mentioned in the blasting and explosive management plan discussed in Section 3.3.3 of this guideline. This guideline recommends following work planning procedure and control requirement in any drilling and blasting operation by any hydropower project in Nepal.

a) The transportation, storage, processing, packaging, and the disposal of the explosive materials should comply with the Nepalese legislations on the use of explosives.
b) Before blasting is carried out, a detailed survey should be conducted in the nearby communities to evaluate the degree of impacts that may be caused due to the blasting activity (e. g. possible damage to structures or infrastructure due to vibration, effects on animals, local residents).
c) The survey (including photographic and video graphic evidences of structures) of all structures located within 250 meters should be conducted prior to the use of any explosives. Compensation should be provided by the concerned hydropower project for any structures reported to be damaged from drilling and blasting activities, to the extent that the structure survey did not find pre-existing damage.
d) The hydropower project should ensure that the enough overburden depth as well as side cover length with proper alignment (with respect to rock type and geological structures) is selected for surface or underground excavation to reduce instabilities within the excavation.
e) No blasting should be allowed by the hydropower project during night time unless prior approval is obtained from the government authority and local residents are notified in advance and if it is allowed in the approved environmental study report. The only exception to this will be for underground blasting for tunnel construction on the basis of geologically stable parts as identified by the geologist of the hydropower project, which will be allowed as long as it can be demonstrated that it will not disturb local residents.
f) Air blast should be avoided during night time due to noise disturbances into the environment.
g) The hydropower project should take necessary precautions to prevent damage to special features in the surroundings (e. g. ecological, historical, or culturally important areas) and the general environment. The benches during surface excavation and tunnel wall during underground excavation should be constructed in a way to withstand blast shock waves.
h) Only qualified and authorized personnel should handle explosives and manage the blasting process.
i) The hydropower projects should adopt optimized blasting techniques using delay detonators for blasting in confined areas (inside the tunnels). Prior to a surface blasting event (i.e., excluding underground blasting), water shall be sprayed on the surface of the blast area to increase its moisture content, and wire mesh, gunny sacks, and sandbags shall be used on top of the blast area at each shot to prevent flying rocks and dust. Blasting shall not be carried out in adverse weather conditions (High wind, Continuous raining period) in order to reduce dust emission effect and viable landslide. Spraying shall be conducted after the blast to control fugitive dust. The work should not be carried out in adverse weather conditions.
j) The hydropower project must ensure to provide notification to any occupants of surrounding land at least one day prior to any surface blasting activity and should address any concerns that they may have.
k) The hydropower project should ensure to issue a warning siren 20 minutes before the blast, again about 1 minute before the blast, and an "all clear" siren shortly after the blast, which can be heard up to approximately 1 kilometer from the surface blast site. This guideline recommends to install and operate a siren of sufficient volume in appropriate locations. However, this guideline does not recommend any hand operated sirens for this provision

l) The hydropower projects should ensure that any unauthorized persons should be located a safe distance (e.g. at least 200 meters) away from the blasting point. The highly probable impact area should be demarcated through temporary barricades and hazard sign board. Before the detonation takes place, the hydropower projects should check that there are no people inside the controlled area.
m) The use of electric detonators should be prohibited during thunderstorms.
n) If there has been a failure in the blasting operation, only designated master blaster should be allowed on drilling and blasting location to do the work necessary to detonate the explosive, or completely redo the drilling and blasting operation.
o) The blasting plan should entail that the face must be checked visually and any undetonated explosives removed by the designated master blaster prior to the start of drilling.
p) The old explosives should be removed by flushing out with water. If there is any doubt, the designated master blaster should be called in for assessment.
q) Drilling in old holes must never take place.
r) The blasting round plan shall be followed precisely.
s) The quantity of blasting materials should be carefully controlled according to the real situation requirements to avoid unnecessary breakage of rock mass.
t) The master blaster should calculate a blast design based on the two parameters i) the powder factor or specific charge (kilograms of explosives per cubic meter of blasted rock) and ii) the drill factor (total length of drill holes per volume of blasted rock (meter/cubic meter). These are indicators of the overall economy of blasting and permit easy comparison among blast patterns.
u) For most typical underground blasting with tunnel diameter ranging from 1m to 13m, the powder factor varies between 0.24 and 32.62 kg/m^3 . The powder factor can vary from 0.24 to 3.62 kg/m3 in a tunnel with an opening size greater than 30 m^2 whereas the powder factor can vary from 1.51 to 31.62 kg/m^3 for a size less than 10 m^2 , in the same type of ground. Typical drill factors vary between 0.8 and 6 m/m3 .
v) If possible, state of the art drilling machines provided with dust extraction system shall be used. In the event that a dust extraction system is not available, water spraying should be used to prevent airborne dust.
w) Explosive materials including explosives and detonators should be of good quality and suitable for the drilling and blasting operation as specified in section 3.1.3.3 of this guideline.
x) Explosives with past expiration dates should not be used.
y) Explosives and detonators must be packed in closed boxes. The explosives damaged by handling or transportation should not be used and shall be disposed of in accordance with established procedures and any national regulations.
z) The boxes of explosives and blasting caps must be visibly labelled with signs indicating their contents and instructions on how to dispose and handle them.
aa) The master blaster should ensure proper stemming after charging of explosives. Since, proper stemming material (stone chips and drill cutting) will help in minimizing dust throw hence lower spread of dust particles in ambient air or within tunnel or adits.
bb) The explosives storage building should be a dry, well-ventilated facility located away from other villages, buildings, roads, and high activity areas. The building should be constructed using materials resistant to firearms, fire, and atmospheric phenomena. It should also have a metal door with a safety lock, lightning protection, warning signs and strict surveillance.

3.3.5.1 Job Hazard Analysis, (JHA)

A Job Hazard Analysis (JHA) for drilling and blasting operations involves a systematic approach to identifying potential hazards and implementing control measures to mitigate risks. In any drilling and blasting operation the major job (task) can be categorized as (1) site preparation and planning, (2) drill rig setup, (3) drilling operation, (4) loading explosives (5) blasting operations (6) post blasting inspection, and (7) Clean-up and muck removal. A typical job hazard analysis for identifying potential hazards and implementing control measures to mitigate risks of the above-mentioned major job of any drilling and blasting operation has been summarized in Table 3-33. It is recommended to carryout job hazard analysis for drilling and blasting operation by every hydropower project in Nepal and include it in the blasting assessment report (BAR) as articulated in Section 3.1.5 of this guideline.

Table 3-33 Recommended Job Hazard Analysis for drilling and blasting operation in Nepal

S.N.	Job	Task	Hazard	Control
1	**Site Preparation and Planning**	Surveying and marking the blast area	Uneven terrain and trip hazards	Conduct site surveys and clear debris
		Preparing access roads and work zones	Traffic from construction vehicles	Use signage and barriers to control traffic
			Poor communication leading to mis co-ordination	Implement clear communication protocols (e.g., radios)
2	**Drill Rig Setup**	Transporting and positioning drill rig	Equipment rollover	Ensure stable ground for rig setup
		Securing rig on site	Pinch points during setup	Use spotters to guide rig positioning
				Follow manufacturer's setup instructions
3	**Drilling Operations**	Drilling blast holes to specified depths	Dust inhalation	Use dust suppression systems (e.g., water sprays)
		Monitoring drill progress	Noise exposure	Provide hearing protection to workers
			Equipment malfunction or failure	Conduct regular equipment maintenance and inspections
4	**Loading Explosives**	Transporting explosives to the site	Handling explosive materials	Train personnel in explosive handling
		Loading blast holes with explosives	Static electricity and accidental ignition	Prohibit smoking and open flames in the area
		Connecting detonators and wiring		Use non-sparking tools and anti-static equipment
5	**Blasting Operations**	Evacuating non-essential personnel	Flyrock and debris	Establish and enforce blast exclusion zones
		Initiating the blast	Ground vibration and noise	Use blast mats to control flyrock
		Monitoring the blast	Misfires or partial detonation	Conduct pre-blast checks and use reliable initiation systems
6	**Post-Blast Inspection**	Inspecting the blast site for hazards	Unexploded charges	Conduct thorough post-blast inspection
		Confirming the detonation of all explosives	Structural instability of blasted area	Use blast residue detection equipment
				Follow protocols for handling misfires
7	**Clean-Up and Debris Removal**	Removing blast debris and materials	Heavy equipment operation	Use appropriate PPE (e.g., dust masks, gloves)
		Restoring the site for next operations	Dust and debris	Implement safe heavy equipment operation practices
				Ensure proper ventilation if in a confined space

3.3.5.2 Standard Operation Procedure, (SOP)

This guideline recommends all the work planning procedure and control requirement mentioned in Section 3.3.5 of this guideline for any drilling and blasting operation by any hydropower project in Nepal. All the hydropower projects should implement all the control measures to mitigate risks of the potential hazards identified in every task involved in a drilling and blasting operation mentioned in section 3.3.5.1 as a standard operation procedure.

3.3.6 Drilling and Loading Operation

For proper handling of the explosive material during drilling and loading operation, this guideline recommends to fulfill the following requirements during any drilling and blasting operation by a hydropower project.

a) The drilling and loading should be performed only by a licensed master blaster;
b) The Master Blaster should prepare a Blasting and Explosive Management Plan (blasting pattern, load factors, and timing sequence) as mentioned in Section 3.3.3 prior to any drilling and blasting operations in a hydropower project.
c) The tunneling works starts with safety measures from underground alignment marking /profiling as per design to make sure that we are going to our perfect destination. When the survey team starts marking the profile then it should always to be assured that all the loose muck at face is scaled out so that nothing falls. After assuring all loose muck is removed by scaling then master blaster must see the face and find out that there is no fuse blasting product at or near the face.
d) After all the survey and blasters clearance, handheld drill or drilling machines like boomer or drilling jumbo should reach the face/ front for drilling the face for new cycle.
e) When drilling completes as per pattern provided by geologist/geotechnical engineer the process of charging the explosive in to the drilled holes starts and during the process all the precautions like avoiding the electricity, mobile flash etc. should be taken.
f) The quantity of charging also known as powder factor should be controlled as per general prescribed limit for surface excavation as mentioned in Section 3.1.6 and for underground excavation as mentioned in Section 3.1.7 of this guideline.
g) The powder factor should be limited to save the rockmass from unnecessary/excess deterioration.
h) The storage of explosive during the charging process should be maintained properly.
i) After proper de-fuming, master blaster should go to drilling and blasting location to see the quality of blast with all proper lighting arrangements.
j) Then the process of de-mucking should start only after assuring that proper scaling of loose detached pieces has been completed.
k) After completing the de-mucking process, the rockmass protection work should be done as per the recommendations of geotechnical engineer. As per geotechnical requirement on the basis of rockmass class, the support in the form of rock bolt, rock bolts with wire mesh, steel ribs with backfill concrete and/ or grouting to consolidate the rockmass should be carried out in order to assure the stability of the next drilling and blasting cycle.
l) Suitable warning signs and audible signals should be made prior to conducting the drilling and blasting operations and all persons employed in the area should be made fully conversant with such signs and signals;
m) Explosives before use should be visually examined for any visible defects and any defective explosive shall not be used;
n) The electric power at the blasting site should be discontinued as far as practicable before charging the explosives
o) No work other than that associated with the charging operations should be carried out within fifteen meters of the holes;
p) The holes, which have been charged with explosives, should not be left unattended till the blasting is completed;
q) No further drilling should be started until previous holes in the blasted area are flushed with air and water;

r) The position of all holes to be drilled should be marked out with white or any distinctly colored paint;
s) The borehole should be carefully checked for the length, presence of water, dust etc.;
t) When charging is completed, any surplus explosives, detonators or fuses should be removed from the vicinity of the hole and stored at a distance;
u) Explosives should not be forced down a borehole or on obstruction in a borehole.
v) The control requirement as stated in the Section 3.3.5 (Work Planning Procedure/Standard Operation Procedure) should be followed for proper handling of the explosive materials.

3.3.7 Explosive Charging

Explosive charging refers to the process of placing the explosive materials in drill holes or designated area in preparation for detonation. For proper handling of the explosive material, this guideline recommends to fulfill the following requirements for explosive charging during any drilling and blasting operation by a hydropower project.

a) When cartridge explosive is used for any drilling or blasting operation, manual charging is the most common method. In manual charging, workers use a wooden or plastic stick to push the explosive cartridge, primer cartridge first, into the blasthole one by one and tamp them with the stick.
b) For blasthole stemming, wet newspaper (or cardboard), Hessian bags, and soil should be used.
c) For better stemming effect, crushed rock stemming (circa 10 mm) in thin plastic sausages is recommended as crushed rock stemming will 'lock' in the blasthole due to its angular shape.
d) For the holes which are inclined upward or vertical from the collar, plastic plugs should be used for holding the explosives in position.
e) When pneumatic charging devices are used, they should be efficiently electrically earthed, and semi conductive (antistatic) loading tubes should be used. Such tube should have a resistance of not less than 15 × 103 Ω/m and should be such length that its resistance is not more than 2 MΩ.;
f) Care must be taken when charging holes contains water.
g) The charging holes must be introduced to the bottom and is pulled out gradually during charging at the same rate that the hole is filled to avoid separation of the explosive column by water pockets.
h) When drilling completes as per pattern provided by geologist/geotechnical engineer the process of charging the explosive in to the drilled holes starts and during the process all the precautions like avoiding the electricity, mobile flash etc. should be taken.
i) The quantity of charging also known as powder factor should be controlled as per general prescribed limit for surface excavation as mentioned in section 3.1.6 and for underground excavation as mentioned in section 3.1.7 of this guideline. The powder is limited to save the rockmass from unnecessary/excess deterioration.
j) The storage of explosive during the charging process should be maintained properly.
k) The control requirement as stated in the Section 3.3.5 (work planning procedure (Standard Operation Procedure) should be followed for proper handling of the explosive materials.

3.3.8 Tying-In of Blasting Circuit (Electrical Short – Firing Circuit)

The tying-in of a blasting circuit is the critical process of connecting individual detonators or blasting caps to the main blasting line or initiation system before a blast. For proper handling of the explosive material with regards to tying-in of blasting circuit, this guideline recommends to fulfill the following requirements during any drilling and blasting operation by a hydropower project.

a) Recommended knots for connection of detonating cords as presented in Figure 3-17 should be applied during tying-in of blasting circuit.
b) Firing circuit should be completely insulated from the ground or by the other conductor;
c) For the purpose of joining, the ends of all wires and cables should have the insulation removed for a maximum length of 5 cm and should be made clean and bright for a minimum length of 2.5 cm;
d) The driller should maintain blast hole boring logs and he or she must communicate it directly to the blaster. The logs should indicate depths and lengths of voids, cavities, fault zones or other weak zones encountered, as well as groundwater conditions;
e) There should not be any electric live wire or cable of any kind near the electric blasting caps or other explosives except at the time of firing;
f) The electric cap wires or the loading wires should be kept short circuited until ready to fire;
g) All holes loaded on a shift should be fired on the same shift;
h) Each electric blasting cap should be tested with an approved galvanometer before and after tamping in a hole to determine whether it will carry the current;
i) If exploder is used, it should be regularly tested and maintained in a fit condition for use in firing.
j) Tying-in procedures should be meticulous in order to ensure the safety, efficiency, and success of the blasting operation

3.3.9 Unused Explosive Material Returned to Magazine

The unused explosive materials including explosives and detonators (initiation system) should be returned to the explosive magazine by maintaining integrity as far as possible. The unused explosive materials should be noted in the daily blasting work sheet as mentioned in Table 3-29 and should be signed, stamped by the designated master blaster, designated magazine keeper, designated security official of Nepal Army and Nepal Police.

3.3.10 Disposal Plan for Surplus, Defective Explosives, and Used Packing Material

The disposal plan for surplus, defective, expired explosives, and used packing material has been depicted in Figure 3-43 for reference. Explosives and its residues should be disposed of by the most suitable method in the designated location as mentioned in the manual of the manufactures (if any) and approved environmental study report of the concerned hydropower project under the supervision of Nepal Army and related administrative bodies. During the environmental study as per Environment Protection Regulation (2077), identification of the most suitable disposal method should be considered based on the nature of the explosive and its hazards, and any hazards associated with the disposal method or created during the disposal process. Explosives that are considered unsafe to transport or for storage are required to be destroyed in a safe manner in compliance with the above-mentioned regulation and approved waste management plan of the hydropower project.

3.3.11 Inspecting and Addressing Misfires

Misfire is the complete or partial failure of explosive material to detonate as planned. The term is also used to describe the explosive material itself that has failed to detonate. This guideline recommends the misfire waiting period when a misfire is suspected to any persons entering the drilling and blasting location until:

1) For 30 minutes if safety fuse and blasting caps are used; or
2) For 15 minutes if any other ignition system (detonators among others) are used.

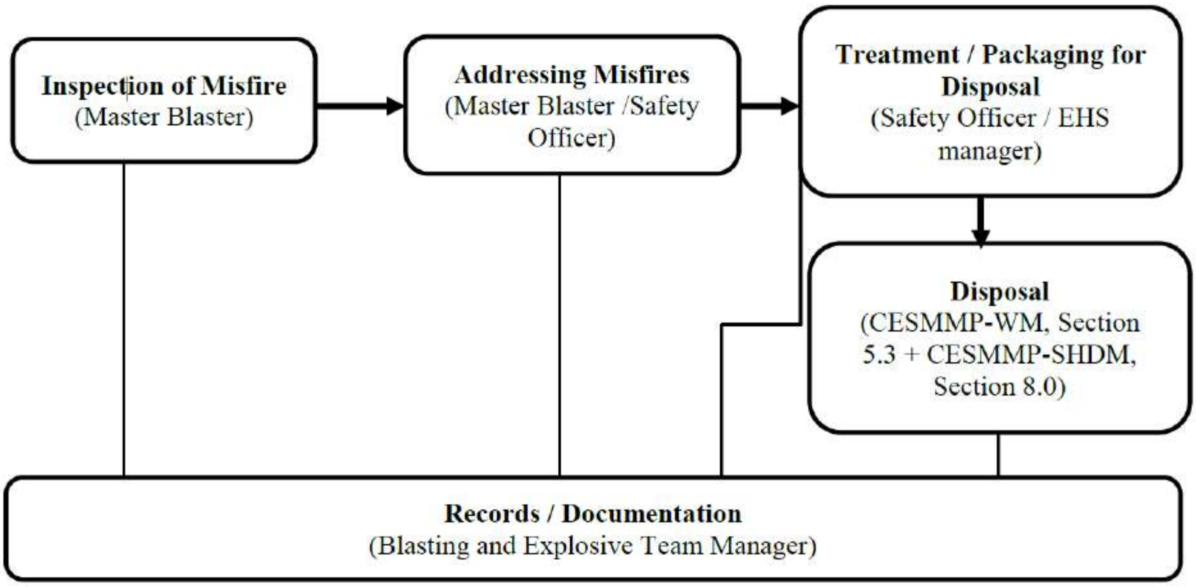


Figure 3-43 Disposal Plan for Defective Explosives (Source: UT-1 HEP Blasting and Explosive Management Plan)

3.3.11.1 Misfire Handling Procedures

This guideline recommends the following misfire handling procedures.

a) Faces and muck piles should be examined for misfires after each blasting operation.
b) Only work necessary to remove a misfire and protect the safety of labors engaged in the removal should be permitted in the affected area until the misfire is disposed of in a safe manner.
c) When a misfire cannot be disposed of safety, each approach to the area affected by the misfire should be posted with a warning sign at a conspicuous location to prohibit entry, and the condition should be reported immediately to project management as well as concerned security office.
d) Misfires occurring during the shift should be reported to project management not later than the end of the shift.

3.3.12 Training Requirement for Safeguards for Personnel

All responsible persons, workers and blasters should be trained in methods, equipment usage and hazard identification in accordance with their respective role(s). For proper handling of the explosive material with regards to training requirement for safeguards for personnel, this guideline recommends to fulfill the following requirements.

a) All employees engaged on site should be trained about the safety rules and safe practices;
b) A worker engaged in loading, unloading, or conveying explosives must be trained in the proper means for handling the explosives, the hazards of fire and mishandling and the procedures to follow in the event of a fire or explosion;
c) Employees and community members (residing near the blasting zone and explosive storage) should undergo mock drill exercise six monthly. Mock drill will be undertaken and evaluated by designate operation health and safety officer.
d) Training module on 'Blasting Safety will be imparted by the lead blaster.
e) The developer of the concerned hydropower project must negotiate with designated Nepal Army Officials for developing and implementing Arms Management Procedure. Additionally, code of conduct should be developed for the army men working on-site consulting duly with

the designated Nepal Army Officials. Annual third party trainings should be provisioned for the army personnel by developing a training module, in line with the agreed procedure.

f) All personnel at bunker attending the general safety basic training should receive instruction by designated operation health and safety officer in the following topics.

    i. Handling of explosives from bunker to the blasting points
    ii. Dangers associated with Explosive Materials
    iii. Notification process of unsecured Explosive Materials
    iv. Toxic and asphyxiating gasses associated with Explosive Materials
    v. Roles and responsibilities of those authorized to handle Explosive Materials
    vi. Placards and Signage associated with the use of Explosive Materials
    vii. Occupational health and safety matters
    viii. Response on emergency execution for any accidents and hazards
    ix. Management of residues after blasting
    x. Safeguards for personnel who may be indirectly impacted by Blasting activities

3.4 Explosive Material Transportation

All transport, storage and use of hazardous substances of any quantity must be in accordance with all the relevant laws and regulations of Nepal such as Explosive Act (2018), Explosive Regulation (2020), Procedure Related to Granting permits for the import,Transport, Storage , and use of explosive materials, (2073), and Explosive materials storage, transportation, and security, as well as military management, monitoring, regulations, and facilities arrangements guidelines (2071) of Nepal. All the safety precautions specified in Section 4.4.1 of this guideline should be applied during transportation with security aided by Nepal Army. The responsibility pertaining to transportation of explosives must be undertaken by the Nepal Army Troops for every transportation from the onsite bunker to the blasting area. The following activities should be ensured for the safe handling of explosives during transportation:

a) Transport of explosives and detonators by road to the site must be in accordance with the requirements of the Nepal Army Authority. Transportation of explosives from the supplier/Army camps to the onsite bunker should be undertaken by Nepal Army.
b) The distance between body and cab should be 15 cm.
c) The wind screen and vehicle window mirror of the explosive material transporting truch should be of non-splinter type.
d) Fuel tank of explosive material transporting vehicle should be protected by steel guard for the safety of fuel tank.
e) The truck carrying explosive material should have provision for the fuel cut off system outside the bonnet.
f) The truck should have two fire extinguishing cylinder which has capacity to extinguish petroleum fire.
g) The truck should have fully insulated wiring system connected to the battery and engine.
h) The truck carrying explosive material should be escorted from front and behind by a troop of Nepal Army but if there are more than two trucks, a addition another vehicle with army escorting team should be provided after each two truck carrying explosive material.
i) The truck carrying the explosive material should be of closed type. The maximum quantity each truck can carry is 10,000 kg only.
j) To avoid the friction between the metallic parts, wooden or rubber material should be provided in such parts.
k) Workers or unauthorized persons should not be transported in a vehicle carrying explosives.

l) The vehicle should carry emergency Procedure Guides for the products in the marked holder securely attached to the driver's side door as shown in Figure 3-44.
m) The vehicle carrying the explosive material should have color siren.
n) The contact of explosives with exposed ferrous metal should be avoided by providing the explosive containers with nonconductive device such as rubber;
o) Two carbon dioxide fire extinguishers each of more than 3 kg capacity should be carried on all vehicles transporting explosives. The approved fire extinguisher should be fully charged and in sound working condition.
p) Detonators and explosives should not be carried on the same vehicle;
q) Personnel involved in transport of explosives should ensure that there is no leakage or spillage of explosive materials;
r) Explosives should be transported only in vehicles in good mechanical and serviced conditions;
s) Explosives should be loaded/unloaded only when the engine of the vehicle is stopped, the wheels chocked and the hand breaks applied;
t) Containers containing explosives should not be dropped;
u) In case of any emergency, the vehicle driver must contact the designated master blaster of the concerned hydropower project.
v) Smoking should not be allowed when handling or transporting explosives.
w) The speed restrictions relative to the transport of explosives should be limited up to15km/h maximum.
x) The loaded vehicle should never be left unattended.

Please refer to the Section 4.4.1 and Section 4.4.3 regarding elimination measures to be adopted during explosives transportation

Figure 3-44 Vehicle for the transportation of explosive material in the project site (Source: UT-1 HEP Blasting and Explosive Management Plan)

3.4.1 Delivery, Acquisition and Inventory of Explosive Material

The delivery of the required quantity of explosive material including explosives and initiation system (detonator) must be carried out based on the general transportation document required for each delivery. The designated contractor of the hydropower project must submit explosives requisition slip to hydropower project developer for approval. The approved requisition slip should be submitted to Army representative for approval and record, a copy of which will be returned to the concerned department of the hydropower project. A sample Request for Information (RFI) for delivery and acquisition of the explosive material from UT-1 HEP (216 MW) has been presented in the Annex-9 for reference. The hydropower project must include a daily blasting work sheet as mentioned in Section **3.2** and Table 3-29 of this guideline in the above mentioned RFI.

The hydropower developer should prepare inventory records of used explosive quantity in the format as mentioned in the Table 3-34 and this inventory information should be communicated to the Ministry of Home Affairs and respective CDO at an interval of three months. The designated magazine keeper should have record keeping responsibility of the delivery, acquisition, and inventory of explosive materials.

Table 3-34 A typical record format for inventory information about explosives to CDO

Name of Project:					
Address:					
Date: From …………………………. To ………………………. Explosive Consumption Summary					
S. N.	**Name of Explosive**	**Total Quantity**	**Actual Quantity Consumed for this Duration**	**Remaining Amount**	**Remarks**
1	Explosive (Emulsion)				
2	Initiation System- Detonators				
3	Initiation System- Detonating Cord				

3.5 Explosive Material Storage

A site magazine for storing explosives is a specialized facility designed to securely and safely store explosive materials which should be carried out complying with stringent regulatory standards mentioned in Explosive Act (2018), Explosive Regulation (2020), Procedure Related to Granting permits for the import,Transport, Storage , and use of explosive materials, (2073), and Explosive materials storage, transportation, and security, as well as military management, monitoring, regulations, and facilities arrangements guidelines (2071) of Nepal. If it is necessary to set up an on-site explosive magazine, an assessment report of its feasibility shall be proposed to the Nepal Army. An Environmental Assessment Report of the hydropower project submitted for getting the generation license from the DoED must include the details of the bunker facilities and setup of the onsite explosive magazine based on the requirements envisaged by the Environment Protection Regulation (2077) of Nepal. The details in the environmental report must include drawings to indicate the location and arrangement of the magazine. The security measures and safe operation regulation and procedure shall be proposed in pursuant to the prevailing laws and guidelines of Nepal.

3.5.1 Types of Explosive Magazines

In Nepal, according to the Explosive Regulation (2020), there are two types of permanent magazines for the storage of explosive materials. They are:

a) Explosive magazine for hard explosives such as Dynamite, Nitroglycerine, T.N.T., Gelignite, etc; and
b) Explosive magazine for soft explosives such as blasting powder,

For the hydropower development, the use of hard explosives is required in pursuant to the regulation stated above. The detail requirements for the explosive magazine used in the drilling and blasting operation have been mentioned in Rule 14 of the regulation which has been summarized in the Table 3-35.

Table 3-35 Type of explosive magazine based on the quantity of the explosive material

S.N.	Type of Explosives Materials	Quantity of explosive materials	Type of explosive magazine	Requirement of the explosive magazine
1	**Hard Explosives**	Up to 57 kg or more	Permanent explosive magazine which should bullet proof, fire proof and theft protection	As mentioned in the Schedule-6 of the Explosive Regulation 2020
		Less than 57 kg	Permanent explosive magazine or Box type magazine	As mentioned in the Schedule-7 of the Explosive Regulation 2020
2	**Initiation System (Detonators)**	Up to 5000-1000000 numbers	Permanent explosive magazine which should bullet proof, fire proof and theft protection	As mentioned in the Schedule-6 of the Explosive Regulation 2020
		Less than 5000 numbers	Permanent explosive magazine or Box type magazine	As mentioned in the Schedule-7 of the Explosive Regulation 2020

3.5.2 Planning and Siting of Bunker Facilities

The location or site of the bunker facilities, should be formally selected by a Siting Board set up and approved by the Nepal Army Authority. When planning for a new location, it is essential that all interested parties are involved from the earliest stage in the proceedings and take advice as necessary from appropriate technical experts. When siting any explosives facility, whether above ground or underground, all factors that may affect its operation under all conditions should be considered. It is unlikely that one area or site will be found which meets all requirements so the best combination of desirable features is to be aimed for and an acceptable compromise sought. The hydropower project should conduct a careful and correct assessment regarding the planning, and siting of major bunker facilities to ensure the following conditions.

a) To conduct every drilling and blasting operations safely, economically and efficiently
b) To ensure an acceptable level of protection to the public and unrelated individuals;
c) To keep the risks from explosive sites at a level that is preferably negligible, but at least as low as reasonably practicable
d) To minimize the loss of stocks due to an accidental or deliberate explosive event;
e) To provide a storage and handling environment in which stocks can be maintained in a fully serviceable condition to enable users to be supplied with reliable explosives natures at the right time and place; and
f) To ensure that the explosives license of existing Potential Explosion Sites (PES) are not compromised.

This guideline recommends considering the following factors or provisions for proper planning and sitting of the bunker facilities (Table 3-36).

a) Location and Accessibility
b) Terrain considerations
c) Types of facilities within bunker area

d) Quantity and separation distances (Refer to Section 3.5.3 for details)
e) Field Storage (Refer to Section 3.5.4 for details)
f) Approval process of new facilities or changes in existing facilities (Refer to Section 3.6.1 for details)
g) Possible procurement process of explosive materials (Refer to Section 3.6.2 for details)
h) Key skills requirements (Refer to Section 3.3.1 for details)
i) Handover and takeover procedures for new or modified facilities (in pursuant to the prevailing laws of Nepal)

3.5.3 Requirements for Quantity and Separation Distances within Storage Space

This guideline recommends the following requirements for quantity and separation distance within storage spaces of explosive magazine in order to safeguard against flashover from a lightning strike or any other triggering factors in pursuant to IATG 06.20 - Storage space requirements:

a) The default separation between the outer face of any explosive package and the inner face of any adjacent structural wall or from metallic fittings such as heaters and luminaries should normally be at least 500 mm in order to provide protection against flashover and. good natural airflow around stacks and good access for visual inspection among others;
b) The separation distance should not be less than 150 mm under any circumstances. Where the separation is less than 500 mm, the storage arrangements should be periodically reviewed with the aim of re–establishing the standard 500 mm separation distance.
c) The explosive magazine should have air space to roof of at least 500 mm (i.e. default separation between the outer face of any explosive package and the inner face of any adjacent structural wall or from metallic fittings such as heaters and luminaries should be at least)
d) All explosive materials including explosives and initiation system (detonators) should be raised 100 mm off the floor by the use of pallet bases or wooden dunnage;
e) Aisles (passage) should be wide enough to permit proper storage and handling. If the mechanical handling equipment (MHE) is used for explosive storage and handling then the passage width should be at least 2.0 m whereas if by hand held transporter is used then the passage width should be at least 1.2 m; and
f) A 20 mm air gap should surround each pallet.

Based on the above-mentioned storage space requirements, only 45% of storage capacity of the bunker facilities shall be utilized as the storage space of explosive materials considering hand held handling provision. However, this guideline recommends using optimum space available in the bunker facilities in coordination with the Nepal Army as per the requirement of each specific hydropower projects.

Table 3-36 Recommended requirements for factors regarding proper planning and siting of bunker facilities

<table>
<tr><th>S.N.</th><th colspan="2">Critical Factors / Provisions</th><th>Recommended Requirements</th></tr>
<tr><td rowspan="2">1</td><td colspan="2" rowspan="2">Quantity and separation distances</td><td>The explosives magazine should be located at the center of the bunker facilities.</td></tr>
<tr><td>If the hydropower project has two or more than two bunker facilities then, it should be ensured that minimum inter-magazine distances are maintained between the bunker sites in order to limit the maximum credible explosive event (MCE)</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Location</td><td rowspan="2">Isolation</td><td>The bunker facilities should be located in the area safe from the natural hazards such as landslides, rock falls, and flooding among others.</td></tr>
<tr><td>Bunker facilitates should be located at least 200 m far from the nearest major existing access roadways or railways. It should be noted that this requirement should not be considered in case of project road constructed by the concerned hydropower project.</td></tr>
</table>

S.N.	Critical Factors / Provisions		Recommended Requirements
			Bunker facilitates should be located at least 300 m far from the nearest inhabited buildings.
			Bunker facilitates should be located at least 500 m far from the vulnerable buildings such as schools, hospitals, airports, and protected cultural heritage sites among others.
			Any bunker facilities of the hydropower project should not be located closer than 50.0 m from any drilling and blasting locations.
			No building or civil amenities should be allowed to construct within the 25.0 m radius of the outermost fencing of the bunker facilities when the explosive magazine is operational or functional. If construction is proposed then the hydropower developer must acquire the given land on temporary or permanent basis.
		Accessibility	There should also be a clearly defined internal traffic circuit within the Bunker facilities. Explosive magazine and other ancillary buildings should be such that vehicles transporting the explosive materials do not face any hindrances.
			The bunker facilities should have good project road connecting to the main access road of the hydropower project
		Storage and handling capacity	The bunker facilities should be located within the project boundary of the hydropower project and should have enough area for the required storage and handling of the explosive material
		Communication – road and rail	The area selected should be accessed by good roads of sufficient width and strength to allow constant use by heavy traffic. However, care must be taken to ensure that Public Traffic Route Distances (PTRD) do not cause a storage problem.
			The facility should have a one-way traffic system, where ever possible, with appropriate speed limitations imposed.
			Gradients should be minimized wherever possible and it is recommended that no gradient should exceed 1:20
			The minimum inside radius at corners should be not less than 9m for normal road vehicles
		Climate and terrain	Dry storage conditions are highly desirable, so the area chosen should be well drained and as dry as possible.
			Areas with high incidences of electrical storms or other atmospheric abnormalities should be avoided
			The subsoil of the chosen bunker facility location should be firm and stable otherwise subsidence of traverses, roads and hard-standings may result.
			Thickly wooded sites have an inherent fire risk in dry weather and may require clearing of undergrowth and firebreaks. Such sites are normally poorly ventilated and are consequently excessively humid. They should be avoided.
			Areas with permeable rock with a high-water table or fissured rock with underground water channels should be avoided for locating the bunker facilities.
			Bunker facilitates should be located at areas with extensive underground workings where serious subsidence may occur.
3	**Types of facilities within a bunker area**	**Disposal area**	The disposal area should be remote from the storage area to ensure complete safety
		Explosives Magazine	Explosive magazine should be sited with due regard to the quantity distances calculated to meet the approved storage requirement as mentioned in Section 3.5.3.
		Lighting arrangements	Street lighting to the standard required in civilian built up areas should be provided for reasons of safety and security.

3.5.4 Field Storage

The selected commercial explosive such as emulsions has mass explosion hazard characteristic are so insensitive that there is very little probability of initiation from burning to detonation under normal condition. So, proper stacking module is required for storage within the explosive magazine. Generally, a stack of explosive material has approximately 1tonne gross weight, which occupies 1 cubic meter. This guideline recommends a Field Stack Module (FSM) that consist of up to 10 stacks, (i.e. a maximum of 10 tonnes gross weight of ammunition). Therefore, an FSM consists of up to 10 stacks as shown in the Figure 3-45. Sufficient space should be allowed between each stack to allow for access by individuals or rough terrain forklift truck, and ideally the field stack module should cover an area of ground of at least 7m x 3m. Field Storage Site (FSS) consists of numbers of FSM. The minimum FSM distance is 2 m but 5 m is preferable. The maximum capacity a FSS is 200 tonne i.e up to 20 FSM. Based on above mentioned fact, this guideline recommends a maximum field storage of 100 tonne by weight in a bunker facility having dimension of 14 m (l)X 7 m (b) X3.7 m (h) of a hydropower project in Nepal. If the explosive material requirement of the hydropower project during construction is more than 100 tonne, then the project must construct another bunker facilities with regards to the explosive material storage requirement stated in Section 3.5.2 and Section 3.5.3.

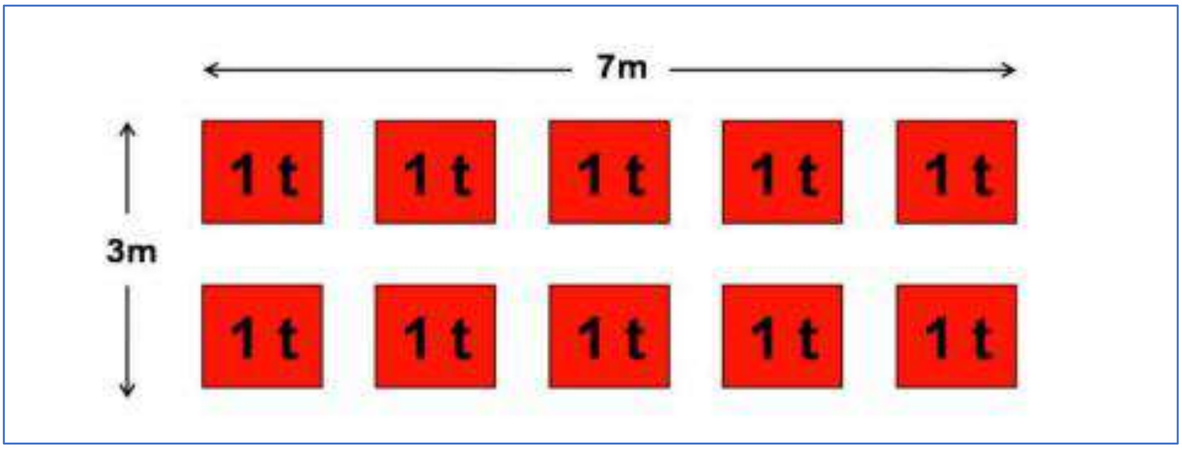


Figure 3-45 Field stack module (FSM)

The defense ministry of Nepal has specified the following requirements for the construction of the bunker facilities by any construction project.

3.5.5 Bunker House Requirements

(i) A solid barricade of sand and/or soil filled bags shall be placed around the periphery of the bunker house. Such barricade shall be placed at a minimum distance of 1m from the exterior wall of the bunker house. Poles of 3m height with barbed wire to a height of 2 m shall then encompass the sand bag barricade;

(ii) The bunker house shall be adequately cross ventilated to the satisfaction of the Employer's Representative. The ventilation provided shall be protected to prevent ingress of insects, pets and birds into the bunker house adjustable so that the ventilation system can be opened or closed as and when required;

(iii) The bunker house shall be equipped with lightening conductor and shall be constructed at least 300 m away from residential building;

(iv) Each door of the bunker house shall have access to a safely insulated light switch connected to a light. Electrical main switch shall be provided at the main gate: and

(v) The floor of the bunker house shall be constructed of wood at least 100 mm thick.

3.6 Explosive Material Procurement

For the procurement of the explosive materials, this guideline recommends to follow Rule 11 of the Explosive Regulation (2020). The Hydropower project must submit the blasting assessment report as mentioned in the Section 3.1.5 for getting recommendation of procurement of explosive materials from the DoED. If additional procurement of explosive material is necessary then also the hydropower project must submit an updated BAR (including inventory information about explosives mentioned in

Table 3-34 and explosive consumption record sheets as mentioned in Table 3-29 and Annex-8 to DoED for getting further recommendation.

3.6.1 Approval process of new facilities or changes in existing facilities

The procurement of the explosives should be made by the licensed company of the concerned HPP either through the main civil contractor or any explosive manufacturers/suppliers hired by the given project.

3.6.2 Explosive Procurement Procedure

The explosive material procurement procedure showing tentative processing dates has been summarized in the Figure 3-46. Similarly, the explosive material procurement procedure showing exact processing dates of already constructed Upper Tamakoshi Hydroelectric Project (456 MW) as a case study has been presented in Figure 3-47 for reference to prospecting hydropower projects of Nepal. A hydropower project generally should follow the following procedure for the procurement of the explosive materials.

a) With the supportive project documents stating estimated quantity of explosive and accessories, the project developer submit application in DOED seeking the permits/licence and NOC if the explosives are planned to buy from abroad.
b) DOED after necessary reviewing and ensuring all required documents in the application forwards the application to MoEWRI (Ministry of Energy, water resource and irrigation) for further process.
c) Then MoEWRI, with recommendation, forwards the application to the Ministry of Home Affairs (MoHA).
d) MoH send the application to its subordinate department, the concerned District Administration office (DAO) to confirm the site details along with safety and security concern while lunching the explosive to the project site. The officers may also visit the project site for the verification. The district security committee which include district administrator officers, CDO, senior officer of Nepal Police, Nepal Army, Armed Police force and other related officers make decision to provide approval on the application of explosive requirement to the project. CDO with his/her recommendation writes back to MoHA for further process.
e) After receiving approval from CDO, MoHA forward the application to Ministry of Defense (MoD) for the necessary steps.
f) MoD forwards the application along with all recommendations and approvals of different authorities to Nepal Army for final evaluation and Approval for issuance of the Permit
g) Nepal army shall study all the documents with respect to security implication. If all the documents, explosive quantity matched with the excavation volume and project requirements, Nepal Army shall quote amount of the explosive and accessories (E & A) which they can supply and certify explosive quantity and the accessories those needs to be imported.
h) Thus, Nepal army send back the application with their approval to the MoD for the issuance of the permit to procure E & A from abroad. (Approval may be conditional and quantities of E & A to be imported shall be revisited during construction period).
i) After receiving and reviewing the document MoD further forwards it to MoHA.
j) Then, Home Ministry finally issue permit to buy the explosive if it is within the country from Nepal Army. In case the explosive has to be brought from abroad, MoH issue the letter to Ministry of Foreign Affairs (MoFA) conveying the decision of MoH to permit the applicant for importing the approved quantity of explosive material from the abroad manufacturer. For the same, MoHA request MoFA for needful action to obtain the No Objection Certificate (NOC) from the concerned Embassy to import the approved quantity of explosive materials.

k) Then MOFA writes letter to the concerned Embassy for NOC to import the approved explosive material from their country.
l) The Embassy refers the report and case to the concerned department of their country for the approval of explosive import. After receiving the approval, the Embassy will issue NOC for the import of explosive material.
m) Till date explosive and accessories are being imported from India except one recent import from China. In the process, Indian Embassy refers the case to the Ministry of Commerce and Industry, Government of India, New Delhi and after receiving approval, issues the NOC for importing E& A from India by the Applicant.
n) Then the importer will contact the foreign explosive supplier and collect from the nearest custom with close assistance of Nepal Army to the project site
o) The explosive consumption report should be periodically submitted to the CDO office and Home Ministry every three months.
p) Forthe aforementioned procedures, generally, it is expected to take about 4-5 months' time to get permission for explosive procurement.

In order to shorten the duration of explosive procurement, procedures mentioned above, this guideline recommends to avoid duplicate works of getting consent from both DoED and MoEWRI, if the procurement procedure has been initiated through DoED. Based on the discussions made in the residential workshop for the preparation of this guideline as mentioned in Section 2.1.4, the time taken for the procurement process can be shortened by at least two weeks if the duplicate work is avoided.

However, it should be noted that this recommendation does not apply for the hydropower project of Nepal in which explosive procurement procedure has been initiated directly by the MoEWRI. For instance, the explosive procurement procedure of Upper Tamakoshi HEP (456 MW) as presented in Figure 3-47.This recommendation has been also pointed out in the recommendation (Section 7.2) of this guideline.

3.6.3 Procedure for changing vendors of the explosive materials

When the manufacturers or suppliers of the estimated explosive material are unable to provide the approved quantity of explosive materials (including explosives and ignition system), this guideline recommends to request the change the detail information of the vendors through an application to the DoED or equivalent institution if there is no change in the estimated quantity of the explosive materials to be procured. However, if hydropower project desires to change the vendor of the explosive materials with change in estimated quantity, then, the project must follow explosive procurement procedure discussed in Section 3.6.2.

Currently, there is a mandatory provision to procure at least 10% of the total estimated quantity of explosive material from the Nepal Army. This provision is entirely dependent on the Nepal Army. However, this guideline recommends to consider the proportion of explosive materials to be procured from the Nepal Army should be based on the demand and supply as well as availability (considering importing constrains of raw materials) of the explosive materials in their inventory. (i.e. this provision should not be made mandatory if the allocated quantity of explosive materials cannot be supplied). This recommendation has been also pointed out in the recommendation (Section 7.2) of this guideline.

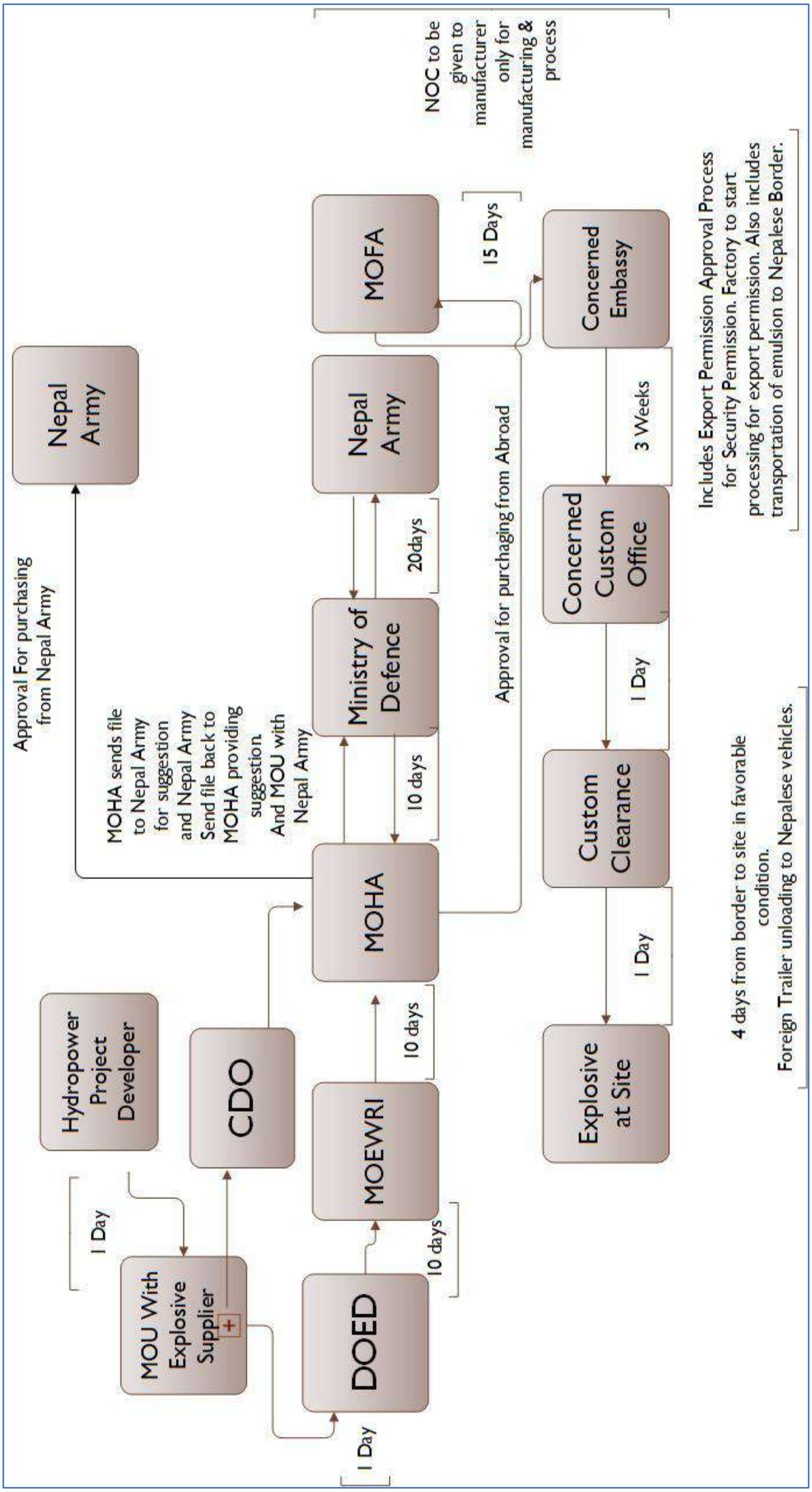


Figure 3-46 Flow chart showing explosive materials procurement procedure showing tentative processing dates (Source: Synex Power)

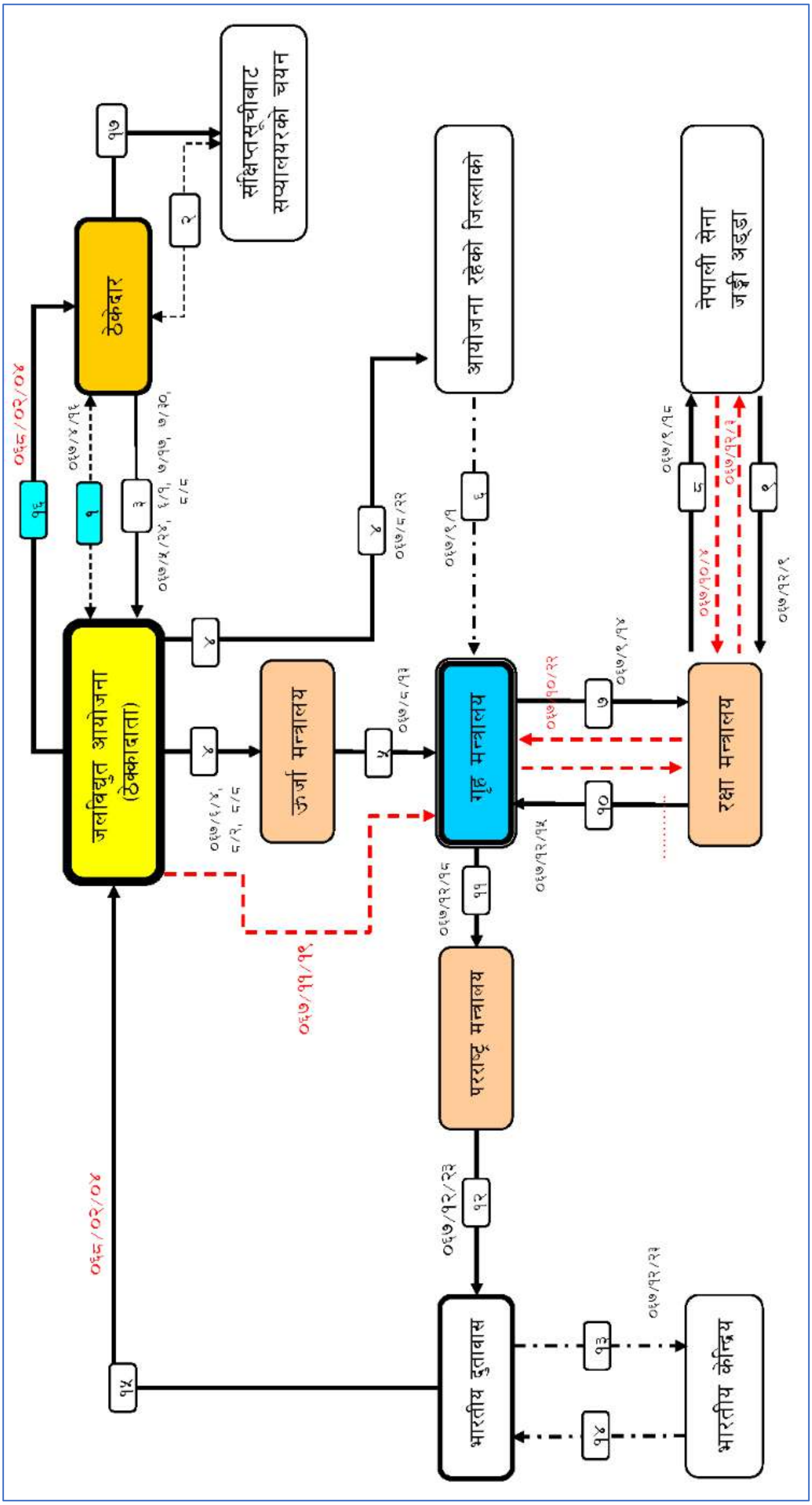


Figure 3-47 Flow chart showing explosive material procedure with exact processing dates (Source: Upper Tamakoshi HEP, 456 MW)

This page intentionally left blank

4 GUIDELINES FRAMEWORK FOR OPERATIONAL HEALTH AND SAFETY REGARDING EXPLOSIVE MATERIALS

4.1 Introduction

Operational health and safety regarding explosive materials encompasses measures and protocols designed to protect personnel, property, and the environment from potential hazards associated with the handling, storage, and use of explosive substances. Generally, operational health and safety includes implementing strict safety procedures, providing comprehensive training to personnel, conducting regular inspections of storage facilities and equipment, utilizing appropriate personal protective equipment (PPE), and establishing emergency response plans. This guideline presents the framework for the operational health and safety regarding explosive materials in the following topics.

a) General requirement for drilling and blasting;
b) Major hazards and risks and its elimination measures;
c) Blasting safety for surface blasting; and
d) Explosive stored in site magazine and site transportation.

4.2 General Requirement for Drilling and Blasting Operation

Certain requirements of operational health and safety should be addressed for all civil engineering works in the hydropower development for the effective drilling and blasting operation. The general requirement for the drilling and blasting operation to be adopted by the hydropower projects of Nepal in pursuant to this guideline has been enlisted below:

a) No person except registered master blaster from CDO office of GoN can handle and prepare the explosive products;
b) No person shall smoke at or near any blasting site while explosives are being removed from a store/magazine or while charges are being prepared for blasting or are being laid;
c) No person except the registered master blaster in charge can set off the shot;
d) Any blasting operations, including storage, transportation, loading, firing, and destroying of any explosive products must be in accordance with the regulation (Explosive Act, 2018; and and Explosive Regulation, 2020 among others), permit conditions and restrictions imposed by the GoN;
e) No person except the registered master blaster can handle any misfire. When a misfire is being handled by the master blaster, the evacuation procedure should be remained effective;
f) No blast shall be fired unless effective and adequate precautions are taken to prevent any fragments being projected in a dangerous manner, in particular going beyond the site boundary;
g) An approved evacuation procedure should be carried out strictly. For a period lasting from 5 min prior to blasting until all charges have been fired, warning gongs shall be beaten continuously so as to be audible at a distance of 200 m from the blast and red flags shall be displayed continuously at all points of access to the place of blasting and at a distance of 200 m from the blast;
h) Any person who, after the commencement of the warning signals referred to in above paragraph, enters or, upon request being made to him by any public servant or any person engaged in the blasting, refuses to leave the blasting area shall be guilty of an offense;
i) Any person who finds any remaining explosive products in the site should report to the registered master blaster or Nepal Army residing in the bunker site of the given hydropower project immediately, and no person except the registered master blaster or designated official from the Nepal Army can handle and destroy the remaining explosives;

j) A strict and effective managing system is one of the most important guarantees to the safety and project progress. The principle of an effective management system should be that "strictly carry out every step of the procedure of blasting works and clarify the duty and responsibility of each step and every person in the working procedure." An example of the flowchart of the procedure of blasting works for any drilling and blasting operation is shown in Figure 4-1; and

k) Please refer to Section 4.2 for further general requirements and elimination measures related to explosives and blasting works.

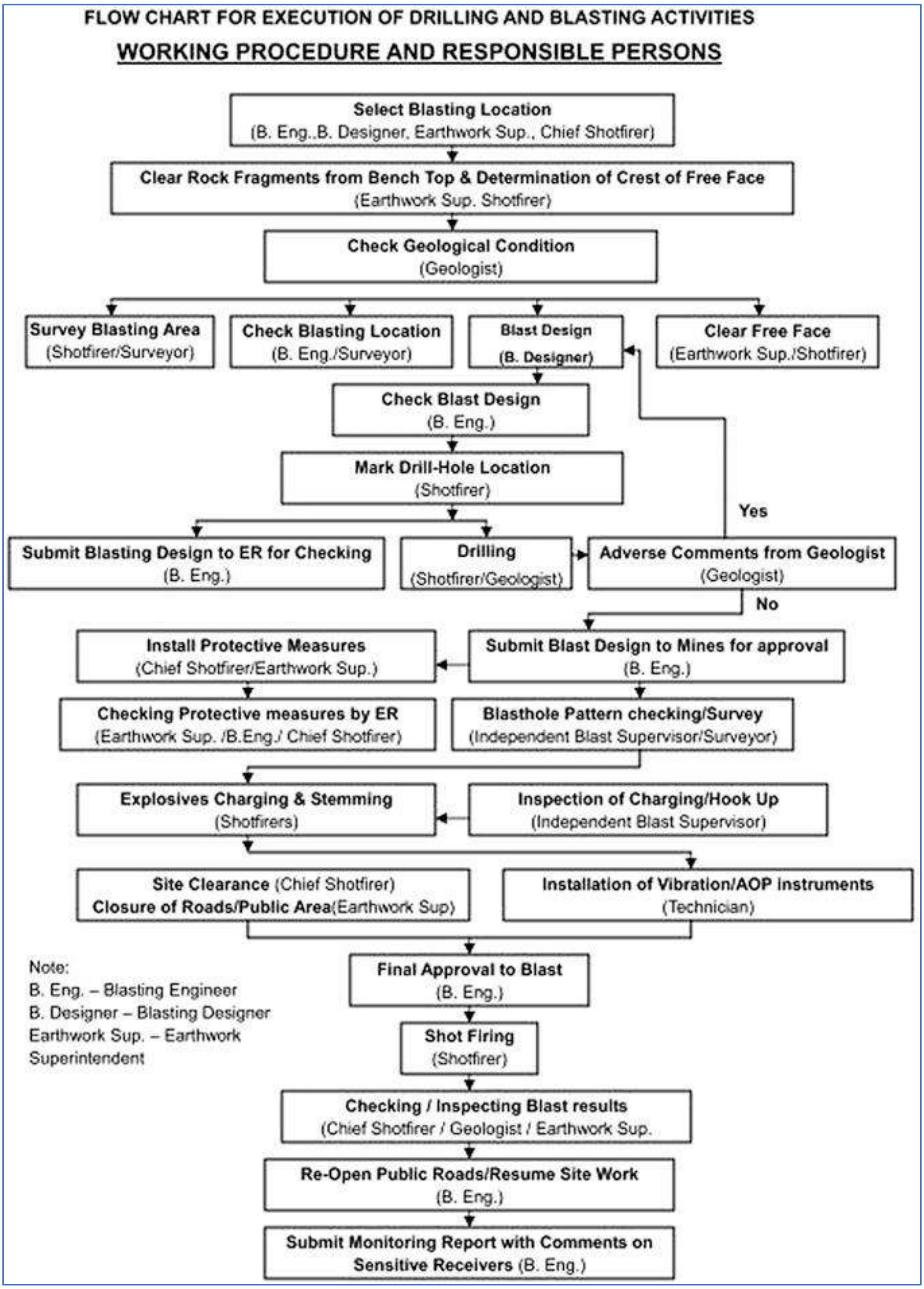


Figure 4-1 Blasting Management Procedure (Source: Zhou, 2017)

For the drilling and blasting activities using explosive materials, the general requirements with regards to operational health and safety mentioned in this section are basically to ensure that the major blasting related impacts like noise, vibration, and slope failure along with the safety of workers, general public and their properties should be adequately managed. It should be noted that maintaining equipment, skilled personnel, and clear communication are crucial for effective drilling and blasting operations. Thus, employee identification system, illumination, communication, and signals in the drilling and blasting location have been considered as general requirements for effective drilling and blasting activities in this guideline. Other activities related to explosive material monitoring has been summarized in the blasting and explosive management plan presented in Section 3.3.3.

4.2.1 Employee Identification System

Employee Identification Systems are tools utilized by organizations to uniquely identify and verify their employees within the workplace. The primary functions of Employee Identification Systems include ensuring workplace security, controlling access to restricted areas, monitoring employee attendance, and streamlining administrative processes within the organization. Moreover, in compliance with regulatory requirements, hydropower projects must demonstrate effective access control and personnel identification measures.

The following requirements of operational health and safety should be addressed herewith for the effective drilling and blasting operation.

a) The contractor must identify and differentiate the workers related to drilling and blasting activities with other workers;
b) The blaster should have a valid blasting license issued by any Chief District Office of Nepal;
c) Entrances to all drilling and blasting location including both underground and surface sites must have check-in and check-out system that provides the contractor with an accurate record of each person at the given location;
d) The system must provide employees with unique identification cards or badges containing essential information such as their name, photo, job title, and possibly access permissions. To ensure that only authorized personnel with proper training and clearance can access these restricted zones;
e) By issuing to employees, the system;
f) The system must be able to identify each individual and its location; and
g) Tally system (also called tag system) which is an effective check-in and check-out system should be employed by the contractor for all personnel entering into the drilling and blasting locations.

4.2.2 Illumination

Illumination is indispensable for drilling and blasting operations as it ensures worker safety by providing visibility to identify hazards and obstacles, facilitates accurate positioning of drilling equipment for optimal blast results, enables quality control inspections of drilled holes before loading explosives, maintains operational efficiency by allowing round-the-clock operations, and ensures compliance with regulatory standards regarding workplace lighting requirements.

The following requirements of operational health and safety regarding the illumination should be addressed herewith for the effective drilling and blasting operation.

a) All the work places and their approaches where there is insufficient natural light should be lit by artificial means with recommended mean lighting levels (quoted from BS 6164: 2011) as stated in the Table 4-1 below.;
b) Provision of the emergency lighting in work places where failure of main lighting system should be established with recommended mean lighting levels as stated in the Table 4-1.

c) Temporary lighting arrangements must be adjusted or supplemented to ensure consistent illumination levels throughout the blasting process, especially in areas where access is limited or where the risk of debris and dust may reduce visibility; and
d) Regular assessments of lighting conditions and adjustments as necessary should be conducted by the designated OHS officer of the hydropower project to maintain adequate safety standards during tunnel blasting operations.

Table 4-1 Lighting level in drilling and blasting location

S.N.	Drilling and Blasting Location	Lighting Level
1	Walkways and tracks	10 lux
2	General working areas	100 lux
3	Tunnel face, excavation area, crane lifting point	100 lux illuminated from at least two widely separated source to avoid shadows

4.2.3 Communication

Communication during blasting operations in tunnels is vital for ensuring the safety of personnel and the effectiveness of the operation. Real-time communication also enables prompt reporting and response to any safety concerns or issues that may arise during the blasting process, allowing for immediate action to mitigate risks and ensure the well-being of personnel.

The following requirements of operational health and safety regarding the communication should be addressed herewith for the effective drilling and blasting operation.

a) Proper communication mechanism for pre-blasting, during blasting and post-blasting operations as well as for emergency condition must be established prior to any drilling and blasting operations of a hydropower project;
b) For pre-blast communication, frequent pre-blast meeting within the workers, and blast plan distribution to the all involved parties must be made;
c) All key personnel must be equipped with two-way radios to ensure continuous and immediate communication;
d) Specific communication channel for different aspect of drilling and blasting operation must be established in order to prevent confusion. For instance, drilling, loading, and blasting teams must have designated communication channels;
e) For the post-blast communication, post-blast signal such as "All Clear" signal and "Re-entry" signal should be used only after results of post blast inspection have been communicated to all the relevant personnel to ensure the area is safe and to address any issues that may have raised.
f) Detail record of all communications including blast plans, notification, signals given, and incident reports must be maintained by the master blaster/ environmental officer;
g) Comprehensive training programs on the communication protocols such as use of equipment and emergency procedures must be provided to all the personnel;
h) Blasting notice board should be maintained in all access point of the hydropower projects which must include blasting construction period, blasting schedule, alarming area, and blasting warning pattern. A sample of blasting notice board has been presented in the Figure 4-2 (Safety induction of UT-1); and
i) Regular maintenance and testing of all communication equipment should be done by the designated officer.

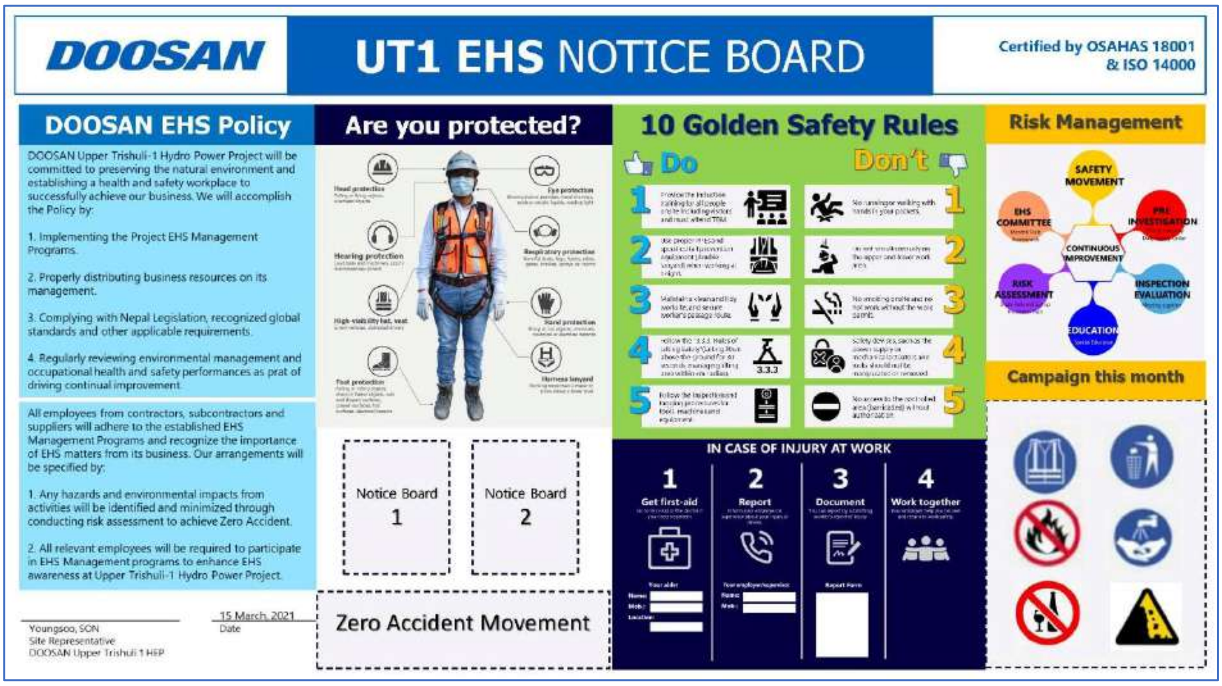


Figure 4-2 Blasting notice board (Source: UT-1 HEP Blasting and Explosive Management Plan)

4.2.4 Safety Signals

Signals are crucial during drilling and blasting operations for ensuring safety, coordination, timing, warning, and quality control. Signals serve as warnings before blasting, allowing for timely evacuation and precautionary measures, thus minimizing risks of accidents or injuries.

The following requirements of operational health and safety regarding the safety signals should be addressed herewith for the effective drilling and blasting operation.

a) Placards displaying: "Be alert of blasting operation" at the vicinity of about 200 m from drilling and blasting location must be established by the contractor. A placard sample acquired from the Upper Trishuli-1 Hydropower Project (216 MW) has been presented in the Figure 4-3 for reference;
b) The notice board sharing the updated information of blasting time, blast area and clearing procedure must be established at all access points by the contractor;
c) Pre-blast signal, blast signal and post blast signal should be clearly discernible and different from one another;
d) Pre-blast signal should have unique warning signal and clearing signal. However, the number and duration of the signal may vary with respect to the distance from the settlement to the blasting site;
e) A single long blast signal must be given immediately before the blast;
f) Post-blast signal should have unique "All Clear" signal and "Re-entry" signal. However, the number and duration of the signal may vary with respect to the distance from the settlement to the blasting site;
g) The specific decibel level of the safety signal should be at least 10-15 dB higher than the surrounding noise recorded during the construction stage of the hydropower project;
h) A combination of audible and visual signal example sirens, horns, strobe lights, flags, should be applied to enhance the effectiveness of the safety signal especially in the noisy environment;
i) Regular testing of the signaling equipment's must be done by the OHS Officer;

j) Detail blasting plan must include the timing and nature of safety signals in order to ensure everyone on site is familiar with the signals used;
k) All personnel must be trained to recognize and respond appropriately to each signal; and
l) Co-ordination with local authorities and communities must be done regarding the blasting schedule and safety signal to minimize the risks and disturbances.

Figure 4-3 Placards displaying: "Be alert of blasting operation" (Source: UT-1 HEP Blasting and Explosive Management Plan)

Major Hazards and Risks and its Elimination Measures

Drilling and blasting operation are inherently hazardous due to the use of explosives, heavy machinery and the potential for the environment impacts. Some of the major hazards and risk associated with this operation along with elimination measures have been elaborated in the following topics in this guideline.

a) Ground risks;
b) Ground vibration produced by blasting;
c) Tunnel transport;
d) Tunnel atmosphere and air quality control;
e) Fire and rescue system; and
f) Explosives and blasting works.

4.2.5 Ground Risks

Ground risks such as ground settlement and ground collapses are the serious failures that can occur during drilling and blasting operations. These ground risk may result in fatalities, damage in properties, and other socio-economic consequences. Moreover, these ground risks also affects financial loss.

4.2.5.1 Elimination Measures of Ground Risks

a) Detailed pre-blast surveys and risk assessments to identify ground parameters, discontinuities, water, gas, and contamination should be made prior to any drilling and blasting operation;
b) Controlled blasting technique should be used to minimize seismic energy transmission;
c) Ground settlement at both ground surface and in the tunnel should be closely monitored in regular intervals near the vicinity of the drilling and blasting operation;
d) Similarly, variation of the ground water table should be closely monitored;
e) Stability of surrounding rock mass and the support system (including rock bolts, rock anchor, shotcrete, and permanent lining) near the drilling and blasting operation should be closely monitored; and
f) Necessary reinforcement measures must be taken as early as possible.

4.2.6 Ground Vibration Produced by Blasting

The ground vibration is produced during blasting operation due to the propagation of seismic waves through ground. Ground vibration may cause damage and disturbance to nearby infrastructures and utilities. So, there are various safety limitation for blasting vibrations/ground vibration level adopted by different countries. So, this guideline adopts the safety limitation for blasting vibration recommended by US Code of Federal Regulation (CFR) 30 which has been presented in Table 4-2. Thus, the blasting vibration criteria adopted in this guideline is based on the peak particle velocity (PPV and distance of infrastructure and utilities to blast area.

Table 4-2 Adopted safety limitation for ground vibration (US Code of Federal Regulation (CFR-30))

S.N.	Distance from infrastructure and utilities to Blast Area (m)	Peak Particle Velocity (mm/s)
1.	0-90	32
2.	90-1500	25
3.	>1500	19

The general formula for prediction of ground vibration in the far-field locations is based on the peak particle velocity. The vibration that results from a blast can be calculated using the formula mentioned below:

$$PPV = K(R/Q^{d})^{-b}$$

Where,

PPV= Predicted Peak Particle Velocity in mm/s;

K= A constants determined by the characteristics of the ground that the vibration passes through and the explosive's power;

Q= Maximum charge weight per delay interval in kg;

R= Distance in meter between the blast and the measuring point;

d= Charge exponent, usually;

b= Attenuation exponent

The value of the above parameters is given in the Table 4-3.

Table 4-3 Value of constant for the ground vibaration (ISEE (1998) Blaster's Handbook)

S.N.	Constant	Adopted Value
1.	d	1/2
2.	K	1140 for average value, 1720 for upper bound and 4316 for heavy confined
3.	b	1.6

4.2.6.1 Mitigation Measures for ground vibration produced by blasting

a) The factors which affect the magnitude of the ground vibration should be classified into controllable and uncontrollable factors. Controllable factors (blast geometry, type and amount of explosive used, priming, and initiation and uncontrollable factors (distance, geological condition, and initiation timing errors) should be duly considered and measured prior to drilling and blasting operation;

b) Detailed pre-blast surveys and risk assessments to identify ground parameters, discontinuities, water, gas, and contamination should be made prior to any drilling and blasting operation;

c) Blast parameters must be controlled and monitored for each drilling and blasting cycle to minimize vibration and over pressure;
d) Appropriate delay detonation technique should be used to spread the blast energy over time;
e) Stability of surrounding rock mass and the support system (including rock bolts, rock anchor, shotcrete, and permanent lining) near the drilling and blasting operation should be closely monitored; and
f) Necessary reinforcement measures must be taken as early as possible.

4.2.7 Explosive misfires

Explosive misfires occur when an explosive charge fails to detonate as intended. Misfires are the serious hazard in blasting operation as they can lead to accidental detonation at an unexpected time. The common causes of misfires may be faulty detonators, improper wiring or connections, damp or contaminated explosives, incorrect charge placement, premature initiation or any other technical malfunctions.

4.2.7.1 Preventive measures for explosive misfire

a) Necessary reinforcement measures must be taken as early as possible;
b) High quality explosive and detonators must be used from a reputable supplier or manufactures;
c) Electric circuits and connection must be thoroughly tested before firing;
d) All blasting setup components must be double checked before initiating the blast;
e) Reliable and well-maintained equipment for detonation must be used; and
f) All personnel handling explosive must be thoroughly trained in properly handling, wiring and detonation procedures.

4.2.8 Chemical exposure

Chemical exposure during drilling and blasting operations can pose significant health and safety risk to workers and the environment. The common hazards related to chemical exposure are respiratory issues, skin and eye irritation, toxic effects in human organs and explosive hazard among others.

4.2.8.1 Elimination Measures for chemical exposure

a) The explosive materials with less hazardous substances should be used wherever possible;
b) Minimum amount of chemical/explosives necessary to achieve the desired result of blasting should be used;
c) Adequate ventilation to disperse fumes and dust should be provided at particularly confined or enclosed spacing in drilling and blasting operations;
d) Physical barriers and enclosures should be used to limit the spread of dust and fumes;
e) Safety protocols for handling, storing and transportation of explosive material/chemical must be developed and enforced;
f) Personal Protective Equipment (PPE) such as respiratory protection, eye protection and skin protection must be used by all personnel during the drilling and blasting operation;
g) Proper storage and handling procedures should be developed and enforced;
h) Emergency Response Plan for chemical spills, exposures and accident must be developed and implemented;
i) First aid station equipped with health personnel and medical facilities must be set up near the vicinity to respond chemical exposure incidents; and
j) Effective communication system to report and manage emergency promptly must be well maintained by the hydropower project.

4.2.9 Tunnel Transport (Access problem and equipment related accident) mis-communication)

A tunnel is a confined space in which visibility is often poor due to lack of lighting. Consequently, there is a high rick of collision between men and machines. Similarly, operation of the heavy drilling equipment can lead to accident in and around the drilling and blasting locations if not properly maintained and operated.

4.2.9.1 Elimination Measures for Tunnel Transport

a) Ground support such as rock bolts, mesh, shotcrete and other support system should be adequately installed to stabilize tunnel walls or rock benches;
b) For proper water management within the tunnels drainage system, water proof barriers, and water pumps should be adequately applied to control water ingress;
c) Continuous monitoring of ground condition, air quality and equipment integrity should be done making routine safety inspection as per need;
d) Personal Protective Equipment (PPE) such as respiratory protection, eye protection and skin protection must be used by all personnel during the drilling and blasting operation;
e) Emergency response plan should be developed and exercised for various scenarios such as fires, explosion and bank collapses among others; and
f) If possible, remote-controlled or automated machinery such as boomers, and drill rigs should be used to reduce the risk of human exposure to hazardous conditions.

4.2.10 Tunnel Atmosphere and Air Quality Control

The quality of atmosphere is very important during any drill and blasting operation because any contaminants present in the tunnel atmosphere may affect everyone working in it. So, there must be a certain air quality requirement especially when operating in confined or enclosed spacing such as tunnel or any other underground structure. Thus, this guideline adopts underground air quality requirement for drilling and blasting operation in tunnel developed by US Reclamation Safety and Health Standards (RSHS) 2014. This guideline recommends that the tunnel atmosphere during the drilling and blasting operation must meet the requirements presented in the Table 4-4 for proper air quality control.

Tunnel ventilation should be properly managed for the safety of the workers in the tunnel or cavern. One incident showing the importance of maintaining tunnel atmosphere and air quality control in Nepal has been highlighted where four workers died inside a tunnel at the construction site of a hydropower project in Bajhang district of Sudurpaschim Province of Nepal primarily caused due to the lack of proper ventilation system inside the tunnel. The workers went inside the tunnel after the long gap of about 35 days after the celebration of Dashain-Tihar festival without operating the ventilation fan, checking the fumes and toxic gases, PPEs and emergency rescues system. The incident happened on November 3, 2019 when a team of seven workers drove into the 1,600-metre-long tunnel.

Table 4-4 Adopted air quality control requirements for occupational tunnel atmosphere (RSHS, 2014)

S.N.	Gases / Contaminants	Concentration
1.	Oxygen, O_2	>19%
2.	Carbon monoxide, CO	<25 ppm
3.	Carbon dioxide, CO_2	<5000 ppm
4.	Nitrogen dioxide, NO_2	<3 ppm
5.	Hydrogen sulphide H_2S	<10 ppm
6.	Methane gas, CH_4	<20% of lower explosive limit (4.4%)
7.	Other flammable gases or vapour	<10% of lower explosive limit
8.	Other airborne contaminants, including dust	5 mg/m^3

4.2.10.1 Elimination Measures for Tunnel Atmosphere and Air Quality Control

a) The tunnel ventilation system should be well designed and properly maintained in a regular basis;
b) The concentration of oxygen, dust, toxic or potentially explosive fumes, or harmful gases in the tunnel atmosphere should be routinely monitored/ tested and steps should be accordingly taken to ensure contaminant levels do not exceed those laid down by national legislation or guidance;
c) Personal Protective Equipment (PPE) such as respiratory protection, eye protection and skin protection must be used by all personnel during the drilling and blasting operation;
d) Emergency response plan must be developed to address any sudden release of harmful gases or fumes during drilling and blasting operations; and
e) All workers and related personnel should be provided with training on the hazards of poor air quality of tunnel atmosphere and importance of proper ventilation and safety procedures.

4.2.11 Fire and Rescue System

The most significant safety hazards of tunneling are fire and smoke. In particular, it is the rapid spread of smoke through the whole tunnel space, rather than radiant heat generated by a fire, which can lead to fatalities. In most tunnels under construction, the main source of fuel for fire is the large quantities of plastic, rubber, and other flammable materials found on plant, and equipment.

4.2.11.1 Elimination Measures for fire and rescue system

a) Fire prevention measures such as regular inspection and maintenance of equipment, proper storage of flammable materials including explosive materials, and adhering to safe practices must be strictly implemented during any drilling and blasting operation in a hydropower project;
b) An effective fire-fighting system must be built up and continually extended along with the tunnel advancing. The system must include both the fixed onboard fire suppression system on all plant and equipment and movable handheld extinguishers and fire mains with hydrants and hose reels. The details of fire extinguishing equipment have been presented in the Section 4.2.11;
c) Clear and well-marked emergency exits and evacuation routes in the drilling and blasting location should be maintained to ensure a swift and safe evacuation in case of a fire;
d) Effective communication must be established to quickly alert all personnel in the event of fire emergency in order to co-ordinate safe evacuation and effective firefighting efforts;
e) Fire drills to practice emergency response procedure should be carried out regularly in order to ensure all personnel are familiar with their roles and responsibilities during a fire emergency;
f) The contractor involved in the drilling and blasting operation must have their own fire and rescue system in place and also comply with safety requirement to minimize the risk of fire incidents;
g) Good housekeeping should be done which is a vital precaution in minimizing the built-up of flammable rubbish; and
h) Regardless of the situation, contacting the Nepal Police and fire brigade is imperative. Any accidents must be reported to DoED within eight days.

4.2.11.2 Rescue system

a) Unrestricted and unobstructed access to all areas including all tunnel areas should be provided at all time;
b) An emergency control center at ground level incorporating an emergency roll call system should be established near each controlled access point to the tunnel. All other points of entry to the tunnels must be secured to prevent unauthorized access;
c) An updated plan showing the layout of the tunnels which includes the locations of refuge, locations of firefighting installations, and designated emergency assembly points should be provided at the emergency control center for reference to all related personnel;

d) Where a tunnel extends greater than 200 m, a suitable vehicle should be provided for conveyance of firefighting equipment and personnel inside the tunnel during emergency;
e) A tally system should be provided at all access points to control and record the number of persons in the tunnel at any time;
f) A dedicated intercommunication system, in the form of direct telephone shall be provided to the emergency control center and locations along the tunnels at not greater than 60 m intervals. Manual alarm points with audible and visual warning devices should be provided. The radio communication system should be also provided. The alarm system should be connected to the emergency control center;
g) Self-luminous exit signs/directional exit signs and emergency lighting should be provided;
h) Gas detectors which are capable of detecting combustible gas, oxygen concentration level, and hazardous poisonous gas should be provided and readily available for emergency use at the emergency control center and at each tunnel portal;
i) A secondary power supply or back-up generators should be provided to support the operation of tunnel lighting and ventilation systems and all emergency services in the event of power failure; and
j) A separate compartment/refuge chamber should be provided in the close proximity of the tunnel entrances to serve as a buffer zone to safeguard fire service operation and breathing apparatus entry control point.

4.2.11.3 Provision of fire extinguishing equipment

Regarding the provision of fire extinguishing equipment, this guideline has adopted the British Standard, BS 6164: 2011. The list of the suitable firefighting equipment has been presented in Table 4-5.

Table 4-5 Portable fire extinguishing equipment

S.N.	Class of materials involved	Extinguishing medium
1.	Fire involving solid usually of an organic nature,	Water extinguisher
2.	Fire involving liquids or liquefiable solids	Foam extinguisher, CO2, and dry powder
3.	Fire involving gases	Water spray to cool cylinder, foam to extinguish any fire when valve has been closed
4.	Fire involving metals	Dry powder, dry sand
5.	Electrical equipment (if live)	Inert gas, dry powder, and dry sand

4.2.12 Explosives and Blasting Works

For drilling and blasting operation, the main hazards mentioned in the above sub-sections such as dust, noise, vibration etc. is due to explosive uses and blasting works. So, the blasting of explosive itself and be regarded as major hazards and risks during any drilling and blasting operation. The main risks from using explosives include premature detonation and atmospheric contamination from the dust and blast fume released by the blast.

4.2.12.1 Elimination measures to be adopted during explosives and blasting works

a) All explosives delivered to the site must be moved directly to the blasting location and charging commenced immediately;
b) Explosives must be handled and used only by the registered master blaster;
c) Only non-electric (shock tube) or electronic detonators shall be used for drilling and blasting operation. There are plans to potentially ban electric detonators in the future, so it is recommended to focus on using non-electric detonators. Non-electric detonators are safer than electric ones;
d) Considering the operation health and safety measures, the use of safety fuse as an initiation system should be completely avoided. The details regarding the use of safety fuse have been explained in Section 3.1.4.1A.

e) If non-electric initiation system is used, one (and one or two for back-up) electric detonator can be used for initiating the non-electric initiation system. These electric detonators must be locked in a wooden case and located in a dry place and visible by the master blaster at all times. It should be noted that the production of electric detonator has been prohibited in the neighboring countries. So, the availability of the electric detonator is in question. Thus, this guideline recommends the use of "State-Of-The-Art" initiation system such as non-electric (shock tube) or electronic detonators for explosive detonation and blasting works;
f) The master blaster must keep the key of the case all the time;
g) Only at the time when the evacuation procedure has been completed and the shot is to be fired, by the registered master blaster;
h) Nobody except the master blaster and their assistants can stay in the drilling and blasting location when the explosive charging is underway;
i) After charging, an approved evacuation procedure must be carried out. Firstly, the master blaster must clear the tunnel, including the adjacent underground work site if any, and ensure all people have been evacuated out of the drilling and blasting location;
j) A tally system (or called tag system) as explained in section 4.2.1 must be used to ensure all people have left the drilling and blasting location prior to firing; all people must leave the portal area and stay in designated safe places;
k) If blast door is required, it should be closed and the guarders must not let any people enter the tunnel before blasting is completed, and entering tunnel is permitted only after sufficient ventilation has been provided;
l) In order to reduce the noise produced by blasting and the impact of rock fragments some buffer materials, such as waste rubber belts and sound insulation materials are recommended to be set up at the drilling and blasting location;
m) If there is a misfire, the master blaster must clear the tunnels again, and the evacuation procedure must remain effective. The master blaster must handle the misfire personally according to the safety procedure explained in Section 4.2.7; and
n) After drilling and blasting operation, the rock face of the tunnel roof and walls or rock benches or trenches must be carefully checked and scaled. Any loosened rock must be barred down and temporary support must be carried out immediately if necessary.

4.2.12.2 Safety procedures for explosive and blasting works

a) All related personnel must be properly trained and competent in the use of the master blaster and associated equipment;
b) Master blaster must conduct a thorough inspection of the drilling and blasting equipment including explosive materials prior to use to ensure they are in good working condition;
c) Detailed written blast plan outlining the sequence of drilling, charging, and blasting operations, as well as any specific safety considerations for the sites must be prepared prior to any drilling and blasting operation;
d) Blast exclusion zones must be clearly marked and communicated to prevent unauthorized access by personnel or equipment;
e) Appropriate Personal Protective Equipment (PPE), such as goggles, ear protection, and blast-resistant clothing must be provided to the master blaster and his/her subordinate to minimize the risk of injury during drilling and blasting operations;
f) Effective communication protocols must be implemented to ensure all personnel involved in the drilling and blasting operation are aware of the blast plan, exclusion zones, and any potential hazards;
g) Pre-blast meeting should be conducted to review the blast plan, identify any potential hazards, and ensure all personnel understand their roles and responsibilities;

h) Weather conditions should be monitored and accordingly the protocols for delaying or canceling drilling and blasting operations if adverse conditions, such as high winds or lightning, could pose a safety risk.
i) Access to the blast site should be secured and regularly maintained to prevent unauthorized entry and ensure all personnel are clear of the area before initiating the blast.
j) After the blast, a thorough inspection of the blast site must be conducted by the designated master blaster in order to identify any misfires or unexploded explosives and implement appropriate measures to safely remove or detonate them.
k) Safety measures to be taken in drilling for the safety of personnel and effectiveness of operation should include
   i. Avoiding drilling in old holes that may contain explosives;
   ii. Meticulous checking of borehole parameters to prevent overloading and identify weak zones; and
   iii. Securing drills against various hazards such as falls, landslides, and vibrations.

4.3 Blasting Safety for Surface Blasting

One of the largest single problems that are faced by a blasting contractor is blasting safety. The principal disturbances created by blasting are flyrocks, ground vibration, and airblasts. All of these disturbances can be the source of serious conflict with the inhabitants who live close to the operation. In order to solve these problems, it is necessary to have more highly qualified blasting engineer and blasting supervisors so that they can reduce the level of disturbances at a reasonable cost.

In situations where complaints persist, continued attention to blast design, effective monitoring, and good record keeping may take on even greater importance. If the complaint is taken to the authorities, records detailing blast design and monitoring records can be very important when discussing the problem. Thus, the general safety requirements of the principal disturbances (such as fly rocks, ground vibrations, air overpressure, etc.) created during the drilling and blasting operation to be adopted by the hydropower projects of Nepal in pursuant to this guideline have been thoroughly discussed in the following sub sections. Moreover, specific blasting safety for trench blasting and boulder blasting have also been thoroughly discussed in the following sub sections.

4.3.1 Fly Rocks and Its Control

Flyrocks, also called rock throw, is the uncontrolled propelling of rock fragments produced in blasting and constitutes one of the main sources of material damage and harm to people. Flyrocks usually appears on the front free face or top free face of the blasted bench. Some of the common causes of flyrocks are as follows:

a) Adverse geological conditions of rock mass;
b) Un-uniform distribution of explosives charge or overloading holes;
c) Inadequate amount of or ineffective stemming; and
d) Inaccurate drilling and poor blasting design.

Determining the safe distance of blasting within which all people should be evacuated from any drilling and blasting location is the most important issue related with the fly rocks. So, this guideline recommends the following formula is used in Hong Kong for calculating the safe distance from flyrocks for blasting in hilly terrain as it takes into account of the relative differences of blast elevation and usually downslope sensitive receivers or area of concern which is similar to topographic condition of Nepal.

$$\boldsymbol{D_s = 150 \times \frac{d}{75} + (H_1 - H_2)}$$

Where,
Ds = safe distance for flyrocks, m;
d = diameter of blastholes, mm;
H_1= blast location elevation, m;
H_2= flyrocks sensitive receiver elevation, m.

4.3.1.1 Measures for Reducing/Controlling the Risk of Flyrocks

For precaution against flyrocks in blasting the following should be kept in mind:

a) Carefully inspect the geological conditions of the rock mass to be blasted and make a proper blasting design to suit the conditions;
b) Keep a proper burden of blast holes specially the holes close to the free face;
c) Have good stemming using free-flowing materials; and
d) Take adequate protective measures to protect nearby properties and public area.

4.3.1.2 Protective Measures for the Prevention of Flyrocks

According to the different circumstances, one or more of the following protective measures should be applied for the prevention of flyrocks in the surface blasting as mentioned in Table 4-6.

Table 4-6 Protective Measures for the Prevention of Flyrocks

S.N.	Protective Measures	Application
1	General ground cover	The horizontal rock face to be blasted is fully covered with gunny sack (or canvas sheets) and mats of wire mesh then weighed down with sufficient sandbags;
2	Heavy ground covers	The horizontal rock face to be blasted is fully covered with rubber tire blasting mats, blasting cages, or backfill.
3	Vertical blasting screens	They may be movable/fixed shall be erected at the sides of the blasting area which are facing to the public or properties
4	Roof cover	In some special situation, a roof cover structure (e.g. use of waste tyres) may be required to built-up to prevent flyrocks from harming public and structures

4.3.2 Ground Vibration and Its Control

The most common type of blasting damage is caused by ground vibrations. When an explosive detonates in a blasthole, it generates intense stress waves moving in the rock. Ground vibrations from blasting are acoustic (as opposed to electromagnetic) waves that propagate through the earth. They are also termed "seismic" waves because their propagation characteristics are similar to the ground motions produced by earthquakes. Ground vibration from blasting have much lower peak amplitudes and higher dominant frequencies than earthquake vibration, primarily because of their lower energies and smaller propagation distance.

Adopted safety limitation for ground vibration, general formula for prediction of ground vibration, and mitigation measures for ground vibration produced by blasting have been thoroughly discussed in Section 4.2.6.

The parameters which affect the characteristics of vibration can be classified in two groups: controllable and uncontrollable. Controllable factors include blast geometry, type and amount of explosive used, priming, and initiation. Uncontrollable includes distance, geological condition, and initiation timing errors. These parameters have been discussed in the Table 4-7.

Table 4-7 Controllable and uncontrollable factors for ground vibration and how it affects

S.N.	Factors		How it affects ground vibration
1.a	Controllable	Geometric Parameter of blasting design	If the burden is excessive, the resistance to rock movement and swelling increases, and more explosive energy will transfer to ground vibration. Wide spacing and small burden can improve the distribution of energy of strain waves in the bench rock, resulting in improved fragmentation, and also reducing the ground vibration due to the reduction in the confinement of the burden rock. Excessive subdrilling will clearly increase the ground vibration due to the higher resistance for shearing the toe rock of the bench. The vibration caused by a blast with less rows and rectangular shape with long free face is obviously less than the vibration caused by a blast with more rows and short free face. The firing direction also affects the ground vibration intensity along different directions of propagation paths.
1.b		Detonator timing scatter	The timing scatter of the detonators in a blast causes timing overlay of some blastholes which should be detonated in different firing time according to the designed firing sequence. The delay interval should be equal to or greater than 8 ms in order that the two charges can be considered separate charges.
1.c		Type, amount, and coupling of explosives	The amplitude of the pressure pulse is directly proportional to the strength of explosive and amount of explosive used. Charge weight per delay is the most important factor which controls the intensity of ground vibration. The larger the quantity of charge detonated per delay, the higher the vibration. The coupling of the explosives charge to the rock affects how much of the energy is transferred to the rock, hence the intensity of the vibration, as well the effectiveness of blasting in fracturing the rock.
2.a	Uncontrollable	Site Geology	Harder rock will have higher wave velocity and frequency. When the rocky substratum is covered by soil overburden, this usually affects the intensity and frequency of vibration. Soil usually has less elasticity modulus than the rock and, for this reason, the wave propagation velocity decreases in this type of material.
2.b		Distance from the blasting	As the distance from the blasting increases, the particle velocity and frequency of ground vibrations decrease due to the absorption, dispersion, and dissipation of the elastic wave.
2.c		Initiation timing errors	

4.3.2.1 Measures for Reducing/Controlling the Risk of Ground Vibration

The most effective measure for controlling the vibration level is (1) an optimal blasting design: and (2) controlling the explosive charge weight per delay. The following methods can be used to obtain and optimum blasting design.

a) An optimal value of burden is very important as it can get the best fragmentation, proper swelling, and the lowest ground vibration. Too large burden and choke blasting must be avoided strictly. The optimal burden can be determined through trial blasts.
b) A carefully adopted initiation pattern and firing sequence is the key to spread the explosive to be used over more intervals and avoid the timing overlap and reverse firing order of charges. Properly longer delay time between rows can avoid reverse firing order and offer an inner free face between adjacent rows to improve the fragmentation and reduce the vibration.
c) Accurate drilling of holes needs to be carried out to avoid uneven burden and excessive subdrilling.
d) Carefully design the firing direction and rock movement, and try to avoid the backward directing from facing the sensitive vibration receivers.
e) Ensure there is a sufficient free face of the blasted rock mass in front of the direction of rock swelling and movement

Similarly, the following methods can be used to reduce the charge weight per delay:

a) Reduce the hole number and diameter;
b) Reduce the bench height or divide a high bench into more benches;
c) Use decked charge by dividing the necessary drillhole charge level into more ignition intervals through inter-stemming; and
d) Use decoupled charge with the cartridges of smaller diameter than the hole diameter

4.3.3 AOP (Air Overpressure) and It's Control

Airblast or air overpressure (AOP) is an energy transmission in the form of pressure waves from the blast site within the atmosphere. The pressure waves consist of energy over a wide spectrum of frequencies, some of which are audible and hence may be sensed in the form of noise, but most at inaudible frequencies at less than 20 Hz and beyond 20,000 Hz. These frequency ranges can be sensed by people in the form of a pressure impact known as concussion. The combination of effects of noise and concussion is known as air overpressure. The maximum excess pressure above normal atmospheric pressure of this wave is known as the peak air overpressure, generally measured in decibels linear (dBL).

Air overpressure is considered to be one of the most detrimental side effects due to the generation of noise and even causing some potential damage to residences.

The parameters which affect the characteristics of air overpressure can be classified in two groups: controllable and uncontrollable. These parameters have been discussed in the Table 4-8.

It should be noted that some literatures have recommended formulas to estimate the intensity of air overpressure but, air overpressure characteristics are not easy to predict because of the uncontrollable factors such as climate and topography as mentioned in the table below. However, majors for reducing AOP produced by surface blasting has been presented in the following sub sections.

4.3.3.1 Measures for Reducing/Controlling the Risk of Air Overpressure

Air overpressure has affected both on physical and human damage. The following measures should be adopted at the drilling and blasting location during surface blasting to reduce the risk of air overpressure.

a) All holes should be adequately stemmed. Stemming column should be 12 times the hole diameter but not more than 1.2 m is recommended to prevent "blowouts" and resultant air blast;
b) Proper front row burden should be provided;
c) Drill hole diameter should not be less than 28 mm for any drilling and blasting operation;
d) Proper timing sequence should be applied during drilling and blasting operation;
e) Any exposed explosives including detonating cord or surface connectors should be avoided. If they cannot be avoided, at least 30 cm thickness of soil or sand should be placed on them;
f) Total weight of explosives during a single drilling and blasting operation should be limited to 250 kg. If the total weight of explosives exceeds 250 kg based on the assigned blasting pattern, then either the drilling depth should be reduced or heading and benching excavation should be employed.
g) The direct movement of the rock should be away from critical areas for example residential area using appropriate number of delays;
h) The drilling and blasting operation should be stopped in the adverse environmental conditions like wind is blowing toward residential areas, and under an atmospheric temperature inversion;
i) Artificial resistance should be used to reduce the air wave propagation towards the residential or public area that arise from drilling and blasting operation. The artificial resistance includes blasting cage barriers made by rubber tire mats, vertical screen covered with canvas, etc; and
j) Good relationship with the project affected public should be maintained and regular notification to them about before, start and end of drilling and blasting operation should be provided by any means stated in Section 4.2.3 in order to minimize the effect of AOP and ground vibration.

Table 4-8 Controllable and uncontrollable factors for air overpressure

S.N.	Factors		S.N.	Parameters
1.a	Controllable	Blast design	i.	Explosive charge weight
			ii.	Blast geometry
			iii.	Firing direction
1.b		Artificial resistance to air wave propagation	i.	Sound barriers
			ii.	Ground covers
2.a	Uncontrollable	Distance between blasting area and the monitoring point		
2.b		Geological conditions of the blasted rock		
2.c		Meteorological condition		
2.d		Topography of the site		

4.3.4 Blasting Safety in Trench Blasting

The details about the trench blasting have been discussed in the Section 3.1.6 of this guideline. Safety requirements with regards to trench blasting have been discussed in this section separately as high ground vibration and great rock throw may occur during trench excavation by drilling and blasting operation because of strong confinement of the rock, high powder factor and close drilling pattern compared to other surface blasting.

The following blasting safety measures should be adopted at the drilling and blasting location during trench blasting to reduce the risk of disturbances discussed in Section 4.3.1, 4.3.2 and 4.3.3 of this guideline.

a) In order to reduce the ground vibration, (1) smaller blast holes should be used; (2) charge weight per delay should be reduced, and (3) the delay time between rows should be properly increased;

b) Heavy ground cover should be used to prevent flyrocks, such as heavy blasting mats, blasting cages, or cover with thick soil or sand after completion of charging and connecting the initiation network; and
c) Appropriate preventive and protective measures must be carried out during trench blasting, especially within or near the urban area or settlements.

4.3.5 Blasting Safety in Boulder Blasting

The details about the boulder blasting have been discussed in the section 3.1.6.2 of this guideline. Safety requirements with regards to boulder blasting have been discussed in this section separately as great rock throw (fly rock) and high air overpressure may occur during boulder blasting excavation by drilling and blasting operation because of limited dimension of the boulder, indecisive powder factor as well as drilling pattern compared to other surface blasting.

The following blasting safety measures should be adopted at the drilling and blasting location during trench blasting to reduce the risk of disturbances discussed in Section 4.4.1, and 4.4.3 of this guideline.

a) In order to reduce the fly rock and air overpressure, (1) larger blast holes should be used; (2) charge weight per delay should be reduced, and (3) the delay time between rows should be properly increased;
b) Strategic placement of explosives within or around the boulders should be made in order to create controlled fractures which may allow the boulders to break into smaller, and more manageable pieces upon detonation;
c) Heavy ground cover should be used to prevent flyrocks, such as heavy blasting mats, blasting cages, or cover with thick soil or sand after completion of charging and connecting the initiation network;
d) Once blasted, fragmented boulders should be inspected and if the size of the fragmented boulders are manageable to further break down using any mechanical means such as rock breaker then, repeating the drilling and blasting operation should be avoided; and
e) Appropriate preventive and protective measures must be carried out during boulder blasting, especially within or near the urban area or settlements.

4.4 Explosives Stored in Site Magazine and Site Transportation

Explosives are usually stored in a site magazine by establishing temporary bunker site as a separate project facility of any hydropower projects in Nepal under the supervision of the Nepal Army. The details about the explosive material storage have been thoroughly discussed in the Section 3.5 whereas the details about the explosive material transportation have been discussed in the Section 3.4 of this guideline.

4.4.1 Fire Extinguisher for Site Magazine and Explosive Trucks and Its Use

The mandate for fire extinguishers in site magazines and explosive trucks is paramount to mitigating the inherent risks associated with handling and transporting explosives. Fire extinguishers serve as critical safety measures, allowing for swift intervention in the event of a fire outbreak to contain and suppress it before it can escalate, thereby averting potential catastrophic consequences such as property damage, injuries, or even fatalities. In both site magazines and explosive trucks, fire extinguishers play a pivotal role in protecting personnel, property, and the environment.

4.4.1.1 Recommended fire extinguisher in site magazine and site transportation

a) The following fire extinguishers must be provided in the site magazine:

  i. Four fire extinguishers, including two of water type and two of CO_2 cartridge type; and
  ii. Four buckets of sand

b) For a typical vehicle with gross vehicle weight of 9 tonnes or above, four fire extinguishers, comprising two 2.5 kg dry powder and two 9-L foam fire extinguishers of an approved type, with certificates, shall be provided. They shall be mounted in front and on both sides of the rear body in easily accessible positions with securely mounted brackets and quick release clamps. For a vehicle with gross vehicle weight of less than 9 tonnes, the required number of fire extinguishers shall be agreed with local authorities (in Hong Kong, the Mines Division).
c) All storekeepers, security guards, and drivers must be trained for use of the above extinguishers by the qualified safety officer.
d) Water type extinguisher should only be used to extinguish wood, paper, and cloth fires and should never be used to extinguish flammable liquid (i.e., oil) or electrical fires. Oil and electrical fire should be extinguished by Carbon dioxide (CO_2) extinguishers.
e) Always aim at the base of the fire when the fire extinguisher is being used

4.4.2 Site Explosive Magazines

The operational health and safety of the site explosive magazine is utmost important the blasting incidents. For instance, an uncontrolled fire in an adjacent warehouse ignited ~2,750 tons of Ammonium Nitrate (AN), producing one of the most devastating blasts in recent history resulting a massive chemical detonation occurred on August 4, 2020 in the Port of Beirut, Lebanon. The blast supersonic pressure and heat wave claimed the lives of 220 people and injured more than 6,500 instantaneously, with severe damage to the nearby dense residential and commercial areas.

Thus, considering the importance and significance of site explosive magazine, this guideline presents the guideline framework for the operational health and safety of the magazine in the following topics.

a. Types of Explosive Magazines;
b. Safety Requirements for Site Explosives Magazine;
c. Construction of Outdoor Site Explosive Magazine; and
d. Management of Site Explosives Magazine.

4.4.2.1 Safety Requirements for Site Explosives Magazine

The safety requirements for the site explosive magazine stated in the Explosive Regulation (2020) have been summarized and enlisted in the following points.

a) The site explosive magazine must be built in pursuant to the Schedule-6 or Schedule-7 of the Explosive Regulation (2020) as mentioned in the Table 3-35.
b) The explosive materials including explosives and detonators (initiation systems) should be stored in appropriate manner based on the type, and quantity of the explosive materials;
c) The site explosive magazine must be built strongly based on the type, and quantity of the explosive materials which should have proper ventilation and adequate illumination (lighting);
d) Appropriate theft protection measures should be provided in the site explosive magazine;
e) In addition to following the standard safety protocols, the designated personnel for the storage and handling of the explosive materials must conduct the duties in an unobstructed manner and should also take other protective measures that should be taken by common sense in any situation;
f) The site explosive magazine must have the placard mentioning danger- explosive materials in appropriate location (Figure 4-4);
g) A set of locks and keys of the explosive magazine must be kept by the designated personnel having valid license and must not allow anyone to open the locks or enter the magazine without

his/her presence. However, license master blaster on his/her liability can open the magazine for using the designated amount of explosive materials required for one complete day;

h) The site explosive magazine must be located 300 meters far from the nearby settlements or industries;
i) The locality in which the explosive magazine is built must have the facilities of firefighting; and
j) The explosives and the detonators (initiation systems) should not be kept in the same explosive magazine.

Apart from the above-mentioned safety requirements of the site explosive magazines, this guideline recommends further safety requirements as mentioned below.

a) A safety assessment should be carried out before any drilling and blasting operation undertaken with explosives, particularly if those explosives have a known health hazard associated with them;
b) The safety assessment should identify the need for appropriate precautions;
c) A qualified medical practitioner should be consulted regarding the need for pre-work screening and subsequent periodical checks before any work where exposure to toxic explosives and associated chemicals is undertaken;
d) Natural air ventilation or forced local exhaust ventilation should be installed;
e) Personal Protective Equipment (PPE) in the form of respirators, gloves, barrier creams or special clothing should be provided to the designated personnel for storage and handling of site magazine, the licensed master blaster and his/her assistant;
f) Hand washbasins or showers must be installed near by the site explosive magazine;
g) Food and drink should not be taken into areas where such materials are handled but it may be allowed within the explosives area in specially designated places. It is important that personnel who handle explosives should wash their hands before touching food;
h) When determining the distance from a magazine to a settlement/ industry, an individual should measure from the nearest edge of the magazine to the nearest edge of the settlement/ industry;
i) If any two or more magazines are separated by less than the specified distance, then the weights in the magazines must be combined and considered as one;
j) Any kinds of detonators, detonating relays, and capped fuses should not be stored with blasting explosives, detonating cords, and boosters;
k) Fireworks should not be stored with blasting explosives or detonators; and
l) The site explosive magazine must be equipped with emergency response procedures and safety equipment.

Figure 4-4 A typical placard mentioning danger- explosive materials

4.4.3 Emergency Plan for Site Magazine and Site Transportation

During the blasting of a tunnel, an emergency plan is a vital component of ensuring the safety of workers, the public, and the environment in the event of unforeseen incidents or accidents. This guideline recommends the emergency plan for site magazine and site transportation as mentioned in the Figure 2-3.

The emergency plan should outline specific procedures and protocols to be followed before, during, and after blasting operations to mitigate risks and manage emergencies effectively

Firstly, before any blasting commences, the emergency plan should detail comprehensive risk assessments and hazard analyses to identify potential risks and establish safety measures accordingly. It should outline protocols for communication and coordination among all personnel involved, including blasting experts, site managers, and emergency responders. Additionally, evacuation procedures, assembly points, and methods for alerting personnel in case of emergencies should be clearly defined.

During blasting operations, the emergency plan should include provisions for monitoring environmental conditions, such as air quality and ground stability, to detect any deviations or signs of potential hazards promptly. It should outline procedures for suspending blasting activities if unsafe conditions arise and initiating emergency response measures as necessary. This may include evacuating personnel from the blast site, shutting down equipment, and implementing containment measures to prevent the spread of debris or hazardous materials.

After blasting, the emergency plan should incorporate protocols for conducting post-blast assessments to ensure the integrity of the tunnel structure and surrounding areas. It should address procedures for inspecting for any damage or hazards, clearing debris, and restoring operations safely. Additionally, the plan should include provisions for documenting incidents, conducting investigations, and implementing corrective actions to prevent similar emergencies in the future.

Overall, an effective emergency plan during the blasting of a tunnel is essential for minimizing risks, ensuring the safety of personnel and the surrounding environment, and maintaining the integrity of the project. It provides a framework for preparedness, response, and recovery, enabling prompt and coordinated actions to address emergencies and mitigate their impact.

In the context of tunnel blasting operations, an emergency plan serves as a crucial framework designed to mitigate risks, ensure the safety of personnel, and effectively manage unforeseen incidents. This plan encompasses a comprehensive assessment of potential hazards associated with blasting activities, including factors such as ground stability, flyrocks projection, air blast, and vibration effects. Through rigorous risk identification and evaluation, the plan aims to preemptively address safety concerns by implementing proactive measures and establishing clear protocols for emergency response.

Central to the emergency plan is the establishment of robust communication channels and procedures to facilitate swift and effective response efforts. This includes defining communication protocols between blasting personnel, site management, and emergency responders, as well as deploying alert systems such as sirens, alarms, or electronic devices to promptly notify individuals of any emergent situations. Evacuation procedures are meticulously outlined, delineating evacuation routes, assembly points, and steps for safely removing personnel from the blast site. Moreover, the plan incorporates mechanisms for continuous environmental monitoring to assess air quality, ground stability, and noise levels, thereby enabling real-time detection of deviations that may pose risks to personnel or the surrounding environment. Through comprehensive training, regular drills, and meticulous documentation, the emergency plan ensures that all stakeholders are adequately prepared to respond to emergencies, mitigate hazards, and safeguard the integrity of the tunnel construction project.

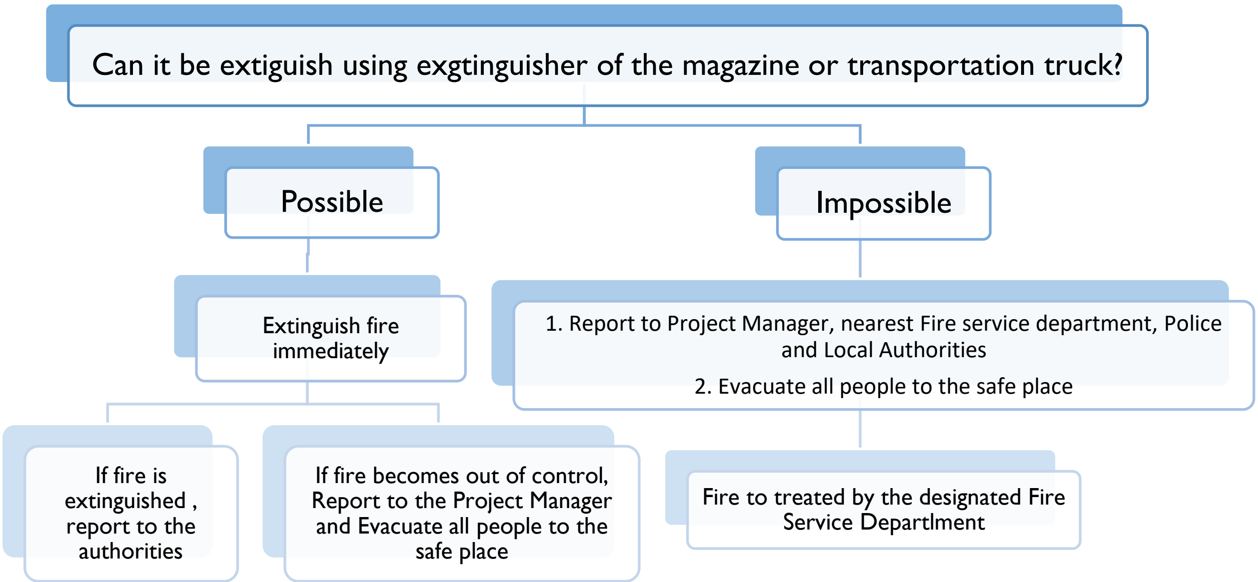


Figure 4-5 Emergency plan for the site magazine and site transportation

5 MANAGEMENT STRATEGIES REQUIRED TO FORMALIZE INSPECTION AND MONITORING OF EXPLOSIVE MATERIALS

One of the scopes of this guideline is to prepare a framework which is applicable to every hydropower project of Nepal at various stages of development as well as applicable to all DoED officials, and personnel (developers, consultants and contractors) exposed to explosive material handling, storage and transportation. The framework is particularly important to ensure that explosive materials management strategies are in place to control the use of explosive materials by incorporating best practices; minimize the risk of injury to all personnel and mitigate environmental impacts from explosive materials during storage, transport and use.

This guideline presents the framework of management strategies to formalize inspection and monitoring of explosive materials in the following topics.

a) Formalized inspection and inventory process of the explosive material;
b) Duties, procedures and methods of inspection;
c) Concerned public entity related to storage transport and uses of explosive material;
d) Summary of federal state and local licenses and permits requirements; and
e) Responsibilities of each specific personnel exposed to explosive material handling, storage, and transportation

5.1 Formalized Inspection and Inventory Process of the Explosive Material

The objective of the formalize inspection and inventory process of the explosive material is to monitor and measure the effectiveness of the explosive material management program, as well as compliance with any related legal and/or contractual obligations, regulatory requirements including all action items specified in the blasting assessment report (BAR) and/or approved environmental study report of the concerned hydropower project. This guideline recommends the framework for formalized inspection and inventory process of the explosive material as presented in Table 3-34 of Section 3.4.1 for reference. Similarly, this guideline recommends a checklist for the inspections of the bunker site and the explosive content presented in Annex-10 which should be carried out by the hydropower project at the site in presence of designated Nepal Army authority and designated magazine keeper.

5.1.1 Review and Reporting

In accordance to the approved environmental study report and the submitted blasting assessment report (BAR), the hydropower project should review the environmental performance of the project and prepare and submit the inspection report to DoED in every six months. The blasting and explosive management monitoring report should include the activities mentioned in Table 5-1. This guideline recommends the reporting schedule of the above-mentioned activities and details as presented in Table 5-1 for reference.

Moreover, the inspection report should cover the following details.

a) Describe the development that was carried out in the relevant calendar year, and the development that is proposed to be carried out during the following calendar year;
b) Include a comprehensive review of the monitoring results and complaints records of the development over the past year, which includes a comparison of these results against the relevant statutory requirements, limits or performance measures/criteria;
c) Monitoring results of previous years and relevant predictions in project environmental impact;
d) Statement and subsequent environmental assessments;

e) Identify any non-compliance over the last year, and describe what actions were (or are being) taken to ensure compliance;
f) Identify any trends in the monitoring data over the life of the development;
g) Identify any discrepancies between the predicted and actual impacts of the development, and analyze the potential cause of any significant discrepancies; and
h) Describe what measures will be implemented over the next year to improve the environmental performance of the development.

Table 5-1 A typical reporting schedule for blasting and explosive management inspection report

S. N.	Reporting on	Report Prepared By	Report Submitted To	Frequency
1.	**Supplied explosive**	Nepal Army at the site, Master Blaster	Project Manager	Monthly
2.	**Carrier vehicle from custom to site**	Nepal Army	Project Manager (Subcontractors)	Regular during transportation duration
3.	**Site Transportation**	Magazine keeper / Nepal Army	Tunnel Manager	At a time of transportation
4.	**Bunker / Storage**	Environmental Officer	Safety Officer	Weekly
		Electrical Division		Twice a year
		Electrical engineer		Yearly
5.	**Stock Packaging**	Magazine keeper	Safety Officer	Weekly
6.	**Blasting Hole Preparation**	Drill Master	Safety Officer	Prior to charging
7.	**Explosive Charging**	Master Blaster	Safety Officer	Prior to blasting
8.	**Accessibility during blasting**	Security Officer / Safety Officer	EHS/OHS Officer	Blasting Phase
9.	**Misfire**	Master Blaster	EHS/OHS Officer	Post blasting phase
10.	**Post Blasting**	Environmental Officer	EHS/OHS Officer	Post blasting phase
11.	**Stock Review**	Magazine Keeper	Project Manager	Monthly
12.	**Impact Monitoring**	Environmental Officer	EHS/OHS Officer	At a time of blasting
13.	**Blast Fume**	Environmental Officer	EHS/OHS Officer	At a time of blasting
14.	**Safety measures**	Safety Officer	EHS/OHS Officer	Post blast
15.	**Grievances**	Public Relation Officer	Project Manager	Trimonthly
16.	**Inspection**	DoED / Nepal Army / Magazine Keeper	Project Manager, DoED	Trimonthly

5.1.2 Carrying out Audits

Third party audit of the blasting and explosive management inspection report should be undertaken annually to assess compliance and adequacy of internal audits undertaken regarding the storage, transportation, handling and usage of the explosive materials. The consultant appointed for the exercise should be qualified in the subject area and should provide a time bound corrective action plan. The consultant should have previous experience of working on construction projects. Corrective and preventive actions should be listed out after every audit and should form basis for upgradation of any management program required or to undertake a risk assessment of any alteration in equipment, process etc. This guideline recommends to carry out audits regarding the current usage of explosive materials by using the Templates for estimation of explosive materials recommended by this guidelines.

5.1.3 Formulation of Corrective and Preventive Actions

The corrective and preventive action should be carried out based on the recommended actions required to be taken mentioned in the audited blasting and explosive management inspection report as mentioned in Section 5.1.1 and Section 5.1.2 of this guideline.

5.2 Responsibilities of Each Specific Personnel Exposed to Explosive Material Handling, Storage, and Transportation

This guideline recommends the overall responsibilities of each specific personnel exposed to explosive material handling, storage, and transportation as mentioned in the Table 3-31 of this guideline. Regarding the inspection responsibilities of the explosive materials, this guideline recommends to prepare blasting and explosive management inspection report (Section 5.1.1 and Section 5.1.2).

5.3 Duties, Procedures and Methods of Inspection

This guideline recommends the duties of the designated personnel of the hydropower project responsible for the explosive storage, transportation, and handling as presented in Table 3-31. The method of inspection for the bunker site (explosive magazine) and the inventory of the available explosive material is to prepare a checklist mentioned in the Annex-10 at the bunker facilities of the hydropower project in presence of Nepal Army and magazine keeper. Similarly, the method of inspection of each drilling and blasting operation should be carried out by inspecting the topics mentioned below.

a) Whether overpressure and vibration monitoring results at the closest to the drilling and blasting location comply with the predefined blast criteria or not;
b) Whether the drilling and blasting operation has potential impacts at the nearest public infrastructure in pursuant to BAR or not;
c) Visual monitoring of blast fumes;
d) Daily blasting work sheet for stocks and returns;
e) Public grievances regarding impact of blasting has been carried out based on the defined grievance redressal mechanism as well as prevailing laws and regulation or not; and
f) Compliance to safety measures has been followed or not.

This page intentionally left blank

6 SYNTHESIS AND DISCUSSION

The data were collected from the different under construction, constructed and studied projects of different hydropower projects. All the collected data via the methodological approach as mentioned in the Section 2.1.1, 2.1.2, 2.1.3, 2.1.4 and 2.1.6 used for processing and analyzing to estimate the quantity of the explosive materials and initiation system required for the development of a hydropower project. For the data processing and analysis all the data were synthesized as average value, maximum value, and minimum value based on the rock type, geological unit, dimension of the tunnel, rock class, and explosive material consumption among others. All together explosive consumption record of 14971 drilling and blasting operation of 18 different hydropower projects presented in Annex-8 were synthesized, analyzed, and presented.

6.1 Details of estimation of explosive materials and ignition system for surface excavation

Out of 14971 explosive consumption record, only six data of drilling and blasting operation for surface blasting have been collected. Thus, the explosive material estimation with only six number of data is not relevant. So, for the powder factor estimation of surface excavation proposed by Gokhale (2010) based on rock strength, rock density, and joint spacing was adopted for this guideline during the review of available information as presented in Table 3-4. For this purpose, intact rock properties (UCS and PLI), have been collected from the geotechnical reports of various hydropower projects in Nepal.

For the processing and analysis of the intact rock properties (UCS and PLI), the absolutely maximum average value and absolutely minimum average value were computed. The powder factor range of all the rock types based PLI and UCS values were based on Gokhale (2010). The data related to the intact rock properties (UCS and PLI) retrieved from the different hydropower projects have been presented in the tabular form in Annex 5.

The summary sheet of the processing and analysis of the intact rock properties (UCS and PLI) of general rock types has been presented in Table 6-1. Similarly, the summary sheet of the processing and analysis of the intact rock properties (UCS and PLI) of the specific rock types found in the Nepal Himalaya has been presented in Annex-11.

For the estimation of explosive materials for surface excavation, the data for calculation of powder factor is presented in the form of the histogram with corresponding tables showing different ranges of PLI and UCS values of different types of rocks found in the Nepal Himalaya (Figure 6-1). Since, there were significant number of data for rocks such as gneiss, schist, limestone, and sandstone, the range of powder factor of different varieties of the above-mentioned rock have also presented in the form of the histogram with corresponding tables (Figure 6-1).

In order to validate the recommended range of the powder factor presented in the Figure 6-1 , the norms for rate analysis of road and bridge works prepared by Department of Road (DoR), Nepal has been considered. According to the norm, the calculated powder factor for the surface blasting considering different parameters ranges from 0.14 - 0.36 kg/m^3 as presented in Table 6-2. This value of powder factor lies within the recommended range of the powder factor as presented in the Figure 6-1.

For the estimation of the initiation system for the surface excavation refer to the Section 6.3 because similar estimation of ignition system for the surface excavation is recommended as that for the estimation of underground excavation. Please refer to the downloadable link Templates for estimation of explosive materials for estimating the explosive materials and ignition system for surface excavation based on the above discussions.

6.2 Details of estimation of explosive materials for underground excavation

Since, 14971 drilling and blasting operation of 18 different hydropower projects presented in Annex-8 were collected during the preparation of this guideline, these data were used for the powder factor estimation of underground excavation. All together 30851.89-meter length of tunnel has been collected from the given 18 hydropower projects of Nepal.

For the processing and analysis of the explosive consumption records, the average powder factor of different rock types and different excavated cross sectional area have been used. The estimation of the explosive material for the underground excavation have been carried out based on various methods/factors namely rock type, rock quality, blastability, regional geology, and a typical blasting pattern.

This guideline recommends the hydropower projects to consider the estimation of explosive material for underground excavation based on any one of the above-mentioned methods or factors with regards to the stage of development of the particular project. For instance, if a hydropower project requires an explosive material for the exploratory test adits excavation during feasibility stage, the project can choose estimation based on rock type or regional geology if abundant geological and geotechnical information is not available.

Similarly, the project can choose estimation based on blastability and rock quality, if there is abundant geological and geotechnical data. Thus, this guideline recommends estimation of the explosive material for the underground excavation on the basis of various methods/factors namely rock type, rock quality, blastability, regional geology, and a typical blasting pattern in the following sections.

Please refer to the downloadable link Templates for estimation of explosive materials for estimating the explosive materials and ignition system for underground excavation based on the discussions mentioned in the following sub sections.

6.2.1 Estimation of explosive material based on rock type

Based on the 14971 drilling and blasting operation of 18 different hydropower projects presented in Annex-8, the average powder factor of different rock types with different excavated cross sectional area have been used to prepare a typical curve (powder factor versus cross-sectional area) for various types of rocks found in Nepal.

This guideline recommends estimation of the explosive material for the underground excavation based on various rock type found in Nepal in the following sections.

6.2.1.1 Estimation of explosive material based on all rock type in general

Based on the 14971 drilling and blasting operation of 18 different hydropower projects presented in Annex-8, the average powder factor of different rock types with different excavated cross sectional area have been used to prepare a typical curve (powder factor versus cross-sectional area) for all types of rocks found in Nepal (Figure 6-2).

In order to validate the trendline of a typical curve based on all types of rock present in Nepal, the trendline of the typical curve based on IDL has been compared or co-related in Figure 6-2. Both Figure 6-2 and Table 6-3 shows that there is a good co-relation between two trendlines which validates the typical curve prepared by this guideline.

Thus, this guideline recommends the typical curve for estimation of explosive material based on all rock type in general prepared by this guideline as presented in Figure 6-2, Figure 6-11, and Table 6-9.

(A) **Recommended Range of Powder Factor For Surface Excavation in Different Types of Rock based on PLI**

Geology	Rock Type / Strength / Point Load Index	Point Load Value Range Diagram(Mpa) (Very Low Strength, Low Strength, Medium Strength, High Strength; 1–10)	PLI Range(Mpa)	UCS Range	Recommended Range of Powder Factor(kg/m³)
Tethys Himalaya	Marble		1.72-5.65	41.28-135.6	0.18-0.88
	Schist		0.95-6.6	22.8-158.4	0.12-0.88
Higher Himalaya	Gneiss		0.54-9.51	30.69-180.04	Refer to Sub-Table C
	Schist		3.14-8.63	75.36-207.12	Refer to Sub-Table D
	Limestone		2.13-5.23	48.99-120.29	Refer to Sub-Table F
	Marble		3.12-8.16	74.88-195.84	0.52-1.37
	Quartzite		1.88	42.86	0.18-0.27
Lesser Himalaya	Gneiss		0.22-9.48	25.36-179.54	Refer to Sub-Table C
	Schist		0.14-9.21	3.36-221.04	0.12-1.37
	Phyllite		0.45-9.8	10.80-235.20	0.12-1.68
	Granite		4.44-5.23	106.56-125.52	0.52-0.88
	Quartzite		0.68-9.78	16.32-234.72	0.12-1.37
	Quartzite and Phyllite		0.56-9.86	13.44-236.64	0.12-1.68
	Shale		0.85-0.95	20.40-22.80	0.18-0.27
	Slate		1.01-6.62	24.24-158.88	0.18-0.88
Siwalik	Mudstone		0.14-6.1	3.00-130.72	0.12-0.88
	Sandstone		0.23-4.21	5.03-92.19	Refer to Sub-Table C
	Siltstone		5.15	123.6	0.68-0.88

(B) **Recommended Range of Powder Factor For Surface Excavation in Different Types of Rock based on UCS**

Geology	Rock Type / Strength / Uniaxial Compressive Strength(UC	Uniaxial Compressive Strength(UCS) Range diagram (Low Strength, Medium Strength, High strength; 20–200)	UCS Range(Mpa)	Recommended Range of Powder Factor(kg/m³)
Tethys Himalaya	Marble		12.67-70.2	0.12-0.52
	Schist		19.76-56.71	0.12-0.52
Higher Himalaya	Gneiss		3.62-178.77	Refer to Sub-Table C
	Schist		14.20-91.30	Refer to Sub-Table D
	Limestone		3.62-73.74	Refer to Sub-Table F
	Quartzite		43.70-59.89	0.18-0.52
Lesser Himalaya	Gneiss		11.07-126.60	Refer to Sub-Table C
	Schist		11.70-71.10	0.12-0.52
	Phyllite		10.08-96.69	0.12-0.68
	Granite		14.35-75.57	0.12-0.88
	Quartzite		2.32-171.65	0.12-1.10
	Shale		10.16-47.00	0.12-0.38
	Slate		1.21-40.90	0.12-0.27
	Sandstone		25.41-54.43	0.12-0.38
Siwalik	Conglomerate		27.88-42.35	0.12-0.27
	Mudstone		11.70-44.92	0.12-0.27
	Sandstone		10.08-73.62	Refer to Sub-Table C
	Siltstone		11.04-86.40	0.12-0.68
	Siltstone and Sandstone		31.56	0.18-0.27

(C) **Recommended Range of Powder Factor For Surface Excavation in specific types of Gneiss based on both PLI and UCS**

Geology	Rock Type / Strength / Point Load Index	Point Load Value Range Diagram(Mpa) (Very Low Strength, Low Strength, Medium Strength, High Strength; 1–10)	PLI Range(Mpa)	UCS Range	Recommended Range of Powder Factor(kg/m³)
Higher Himalaya	Gneiss(Augen)		1.41-8.21	45.17-158.39	0.27-0.88
	Gneiss(Feldspathic Augen)		3.50-4.70	79.97-99.95	0.38-0.68
	Gneiss(Feldspathic)		2.00-6.65	55.00-132.42	0.27-0.88
	Gneiss(Sillimanite)		1.41-1.66	45.17-49.33	0.27-0.38
Lesser Himalaya	Gneiss		0.86-8.63	36.01-165.38	0.18-1.10
	Gneiss(Augen)		0.56-9.53	31.02-180.37	0.18-1.10
	Gneiss(Bitotite,Plagioclase)		0.64-3.06	32.35-72.64	0.27-0.68
	Gneiss(Amphibole)		0.8	35.02	0.27-0.38
	Gneiss(Micaceous)		0.91-2.55	36.85-64.15	0.27-0.52
	Gneiss(Plagioclase)		1.01-3.43	38.51-78.80	0.27-0.52

Geology	Rock Type / Strength / Uniaxial Compressive Strength(UCS)	Uniaxial Compressive Strength(UCS) Range diagram (Very Low Strength, Low Strength, Medium Strength, High Strength; 1–10)	UCS Range(Mpa)	Recommended Range of Powder Factor(kg/m³)
Higher Himalaya	Gneiss(Augen)		32.60-105.70	0.18-0.68
	Gneiss(Cal-Silicate Biotite)		18.6	0.12-0.18
	Gneiss(Feldspathic Augen)		64.70-86.20	0.38-0.68
	Gneiss(Feldspathic)		24.00-90.70	0.12-0.68
	Gneiss(Sheopuri)		8.40-66.10	0.12-0.52
	Gneiss(Sillimanite)		9.30-11.60	0.12-0.18
Lesser Himalaya	Gneiss		11.07-108.23	0.12-0.68
	Gneiss(Augen)		14.80-126.60	0.12-0.88
	Gneiss(Bitotite,Plagioclase)		16.12-52.78	0.12-0.38
	Gneiss(Amphibole)		16	0.12-0.18
	Gneiss(Augen,Plagioclase)		21.20-40.00	0.12-0.38
	Gneiss(Micaceous)		14.35-75.57	0.12-0.52
	Gneiss(Plagioclase)		2.32-171.65	0.12-1.10

(D) **Recommended Range of Powder Factor For Surface Excavation in specific types of Schist based on both PLI and UCS**

Geology	Rock Type / Strength / Point Load Index	Point Load Value Range Diagram(Mpa) (Very Low Strength, Low Strength, Medium Strength, High Strength; 1–10)	PLI Range(Mpa)	UCS Range(Mpa)	Recommended Range of Powder Factor(kg/m³)
Higher Himalaya	Schist		2.24-5.02	53.76-120.48	0.27-0.88
	Schist(Calcarious)		9.14-9.86	219.36-236.64	1.10-1.37
	Schist(Gernetiferous)		0.15-2.86	3.60-68.64	0.12-0.52
	Schist(Carbonate-Silicate)		2.10	50.4	0.12-0.52

Geology	Rock Type / Strength / Uniaxial Compressive Strength(UCS)	Uniaxial Compressive Strength(UCS) Range diagram (Low Strength, Medium Strength, High strength; 20–200)	UCS Range(Mpa)		Recommended Range of Powder Factor(kg/m³)
Higher Himalaya	Schist		43.70-59.89	1048.80-1437.36	0.27-0.52
	Schist(Carbonate-Silicate)		36.10	866.40	0.18-0.27

(E) **Recommended Range of Powder Factor For Surface Excavation in specific types of Sandstone based on both PLI and UCS**

Geology	Rock Type / Strength / Point Load Index	Point Load Value Range Diagram(Mpa) (Very Low Strength, Low Strength, Medium Strength, High Strength; 1–10)	PLI Range(Mpa)	UCS Range(Mpa)	Recommended Range of Powder Factor(kg/m³)
Siwalik	Sandstone		0.23-4.22	5.03-92.41	0.12-0.68
	Sandstone/Mudstone		0.58	13.92	0.12-0.18
	Sandstone/Siltstone/ Mudstone		0.64	15.36	0.12-0.18
	Very Fined Sandstone		0.48-1.75	10.51-38.32	0.12-0.27

Geology	Rock Type / Strength / Uniaxial Compressive Strength(UCS)	Uniaxial Compressive Strength(UCS) Range diagram (Low Strength, Medium Strength, High strength; 20–200)	UCS Range(Mpa)	Recommended Range of Powder Factor(kg/m³)
Siwalik	Sandstone/Mudstone		26.6	0.12-0.18
	Sandstone/Siltstone/ Mudstone		22.59	0.12-0.18
	Very fine grained Sandstone		14.5	0.12-0.18

(F) **Recommended Range of Powder Factor For Surface Excavation in specific types of Limestone based on both PLI and UCS**

Geology	Rock Type / Strength / Point Load Index	Point Load Value Range Diagram(Mpa) (Very Low Strength, Low Strength, Medium Strength, High Strength; 1–10)	PLI Range(Mpa)	UCS Range(Mpa)	Recommended Range of Powder Factor(kg/m³)
Higher Himalaya	Limestone		3.16-6.43	72.68-147.89	0.52-1.10
	Marble		3.14-4.45	75.36-106.8	0.52-0.68
	Marble(Dolomitic)		9.14-9.85	219.36-236.4	1.10-1.68

Figure 6-1 Recommended estimation of explosive material for surface excavation based on the intact rock properties (PLI and UCS)

This page intentionally left blank

Table 6-1 Summary sheet of the intact rock properties UCS and PLI collected for the preparation of this guideline

Region	Marble			Schist					
Tethys Himalaya	Value	PLI	UCS	Value	PLI	UCS			
	Maximum	5.67	70.20	Maximum	6.61	56.71			
	Minimum	1.73	12.67	Minimum	0.98	19.76			
	Average	2.98	33.87	Average	2.98	33.87			
	Absolutely Maximum Average Value	5.65	70.14	Absolutely Maximum Average Value	6.6	55.63			
	Absolutely Minimum Average Value	1.72	12.62	Absolutely Minimum Average Value	0.95	18.35			
	Total Test Data No.	51	29	Total Test Data No.	12	16			
Higher Himalaya	**Gneiss**			**Schist**			**Limestone**		
	Value	PLI	UCS	Value	PLI	UCS	Value	PLI	UCS
	Maximum	9.63	178.77	Maximum	9.14	91.30	Maximum	5.68	73.74
	Minimum	0.56	3.62	Minimum	3.14	14.20	Minimum	0.00	3.62
	Average	4.27	51.04	Average	5.54	37.94	Average	2.31	31.07
	Absolutely Maximum Average Value	9.51	178.77	Absolutely Maximum Average Value	8.63	91.11	Absolutely Maximum Average Value	5.23	72.25
	Absolutely Minimum Average Value	0.54	3.58	Absolutely Minimum Average Value	3.14	13.46	Absolutely Minimum Average Value	2.13	12.21
	Total Test Data No.	241	90	Total Test Data No.	15	16	Total Test Data No.	11	6
	Marble			**Quartzite**			**Pegmatite**		
	Value	PLI	UCS	Value	PLI	UCS	Value	PLI	UCS
	Maximum	9.14		Maximum	1.88	59.89	Maximum		68.00
	Minimum	3.14		Minimum	1.88	43.70	Minimum		11.50
	Average	5.57		Average	1.88	49.11	Average		36.33
	Absolutely Maximum Average Value	8.16		Absolutely Maximum Average Value	1.88	99.23	Absolutely Maximum Average Value		68
	Absolutely Minimum Average Value	3.12		Absolutely Minimum Average Value	1.88	15.46	Absolutely Minimum Average Value		11.48
	Total Test Data No.	16	0	Total Test Data No.	1	6	Total Test Data No.	0	3
Lesser Himalaya	**Gneiss**			**Schist**			**Phyllite**		
	Value	PLI	UCS	Value	PLI	UCS	Value	PLI	UCS
	Maximum	9.53	126.60	Maximum	10.00	71.10	Maximum	9.82	96.69
	Minimum	0.22	11.07	Minimum	0.16	11.70	Minimum	0.47	10.08
	Average	3.02	40.51	Average	3.34	33.85	Average	2.80	31.59
	Absolutely Maximum Average Value	9.48	125.2	Absolutely Maximum Average Value	9.21	71.1	Absolutely Maximum Average Value	9.8	95.55
	Absolutely Minimum Average Value	0.22	10.36	Absolutely Minimum Average Value	0.14	10.25	Absolutely Minimum Average Value	0.45	10.01
	Total Test Data No.	794	468	Total Test Data No.	103	117	Total Test Data No.	99	56
	Granite			**Quartzite**			**Quartzite and Phyllite**		
	Value	PLI	UCS	Value	PLI	UCS	Value	PLI	UCS
	Maximum	5.23	75.57	Maximum	9.78	171.65	Maximum	10.00	
	Minimum	3.12	14.35	Minimum	0.68	2.32	Minimum	0.64	
	Average	4.45	38.30	Average	2.73	67.98	Average	5.04	

	Absolutely Maximum Average Value	5.23	74.23	Absolutely Maximum Average Value	9.78	313.56	Absolutely Maximum Average Value	9.86	
	Absolutely Minimum Average Value	4.44	14.21	Absolutely Minimum Average Value	0.68	2.12	Absolutely Minimum Average Value	0.56	
	Total Test Data No.	7	8	Total Test Data No.	89	94	Total Test Data No.	124	
	Sandstone			**Shale**			**Schist**		
	Value	**PLI**	**UCS**	**Value**	**PLI**	**UCS**	**Value**	**PLI**	**UCS**
	Maximum		57.43	Maximum	0.95	47.00	Maximum	8.15	77.70
	Minimum		25.41	Minimum	0.86	10.16	Minimum	0.22	13.56
	Average		45.47	Average	0.60	26.18	Average	2.48	33.22
	Absolutely Maximum Average Value		57.23	Absolutely Maximum Average Value	0.95	47	Absolutely Maximum Average Value	8.14	76.23
	Absolutely Minimum Average Value		24.43	Absolutely Minimum Average Value	0.85	10.16	Absolutely Minimum Average Value	0.21	13.22
	Total Test Data No.	0	7	Total Test Data No.	2	4	Total Test Data No.	2	4
	Slate								
	Value	**PLI**	**UCS**						
	Maximum	6.64	40.90						
	Minimum	1.10	1.21						
	Average	3.61	23.26						
	Absolutely Maximum Average Value	6.62	39.52						
	Absolutely Minimum Average Value	1.01	1.21						
	Total Test Data No.	52	86						
Siwaliks	**Conglomerate**			**Mudstone**			**Sandstone**		
	Value	**PLI**	**UCS**	**Value**	**PLI**	**UCS**	**Value**	**PLI**	**UCS**
	Maximum		42.35	Maximum	6.13	44.92	Maximum	4.22	73.62
	Minimum		27.88	Minimum	0.16	11.70	Minimum	0.23	10.08
	Average		35.59	Average	3.34	33.85	Average	2.97	31.59
	Absolutely Maximum Average Value		42.35	Absolutely Maximum Average Value	6.10	43.23	Absolutely Maximum Average Value	4.21	73.61
	Absolutely Minimum Average Value		27.88	Absolutely Minimum Average Value	0.14	11.3	Absolutely Minimum Average Value	0.23	9.56
	Total Test Data No.	0	3	Total Test Data No.	103	117	Total Test Data No.	201	56
	Siltstone			**Siltstone and Sandstone**					
	Value	**PLI**	**UCS**	**Value**	**PLI**	**UCS**			
	Maximum	5.17	86.40	Maximum		31.56			
	Minimum	3.12	11.04	Minimum		31.56			
	Average	4.45	38.30	Average		31.56			
	Absolutely Maximum Average Value	5.15	85.36	Absolutely Maximum Average Value		31.56			
	Absolutely Minimum Average Value	3.1	11.04	Absolutely Minimum Average Value		31.56			
	Total Test Data No.	81	76	Total Test Data No.	0	1			

Table 6-2 Estimation of explosive materials for surface blasting proposed by DoR norms (2077)

S. N.	Material and blasting method	Volume (m^3)	Gelatin (kg)	Detonator (Nos)	Fuse wire (m)	Powder factor (kg/m^3)	Detonators /kg of explosive
1	Making Rubbles with drilling and blasting	1	0.25	2	2	0.25	8
2	Road excavation with manual /mechanical drill and blast method	90	32	126	180	0.36	4
3	Hard rock requiring manual drilling and blasting	10	3.5	14	20	0.35	4
4	Hard rock (6 m dia well) Unit= meter (for 1 m) Depth in hard rock up to 3 m	28.08	4	18		0.14	5
5	Hard rock (7 m dia well) Unit= meter (for 1 m) Depth in hard rock up to 3 m	38.22	7	30		0.18	4
6	Hard rock (8 m dia well) Unit= meter (for 1 m) Depth in hard rock up to 3 m	49.92	8	32		0.16	4
7	Hard rock (10 m dia well) Unit= meter (for 1 m) Depth in hard rock up to 3 m	78	11	44		0.14	4
8	Landslide clearance in Hard rock requiring blasting	100	17.5	70		0.18	4

Table 6-3 Comparison of powder factor based on typical curve of all rock types recommended by this guideline with the powder factor based on typical curve recommend by IDL

Diameter (m) of typical circular section	Cross Section area (m^2) of typical circular section	Powder factor based typical curve of all rock types recommended by this guideline	Powder factor based on the typical curve recommended by IDL
1.00	0.79	10.92	5.75
1.50	1.77	7.20	4.30
1.60	2.01	6.74	4.11
1.70	2.27	6.33	3.93
1.80	2.54	5.97	3.78
1.90	2.83	5.65	3.63
2.00	3.14	5.36	3.50
2.10	3.46	5.10	3.38
2.20	3.80	4.86	3.27
2.30	4.15	4.65	3.17
2.40	4.52	4.45	3.08
2.50	4.91	4.26	2.99
2.60	5.31	4.10	2.90
2.70	5.72	3.94	2.83
2.80	6.15	3.80	2.75
2.90	6.60	3.66	2.69
3.00	7.07	3.54	2.62
3.10	7.54	3.42	2.56
3.20	8.04	3.31	2.50
3.30	8.55	3.21	2.45
3.40	9.07	3.11	2.40
3.50	9.62	3.02	2.35
3.60	10.17	2.93	2.30
3.70	10.75	2.85	2.26
3.80	11.34	2.78	2.22
3.90	11.94	2.70	2.17
4.00	12.56	2.63	2.14
4.10	13.20	2.57	2.10
4.20	13.85	2.50	2.06
4.30	14.51	2.44	2.03
4.40	15.20	2.39	1.99
4.50	15.90	2.33	1.96
4.60	16.61	2.28	1.93
4.70	17.34	2.23	1.90
4.80	18.09	2.18	1.87
4.90	18.85	2.14	1.85
5.00	19.63	2.09	1.82
5.10	20.42	2.05	1.80

Diameter (m) of typical circular section	Cross Section area (m²) of typical circular section	Powder factor based typical curve of all rock types recommended by this guideline	Powder factor based on the typical curve recommended by IDL
5.20	21.23	2.01	1.77
5.30	22.05	1.97	1.75
5.40	22.89	1.94	1.72
5.50	23.75	1.90	1.70
5.60	24.62	1.86	1.68
5.70	25.50	1.83	1.66
5.80	26.41	1.80	1.64
5.90	27.33	1.77	1.62
6.00	28.26	1.74	1.60
6.10	29.21	1.71	1.58
6.20	30.18	1.68	1.56
6.30	31.16	1.65	1.54
6.40	32.15	1.63	1.53
6.50	33.17	1.60	1.51
6.60	34.19	1.58	1.49
6.70	35.24	1.55	1.48
6.80	36.30	1.53	1.46
6.90	37.37	1.50	1.45
7.00	38.47	1.48	1.43
7.10	39.57	1.46	1.42
7.20	40.69	1.44	1.40
7.30	41.83	1.42	1.39
7.40	42.99	1.40	1.38
7.50	44.16	1.38	1.36
7.60	45.34	1.36	1.35
7.70	46.54	1.34	1.34
7.80	47.76	1.33	1.33
7.90	48.99	1.31	1.31
8.00	50.24	1.29	1.30
8.50	56.72	1.22	1.25
9.00	63.59	1.15	1.20
9.50	70.85	1.08	1.15
10.00	78.50	1.03	1.11
11.00	94.99	0.93	1.04
12.00	113.04	0.85	0.97
13.00	132.67	0.79	0.92

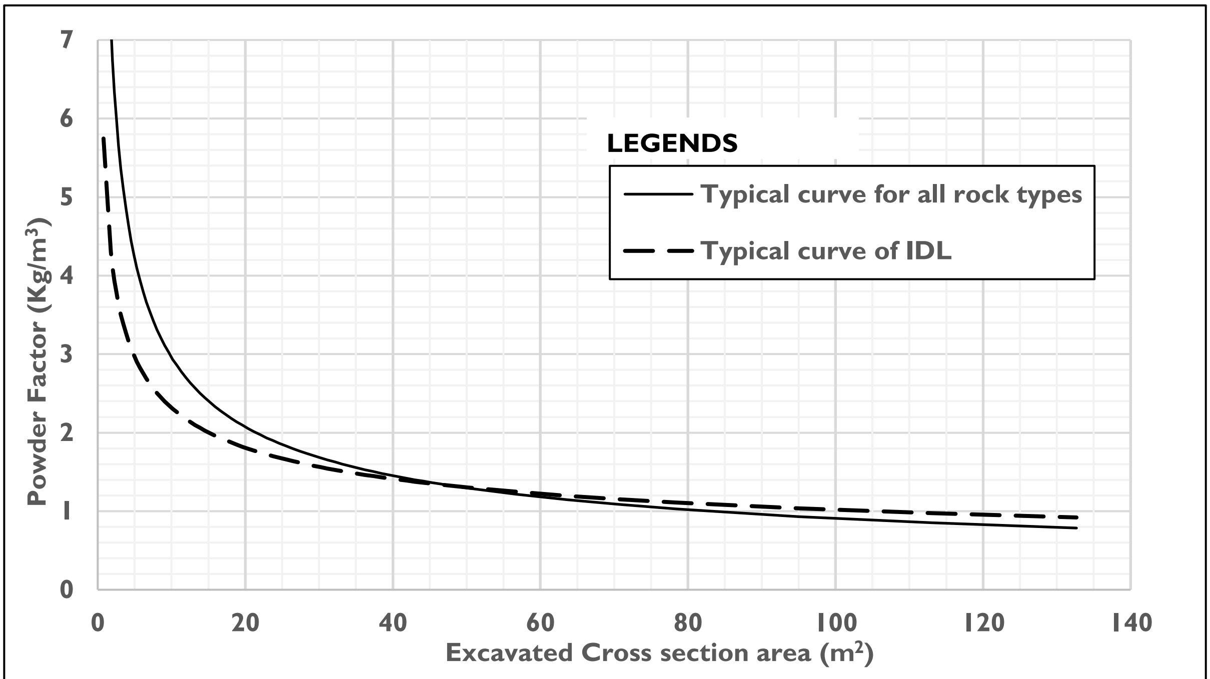


Figure 6-2 Recommended typical curve for estimation of explosive material for underground excavation for all rock types by this guideline along with typical curve of IDL for comparison

6.2.1.2 Estimation of explosive material based on specific rock type

Similarly, based on the 14971 drilling and blasting operation of 18 different hydropower projects presented in Annex-8, the average powder factor of different rock types with different excavated cross sectional area have been used to prepare a typical curve (powder factor versus cross-sectional area) for specific types of rocks found in Nepal Himalaya (Figure 6-3). Since, there were significant number of data for rocks such as gneiss, schist, phyllite, slate, quartzite and dolomite, this guideline recommends the typical curve for estimation of explosive material based on specific rock type mentioned above prepared by this guideline as presented in Figure 6-3 and Table 6-4.

During the review of available literature, there was only one typical curve for schist rock available which was proposed by ICI Australia Operations Pty Ltd (1980). So, out of the six varieties of rock mentioned above, the trendline of only schist rock could be compared or co-related with the trendline of typical curve of proposed by ICI Australia Operations Pty Ltd (1980) for validation (Figure 6-3)).

Both Figure 6-3 and Table 6-4 shows that there is a fair co-relation between two trendlines. However, the powder factor of the Schist of Nepal seems to be relatively less than powder factor proposed by ICI Australia Operations Pty Ltd (1980). Thus, this guideline recommends the typical curve for estimation of explosive materials based on specific rock type prepared by this guideline as presented in Figure 6-3, Figure 6-11 and Table 6-9.

Table 6-4 Comparison of powder factor based on typical curve of schist rock recommended by this guideline with the powder factor based on typical curve of schist rock recommended by ICI-Australia

Diameter (m) of typical circular section	Cross Section area (m^2) of typical circular section	Powder factor based typical curve of schist rock recommended by this guideline	Powder factor based on the typical curve of schist rock recommended by ICI-Australia
1.00	0.79	8.64	18.50
1.50	1.77	4.91	10.76
1.60	2.01	4.49	9.88
1.70	2.27	4.12	9.11
1.80	2.54	3.81	8.44
1.90	2.83	3.53	7.85
2.00	3.14	3.29	7.33
2.10	3.46	3.07	6.87
2.20	3.80	2.88	6.45
2.30	4.15	2.71	6.08
2.40	4.52	2.55	5.75
2.50	4.91	2.41	5.44
2.60	5.31	2.28	5.16
2.70	5.72	2.16	4.91
2.80	6.15	2.06	4.68
2.90	6.60	1.96	4.46
3.00	7.07	1.87	4.26
3.10	7.54	1.78	4.08
3.20	8.04	1.71	3.91
3.30	8.55	1.64	3.75
3.40	9.07	1.57	3.61
3.50	9.62	1.51	3.47
3.60	10.17	1.45	3.34
3.70	10.75	1.39	3.22
3.80	11.34	1.34	3.11
3.90	11.94	1.30	3.00
4.00	12.56	1.25	2.90
4.10	13.20	1.21	2.81
4.20	13.85	1.17	2.72
4.30	14.51	1.13	2.64
4.40	15.20	1.10	2.56
4.50	15.90	1.06	2.48
4.60	16.61	1.03	2.41
4.70	17.34	1.00	2.34
4.80	18.09	0.97	2.28
4.90	18.85	0.94	2.21

Diameter (m) of typical circular section	Cross Section area (m^2) of typical circular section	Powder factor based typical curve of schist rock recommended by this guideline	Powder factor based on the typical curve of schist rock recommended by ICI-Australia
5.00	19.63	0.92	2.15
5.10	20.42	0.89	2.10
5.20	21.23	0.87	2.04
5.30	22.05	0.85	1.99
5.40	22.89	0.82	1.94
5.50	23.75	0.80	1.90
5.60	24.62	0.78	1.85
5.70	25.50	0.76	1.81
5.80	26.41	0.75	1.77
5.90	27.33	0.73	1.73
6.00	28.26	0.71	1.69
6.10	29.21	0.69	1.65
6.20	30.18	0.68	1.62
6.30	31.16	0.66	1.58
6.40	32.15	0.65	1.55
6.50	33.17	0.64	1.52
6.60	34.19	0.62	1.49
6.70	35.24	0.61	1.46
6.80	36.30	0.60	1.43
6.90	37.37	0.59	1.40
7.00	38.47	0.57	1.37
7.10	39.57	0.56	1.35
7.20	40.69	0.55	1.32
7.30	41.83	0.54	1.30
7.40	42.99	0.53	1.28
7.50	44.16	0.52	1.25
7.60	45.34	0.51	1.23
7.70	46.54	0.50	1.21
7.80	47.76	0.49	1.19
7.90	48.99	0.48	1.17
8.00	50.24	0.48	1.15
8.50	56.72	0.44	1.06
9.00	63.59	0.40	0.98
9.50	70.85	0.37	0.91
10.00	78.50	0.35	0.85
11.00	94.99	0.31	0.75
12.00	113.04	0.27	0.67
13.00	132.67	0.24	0.60

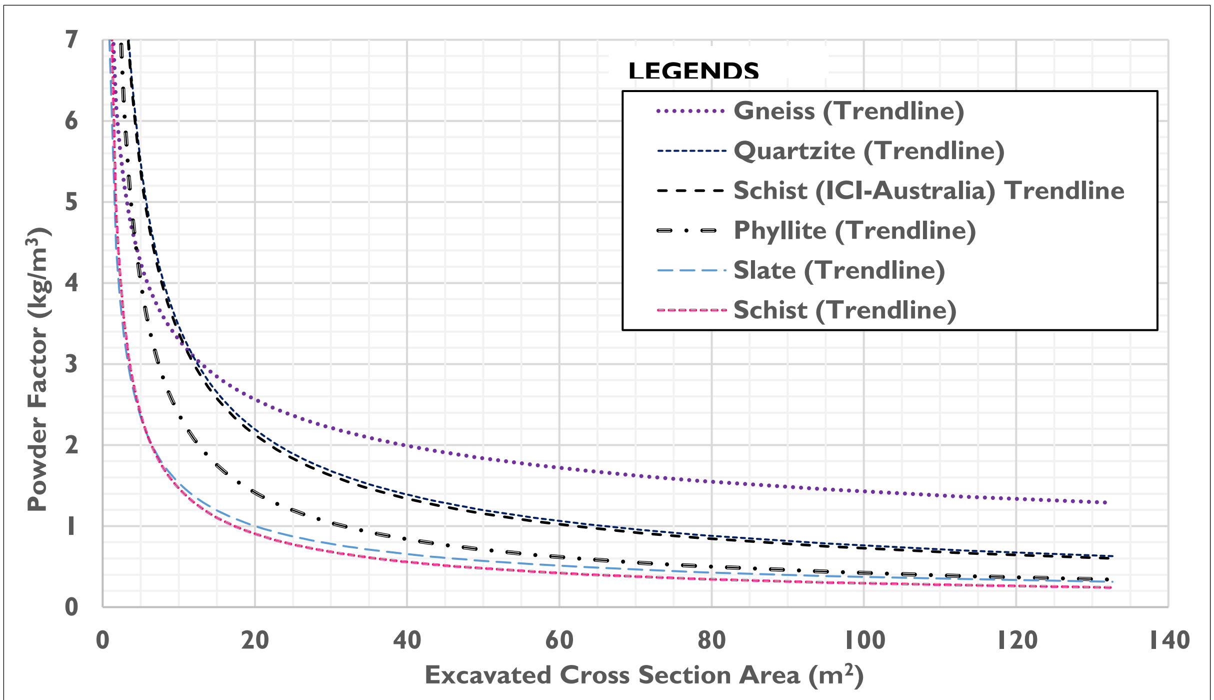


Figure 6-3 Recommended estimation of explosive material for underground excavation for all common rock types present in the Nepal Himalaya and Schist by ICI-Australia

6.2.2 Estimation of explosive material based on blastability of rock

The term blastability is used to indicated the susceptibility of the rock mass to blasting and is closely related with the powder factor. NTNU (1995) has proposed two different typical curves for the estimation of explosive materials for good blastability and poor blastability rocks using Powder factor v/s Excavated cross sectional area graph. In pursuant to Zare (2007), there is different blastablity for different types of rocks which is given by the Blastability Index (SPR). Thus, two broader group of rocks of Nepal has been categorized in Table 6-5 based on the blastablity index proposed by Zare (2007) and PLI and UCS values presented in Table 6-1 and Section 3.1.2.3.

Out of 14971 drilling and blasting operation of 18 different hydropower projects presented in Annex 8, 8921 data was used for computation for good blastability rocks whereas 8864 data used for computation for poor blastability rocks. It should be noted that about 3,896 number of data had not specified any rock type so it had been used for computation of both categories considering the limited number of information regarding drilling and blasting operation. The average powder factor of different rock types with different excavated cross sectional area have been used to prepare a typical curve (powder factor versus cross-sectional area) based on the blastability of the rocks (Figure 6-4).

In order to validate the trendline of a typical curve based on the blastability of the rock, the trendline of the typical curve based on NTNU based on blasatbility has been compared in Figure 6-4. Both Figure 6-4 and Table 6-6 shows that there is a good co-relation between two trendlines of good blastablity rock whereas there is fair correlation between two trendlines of poor blastablity rock. However, the powder factor of the poor blastability rocks seems to be relatively less than powder factor proposed by NTNU (1995). Thus, this guideline recommends the typical curve for estimation of explosive material based on blastability of the rocks prepared by this guideline as presented in Figure 6-4, Figure 6-11 and Table 6-9.

Table 6-5 Blastability for different types of rock based on blastablity index (SPR) proposed by Zare (2007)

S.No.	Poor Blastability Rocks	Good Blastability Rocks
1	Amphibolite	Phyllite
2	Amphibolitic Gneiss	Mica Gneiss
3	Gneiss	Mica Schist
4	Granitic Gneiss	Mudstone
5	Calcareous Sandstone	Shale
6	Limestone / Dolomite	Schist
7	Quartzite	Slate
8	Marble	Siltstone
9	Magnetite	
10	Sandstone	

Table 6-6 Comparison of powder factor based on typical curve of good and poor blastability rocks recommended by this guideline with the powder factor based on typical curve of good and poor blastability rocks recommended by NTNU

Diameter (m) of typical circular section	Cross Section area (m²) of typical circular section	Recommended by NTNU		Recommended by this guideline	
		Powder factor based on typical curve of good blastability rocks	Powder factor based on typical curve of poor blastability rocks	Powder factor based on typical curve of poor blastability rocks	Powder factor based on typical curve of good blastability rocks
1.00	0.79	5.95	6.66	10.39	12.26
1.50	1.77	4.49	5.11	7.09	7.66
1.60	2.01	4.29	4.90	6.67	7.11
1.70	2.27	4.12	4.70	6.30	6.62
1.80	2.54	3.96	4.53	5.97	6.20
1.90	2.83	3.81	4.37	5.67	5.82
2.00	3.14	3.68	4.23	5.40	5.49
2.10	3.46	3.56	4.10	5.16	5.18

Diameter (m) of typical circular section	Cross Section area (m^2) of typical circular section	Recommended by NTNU		Recommended by this guideline	
		Powder factor based on typical curve of good blastability rocks	Powder factor based on typical curve of poor blastability rocks	Powder factor based on typical curve of poor blastability rocks	Powder factor based on typical curve of good blastability rocks
2.20	3.80	3.44	3.97	4.94	4.91
2.30	4.15	3.34	3.86	4.73	4.67
2.40	4.52	3.24	3.75	4.55	4.44
2.50	4.91	3.15	3.65	4.38	4.24
2.60	5.31	3.07	3.56	4.22	4.05
2.70	5.72	2.99	3.47	4.07	3.87
2.80	6.15	2.91	3.39	3.93	3.71
2.90	6.60	2.84	3.31	3.80	3.57
3.00	7.07	2.78	3.24	3.68	3.43
3.10	7.54	2.71	3.17	3.57	3.30
3.20	8.04	2.65	3.11	3.47	3.18
3.30	8.55	2.60	3.04	3.37	3.07
3.40	9.07	2.54	2.99	3.27	2.96
3.50	9.62	2.49	2.93	3.19	2.87
3.60	10.17	2.45	2.88	3.10	2.77
3.70	10.75	2.40	2.82	3.02	2.69
3.80	11.34	2.36	2.78	2.95	2.61
3.90	11.94	2.31	2.73	2.88	2.53
4.00	12.56	2.27	2.68	2.81	2.46
4.10	13.20	2.23	2.64	2.74	2.39
4.20	13.85	2.20	2.60	2.68	2.32
4.30	14.51	2.16	2.56	2.62	2.26
4.40	15.20	2.13	2.52	2.57	2.20
4.50	15.90	2.09	2.48	2.51	2.14
4.60	16.61	2.06	2.45	2.46	2.09
4.70	17.34	2.03	2.41	2.41	2.04
4.80	18.09	2.00	2.38	2.36	1.99
4.90	18.85	1.97	2.35	2.32	1.94
5.00	19.63	1.95	2.32	2.27	1.90
5.10	20.42	1.92	2.29	2.23	1.85
5.20	21.23	1.89	2.26	2.19	1.81
5.30	22.05	1.87	2.23	2.15	1.77
5.40	22.89	1.85	2.20	2.12	1.73
5.50	23.75	1.82	2.18	2.08	1.70
5.60	24.62	1.80	2.15	2.04	1.66
5.70	25.50	1.78	2.13	2.01	1.63
5.80	26.41	1.76	2.10	1.98	1.60
5.90	27.33	1.74	2.08	1.95	1.56
6.00	28.26	1.72	2.06	1.92	1.53
6.10	29.21	1.70	2.03	1.89	1.50
6.20	30.18	1.68	2.01	1.86	1.48
6.30	31.16	1.66	1.99	1.83	1.45
6.40	32.15	1.64	1.97	1.80	1.42
6.50	33.17	1.62	1.95	1.78	1.40
6.60	34.19	1.61	1.93	1.75	1.37
6.70	35.24	1.59	1.91	1.73	1.35
6.80	36.30	1.57	1.89	1.70	1.33
6.90	37.37	1.56	1.88	1.68	1.30
7.00	38.47	1.54	1.86	1.66	1.28
7.10	39.57	1.53	1.84	1.63	1.26
7.20	40.69	1.51	1.83	1.61	1.24
7.30	41.83	1.50	1.81	1.59	1.22
7.40	42.99	1.48	1.79	1.57	1.20
7.50	44.16	1.47	1.78	1.55	1.18
7.60	45.34	1.46	1.76	1.53	1.17
7.70	46.54	1.44	1.75	1.51	1.15
7.80	47.76	1.43	1.73	1.49	1.13
7.90	48.99	1.42	1.72	1.48	1.11
8.00	50.24	1.41	1.70	1.46	1.10
8.50	56.72	1.35	1.64	1.38	1.02
9.00	63.59	1.29	1.58	1.31	0.96
9.50	70.85	1.25	1.52	1.24	0.90
10.00	78.50	1.20	1.47	1.18	0.85
11.00	94.99	1.13	1.38	1.08	0.76
12.00	113.04	1.06	1.31	1.00	0.69
13.00	132.67	1.00	1.24	0.92	0.63

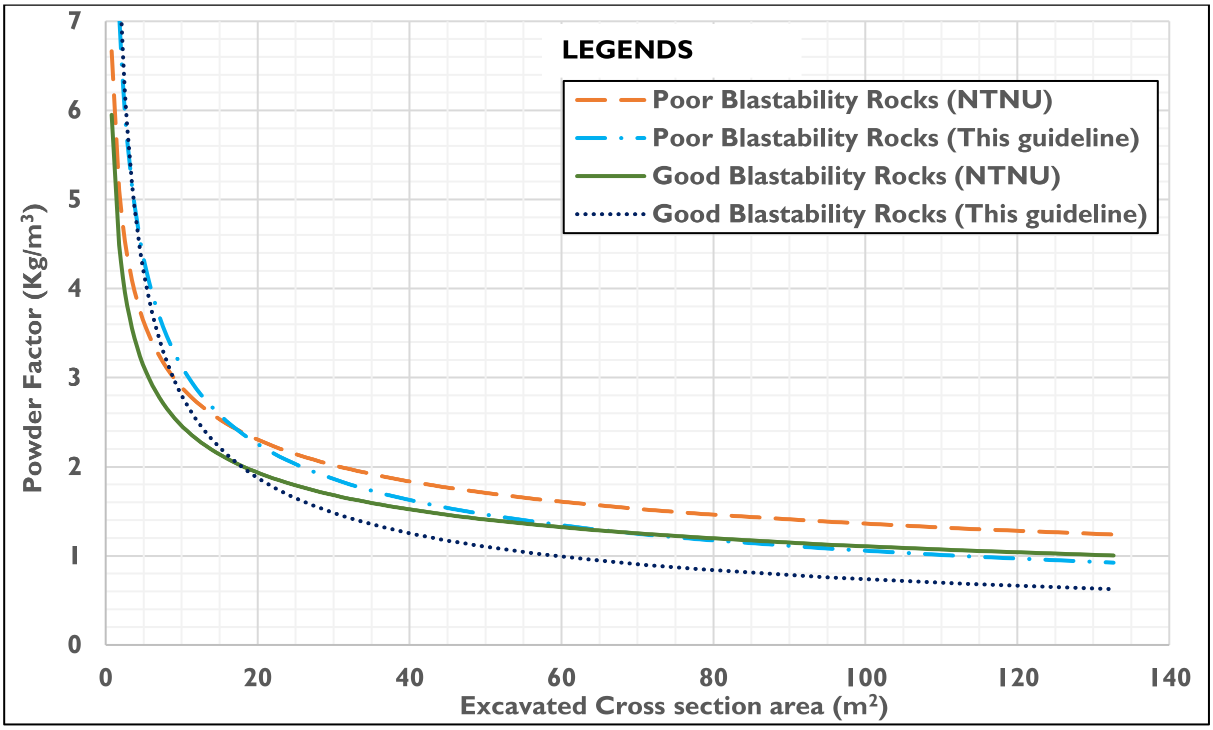


Figure 6-4 Recommended typical curve for estimation of explosive material for underground excavation based on the blastability of rocks by this guideline along with typical curve of NTNU for comparison

6.2.3 Estimation of explosive material based on rock quality

Out of 14971 information regarding drilling and blasting operation, only 12520 included the details regarding the rock quality. Since, 12520 number of information regarding drilling and blasting information included the rock quality, this guideline has proposed typical curve based on rock quality into two broad categories namely good blastablity rocks and poor blastability rocks in pursuant to the categorization based on blastability as mentioned in Section 6.2.2 and Table 6-5.

Out of the 12520 information, about half of the drilling and blasting operations were conducted in Rock class IV with very few information on the Rock class I and rock class II. Thus, based on the data density available, this guideline has proposed the estimation of the explosive materials based on rock quality for both good blastablility rocks and poor blastability rocks by defining the five-rock class with respective ranges of RMR and Q-values as shown in Table 6-7.

Table 6-7 Modified Rock Mass Class used to define rock quality for this guideline

Rock class	Q-Value	RMR range	Rock Quality
I	> 32	75-100	Very Good Rock
II	6-32	60-75	Good Rock
III	0.7-6	40-60	Fair Rock
IV	0.07-0.7	20-40	Poor Rock
V	0.001-0.07	0-20	Very Poor Rock

6.2.3.1 Estimation of explosive material based on rock quality for poor blastability rocks

Based on the 7757 (out of 12520) information regarding drilling and blasting operation of 18 different hydropower projects presented in Annex 8, the average powder factor of different rock classes with different excavated cross sectional area have been used to prepare a typical curve (powder factor versus cross-sectional area) based on rock quality for poor blastability rocks.

Since, the information of Rock Class III, IV and V has abundant data, the typical curve was obtained, however due to limited number of information of Rock Class I and II, a proper typical curves were not obtained. It was observed that the typical curve of Rock Class III had recommended powder factor relatively higher than the Rock Class IV and Rock Class IV had recommended powder factor relatively higher than the Rock Class V.

So, the difference in the powder factor between Rock Class III and Rock Class IV from the respective excavated cross-sectional area was added to the powder factor of Rock Class III to obtain the typical curve of Rock Class II. Similarly, the difference in the powder factor between Rock Class II and Rock Class III from the respective excavated cross-sectional area was added to the powder factor of Rock Class II to obtain the typical curve of Rock Class I.

Thus, this guideline recommends the typical curve for estimation of explosive material based on rock quality for poor blastability rocks prepared by this guideline as presented in Figure 6-5, Figure 6-11 and Table 6-9.

6.2.3.2 Estimation of explosive material based on rock class for good blastability rocks

Similarly, good blastability rocks were divided into five classes. However, there is enough data for the rock classes III, IV, and V while limited data was available for other rock classes I and II, so to create graphs for classes I and II, the information from the other three classes were used as mentioned in the Section 6.2.3.1.

Thus, this guideline recommends the typical curve for estimation of explosive material based on rock quality for good blastability rocks prepared by this guideline as presented in Figure 6-6, Figure 6-11 and Table 6-9.

6.2.4 Estimation of explosive material based on regional geology

Out of 14971 information regarding drilling and blasting operation, only 12520 included the details regarding the regional geology. There were no information of the drilling and blasting operation of Tethys Himalaya and only 646 number of drilling and blasting operation in Siwaliks. So, the typical curve for the estimation of explosive materials for the Tethys Himalaya could not be proposed by this guideline.

Similarly, all the 646 drilling and blasting operation in Siwalik was carried out in tunnel alignment of only one hydropower project having same excavated cross-sectional area. So, a typical curve for the estimation of explosive materials could not be proposed by this guideline. However, the single point has been presented in Figure 6-7 to acknowledge the data available and compare it with the typical curve of Higher Himalaya rocks and Lesser Himalaya rocks.

The average powder factor of different rock types with different excavated cross sectional area have been used to prepare a typical curve (powder factor versus cross-sectional area) based on the different regional geology (Figure 6-7 and Table 6-9). It is observed that the typical curve of Higher Himalaya Rock recommends two to three times more powder factors in the respective excavated cross-sectional area compared to the typical curve of Lesser Himalaya rocks proposed by this guideline.

Thus, this guideline recommends the typical curve for estimation of explosive material based on regional geology for the Higher Himalayan rocks and Lesser Himalayan rocks prepared by this guideline as presented in Figure 6-7,
and Table 6-9.

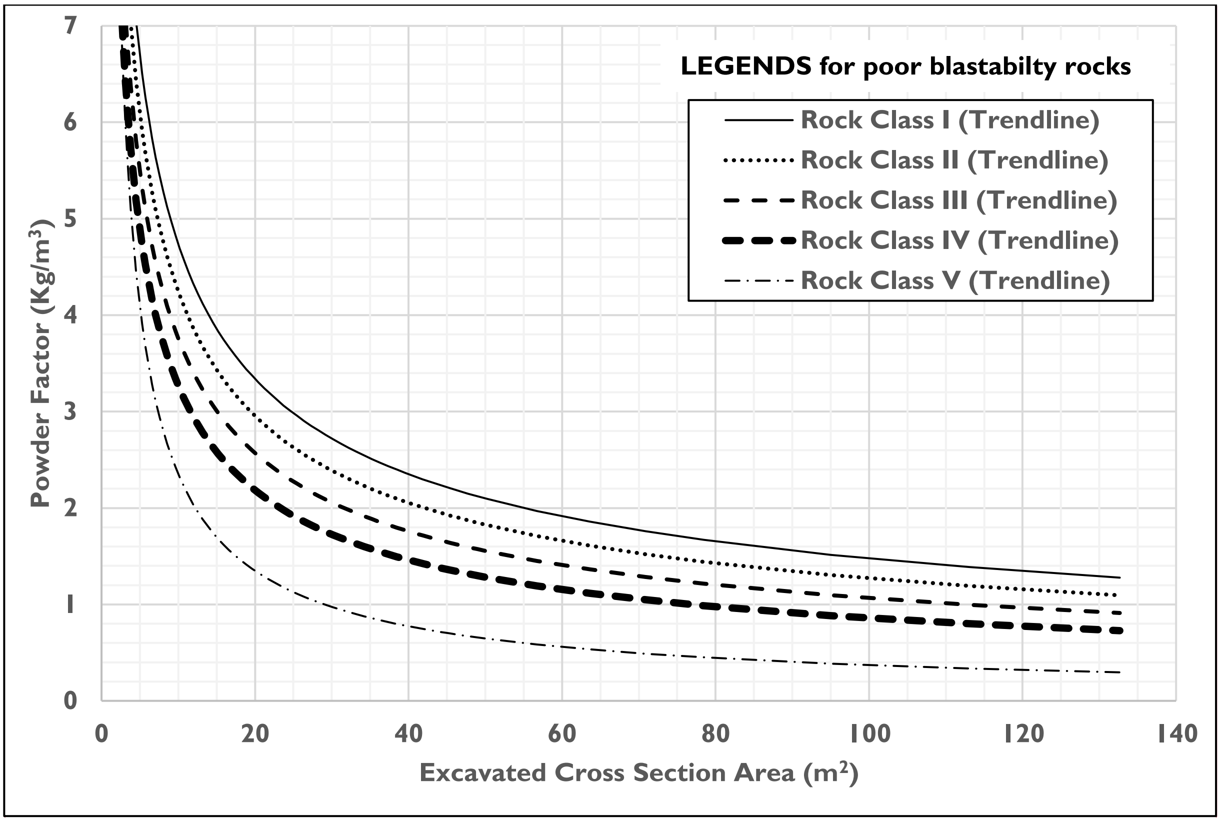


Figure 6-5 Recommended estimation of explosive material for underground excavation for poor blastability rocks based on rock classes

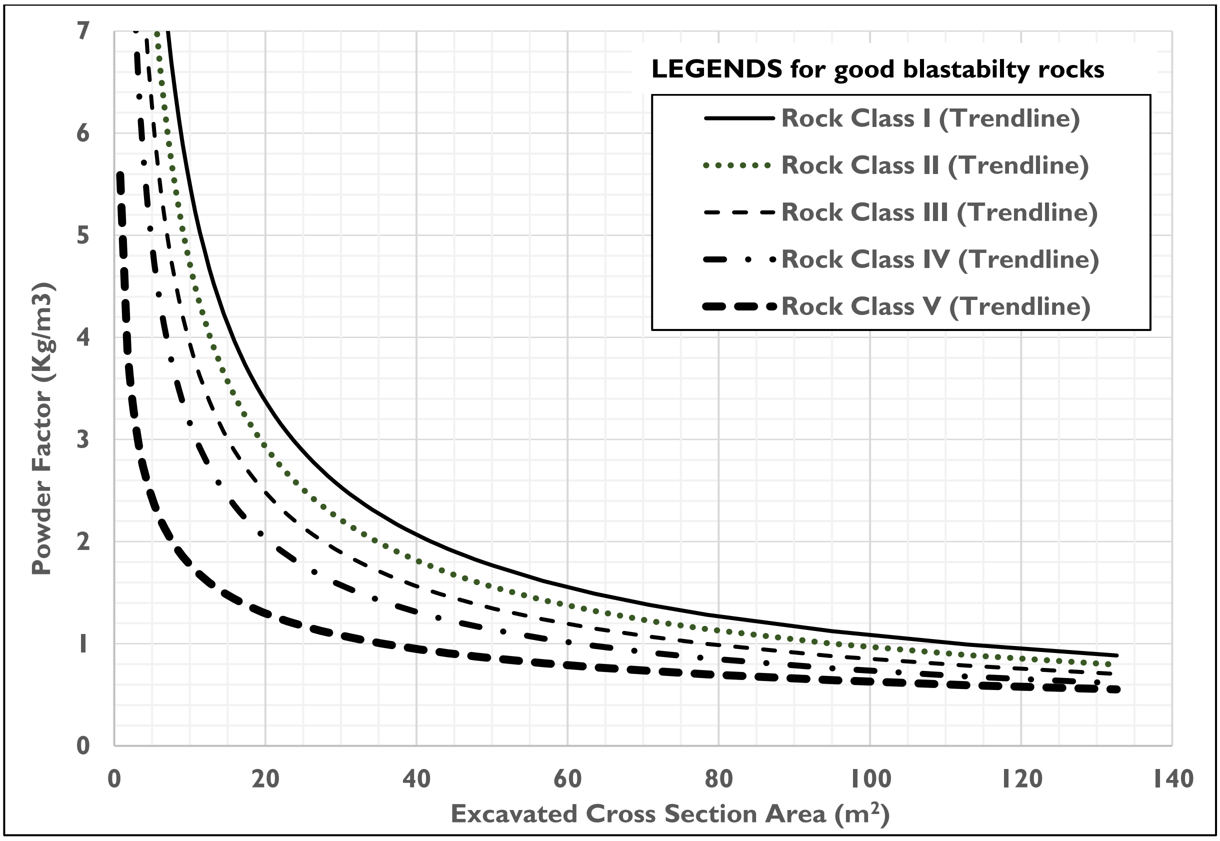


Figure 6-6 Recommended estimation of explosive material for underground excavation for good blastability rocks based on rock classes

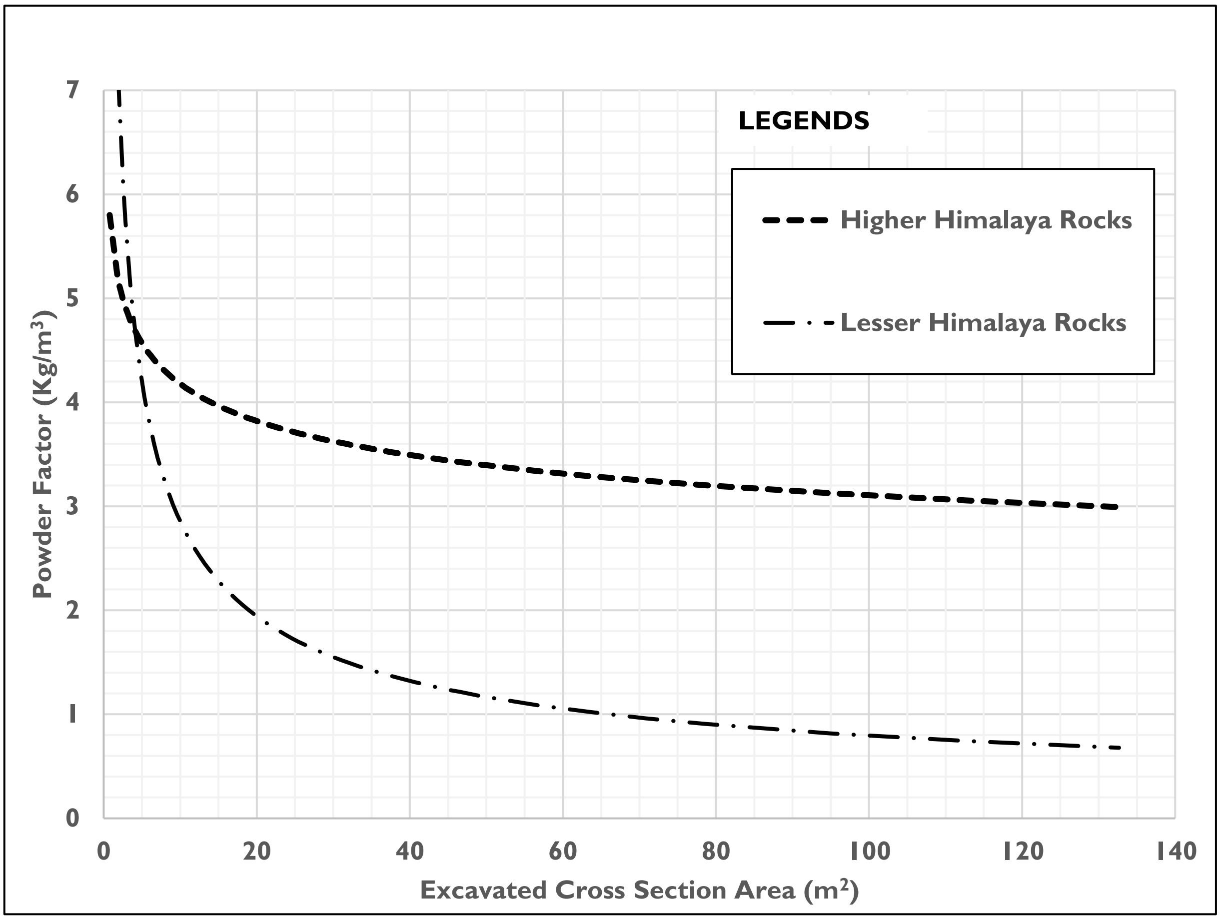


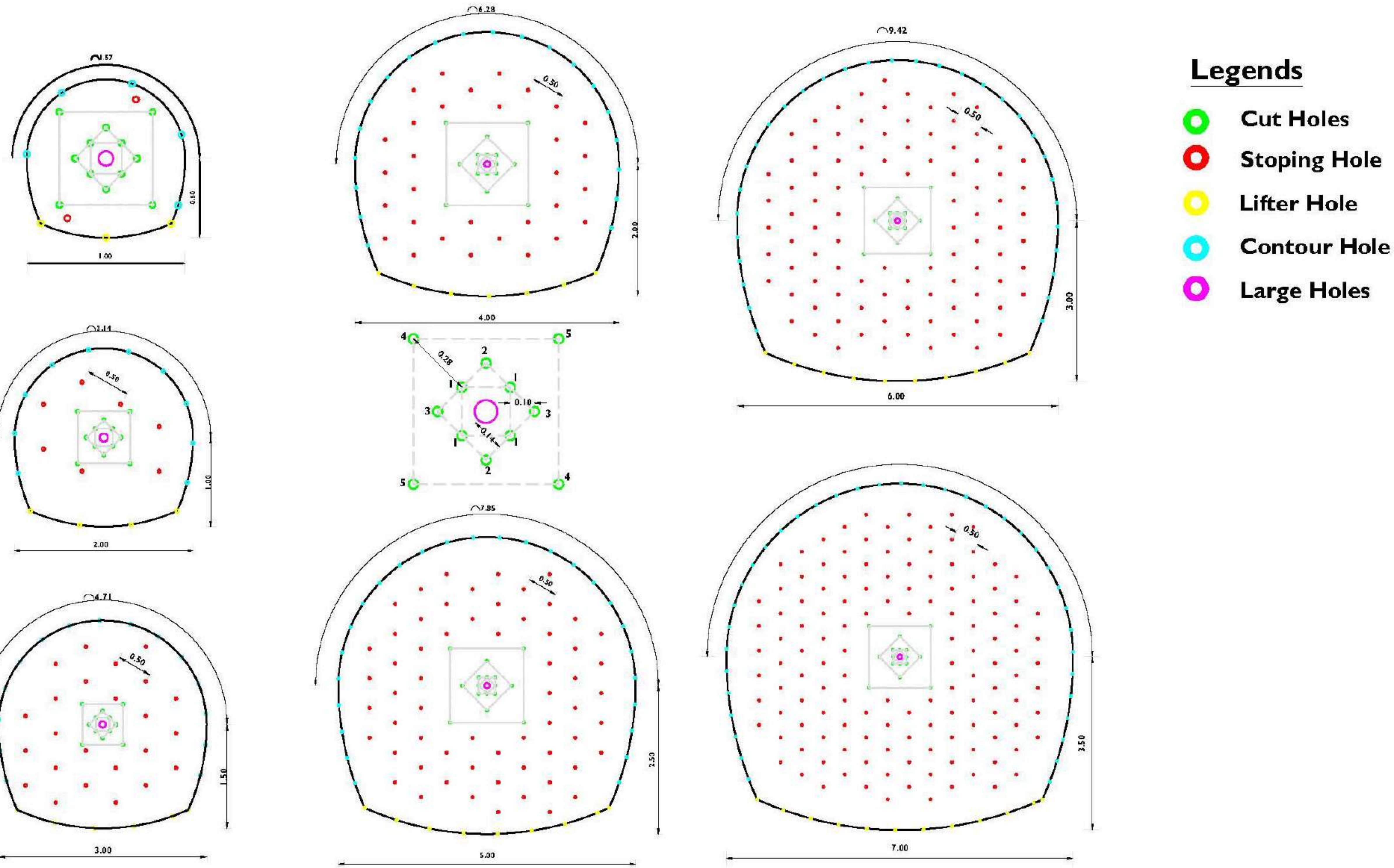
Figure 6-7 Recommended estimation of explosive material for underground excavation for different geological units of the Nepal Himalaya

6.2.5 Estimation of explosive material based on blasting pattern

Blasting pattern is the practical basis for estimation of explosive materials. There are numerous types of tunnel shape, tunnel diameter and other tunnel parameter used during the tunneling in the hydropower projects of Nepal. So, estimation based on blasting pattern with variety of tunnel parameters and blasting parameters will be cumbersome. Thus, a typical blasting pattern of horse shoe shaped tunnel with diameter ranging from 1 to 13 m have been devised by this guideline following the recommended parameters mentioned in section 3.1.7.6 in order to propose the typical curve based on the typical blasting pattern (Figure 6-8 and Figure 6-9). The details of geometrical parameters for the typical blasting pattern have been presented in Table 6-8. Thus, this guideline recommends the typical curve for estimation of explosive material based on typical blasting pattern proposed by this guideline as presented in Figure 6-10, Figure 6-11 and Table 6-9.

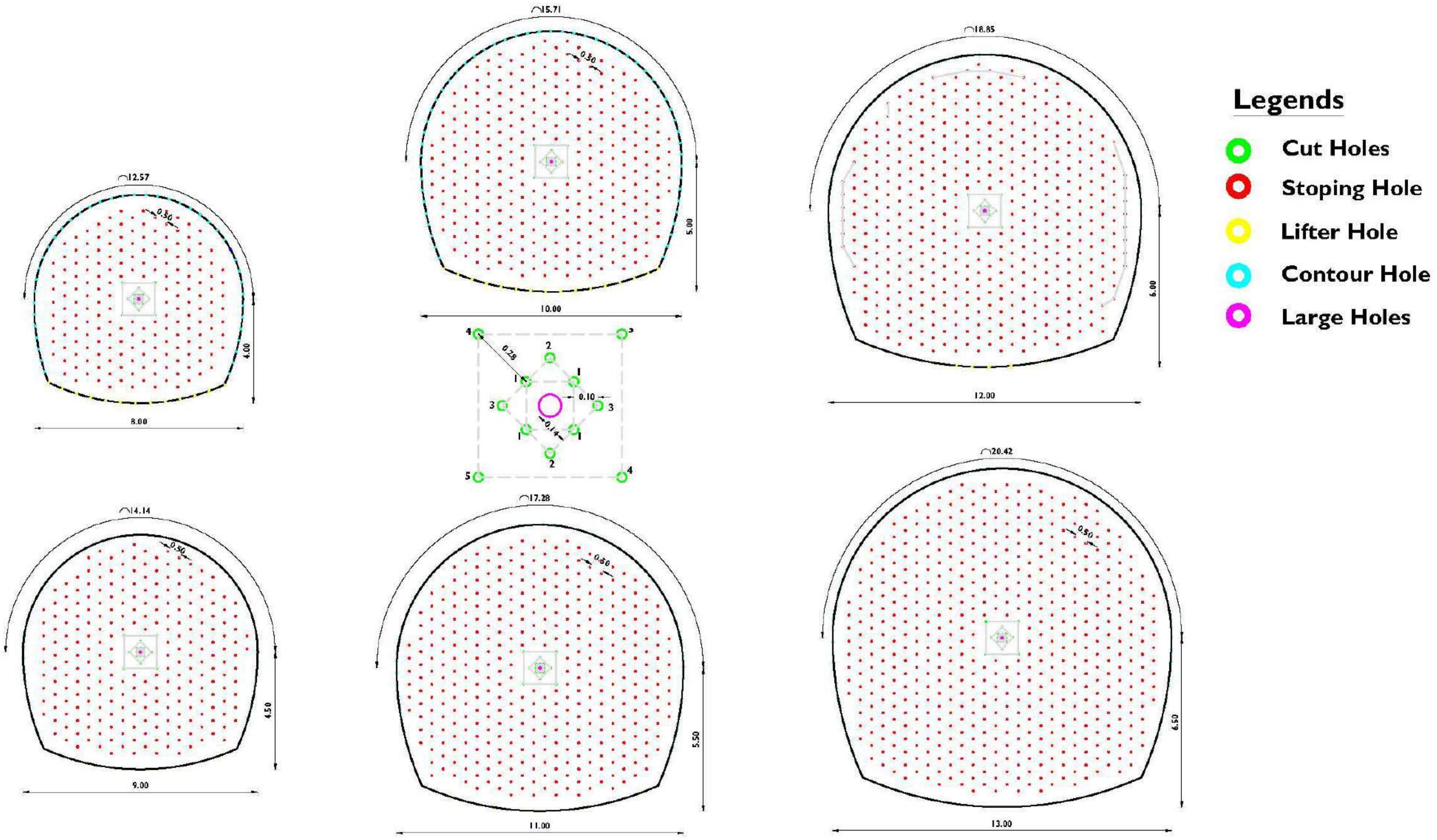
6.2.6 Comparison of estimation of explosive material for underground excavation based on factors recommended by this guideline

In order to compare and assess the recommended typical curve for estimation of explosive material for underground excavation based on rock type, blastability, rock quality, regional geology, and typical blasting pattern for the prospecting hydropower projects of Nepal, this guideline has prepared a master curve and master table in Figure and Table respectively. For the estimation of explosive materials for underground excavation in any hydropower projects in Nepal, this guideline recommends to select at least two typical curves as presented in Figure 6-11 and Table 6-9.



Diameter of Typical Horse-Shoe Shaped tunnel	Cross-Section Area of Typical Horse-Shoe Shaped tunnel (m^2)	Perimeter of a Typical Horse Shoe Shaped Tunnel(m)	No. of Empty Blast hole	No. of Charged Blast Holes				Total No.of Charged Blast holes	Linear charge Concentration of Cut holes	Linear charge Concentration of Stoping holes(500*500)	Linear charge Concentration of Lifter holes	Linear charge Concentration of Contour holes	Explosive Loading Density for Cut hole	Explosive Loading Density for Stoping hole(500*500)	Explosive Loading Density for Lift hole	Explosive Loading Density for Contour hole	No. of Sticks or cartridges or Emulsion per charged Blasting	Explosive quantity required with 500*500 stoping holes	Volume of the rock excavation	Powder Factor with 500*500 stoping holes	Requirement of Ignition system			
				Cut holes	Stopping holes 500 mm*500mm	Lifter holes	Contour holes														No. of Detonators	No. of Detonators per unit weight of explosive consumed	Length of Detonating cord	Length of Detonating cord per unit weight of explosive consumed
1	0.829	3.26	1	12	2	3	5	22	1.05	1.8	1.5	1.4	12.6	3.6	4.5	7	5.54	27.7	2.35	11.75	22	0.79	32	1.16
2	3.317	6.53	1	12	7	4	10	33	1.05	1.8	1.5	1.5	12.6	12.6	6	15	9.24	46.2	9.42	4.9	33	0.71	53	1.15
3	7.407	7.46	1	12	24	6	15	57	1.05	1.8	1.5	1.5	12.6	43.2	9	22.5	17.46	87.3	21.21	4.11	57	0.65	87	1.00
4	13.26	13.06	1	16	31	7	20	74	1.05	1.8	1.5	1.5	16.8	55.8	10.5	30	22.62	113.1	37.71	2.99	74	0.65	114	1.01
5	20.73	16.32	1	16	61	9	26	112	1.05	1.8	1.5	1.5	16.8	109.8	13.5	39	35.82	179.1	58.92	3.03	112	0.63	164	0.92
6	29.85	19.60	1	16	95	10	31	152	1.05	1.8	1.5	1.5	16.8	171	15	46.5	49.86	249.3	84.85	2.93	152	0.61	214	0.86
7	46.63	22.86	1	16	131	12	37	196	1.05	1.8	1.5	1.5	16.8	235.8	18	55.5	65.22	326.61	115.5	2.82	196	0.60	270	0.83

Figure 6-8 Typical blasting pattern based on the geometrical parameter for the drill length of the 3.0 m for diameter of 1.0-7.0 m diameter



Diameter of Typical Horse-Shoe Shaped tunnel	Cross-Section Area of Typical Horse-Shoe Shaped tunnel (m^2)	Perimeter of a Typical Horse Shoe Shaped Tunnel(m)	No. of Empty Blast hole	No. of Charged Blast Holes				Total No.of Charged Blast holes	Linear charge Concentration of Cut holes	Linear charge Concentration of Stoping holes(500*500)	Linear charge Concentration of Lifter holes	Linear charge Concentration of Contour holes	Explosive Loading Density for Cut hole	Explosive Loading Density for Stoping hole(500*500)	Explosive Loading Density for Lift hole	Explosive Loading Density for Contour hole	No. of Sticks or cartridges or Emulsion per charged Blasting	Explosive quantity required with 500*500 stoping holes	Volume of the rock excavation	Powder Factor with 500*500 stoping holes	Requirement of Ignition system			
				Cut holes	Stopping holes 500 mm*500mm	Lifter holes	Contour holes														No. of Detonators	No. of Detonators per unit weight of explosive consumed	Length of Detonating cord	Length of Detonating cord per unit weight of explosive consumed
8	53.29	26.20	1	16	185	13	42	256	1.05	1.8	1.5	1.5	16.8	333	19.5	63	86.46	432.3	150.85	2.86	256	0.59	340	0.79
9	67.17	29.40	1	16	246	14	48	324	1.05	1.8	1.5	1.5	16.8	442.8	21	72	110.52	552.6	190.92	2.89	324	0.59	420	0.76
10	82.93	32.67	1	16	319	16	53	404	1.05	1.8	1.5	1.5	16.8	574.2	24	79.5	138.9	694.5	235.71	2.94	404	0.58	510	0.73
11	100.34	35.93	1	16	390	17	58	481	1.05	1.8	1.5	1.5	16.8	702	25.5	87	166.26	831.3	285.21	2.91	481	0.58	597	0.72
12	119.42	39.20	1	16	472	19	64	571	1.05	1.8	1.5	1.5	16.8	849.6	28.5	96	198.18	990.9	339.28	2.91	571	0.58	699	0.71
13	140.15	42.47	1	16	557	20	69	662	1.05	1.8	1.5	1.5	16.8	1002.6	30	103.5	230.58	1152.9	398.35	2.89	662	0.57	800	0.69

Figure 6-9 Typical blasting pattern based on the geometrical parameter for the drill length of the 3.0 m for diameter of 8.0-13.0 m diameter

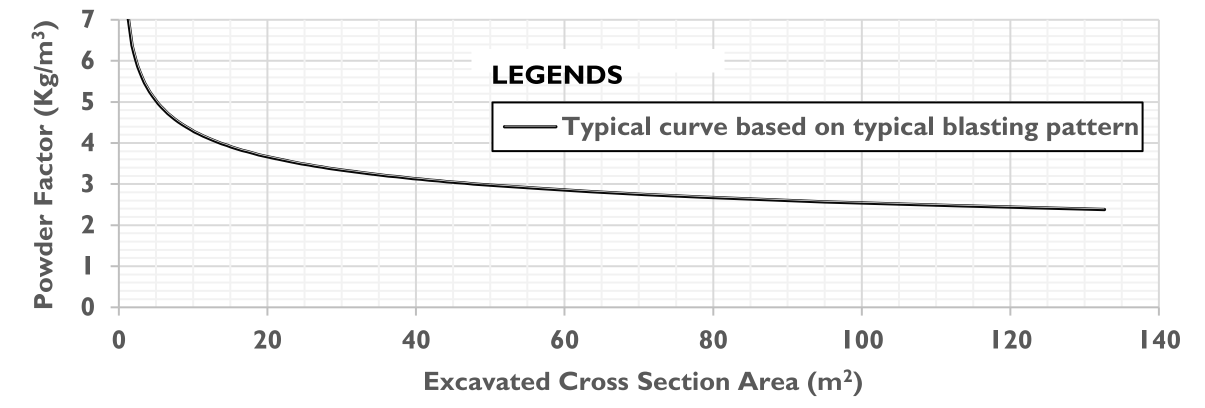


Figure 6-10 Recommended estimation of explosive material based on typical blasting pattern

Table 6-8 Details of typical blasting pattern proposed by this guideline

Types of Blastholes	Geometrical parameters	Used Values		Remarks
Cutholes	Number of large empty blast hole	1		3 square cut section is adopted in the typical blasting pattern for the tunnel section upto 3m diameter wheresas 4 square cut section is adopted for the tunnel section having diameter of 4 m or more
	Blast hole depth (m)	3		
	Equivalent large hole diameter (mm)	92		
	Equivalent cuthole diameter (mm)	38		
	Burden of Cut holes (mm)	First Cut Hole	138.24	
		Second Cut Hole	195.50	
		Third Cut Hole	414.72	
		Fourth Cut Gole	879.75	
	Spacing of cut holes (mm)	First Square Cut	195.50	
		Second Square Cut	276.48	
		Third Square Cut	586.50	
		Fourth Square Cut	1244.16	
	Stemming of cut holes (mm)	First Square Cut	138.24	
		Second Square Cut	97.75	
		Third Square Cut	622.08	
		Fourth Square Cut	1061.96	
	Linear Charge Concentration (kg/m)	1.05		0.35*drill length
Lifter Hole	Explosive Loading Density (kg/dm3)	12.6 (for tunnel diameter less than 4m) and 16.8 (for tunnel diameter of 4m or more)		
	Blast hole depth (m)	3		
	Equivalent cuthole diameter (mm)	38		
	Explosive Density (g/cc)	1.15		
	Explosive Loading Density (kg/dm3)	0.92		3.14159*D²*P (density of explosive)/4000
	PRP (ANFO) - Relative weight strength of explosive related to ANFO	1.22		
	Fixation Factor	1.45		
	Rock Constant (c̄)	0.47		
	Burden of Lifter holes (m)	1.16		
	Spacing of lifter holes	0.58		Although S/B =1 is assumed, the spacing is taken half of the burden measured in order to get smooth blasting and 3 number of lifter hole for given burden calculated
	Ratio Spacing/Burden	1		
	Number of lifter holes	3		
	Linear Charge Concentration (kg/m)	1.5		0.5* drill length
	Stemming of lifter holes (mm)	380		
	Explosive Loading Density (kg/dm3)	4.5 -30		3.14159*D²*P (density of explosive)/4000
Contour Hole	Contour hole diameter (mm)	38		
	Blast hole depth (m)	3		
	Explosive Density (g/cc)	1.15		
	Explosive Loading Density (kg/dm³)	0.402		
	PRP (ANFO) - Relative weight strength of explosive related to ANFO	1.22		
	Fixation Factor	1.2		
	Rock Constant (c̄)	0.47		
	Burden of Lifter holes (m)	0.894		
	Spacing of lifter holes (m)	0.45		Although S/B =1 is assumed, the spacing is taken half of the burden measured in order to get smooth blasting and 3 number of lifter hole for given burden calculated
	Ratio Spacing/Burden	1.25		
	Linear Charge Concentration (kg/m)	1.5		0.5* drill length
Stoping Holes	Burden (mm)	500		
	Extension (mm)	500		
	Spacing (mm)	500		
	Linear Charge Concentration (kg/m)	1.8		0.6*drill length

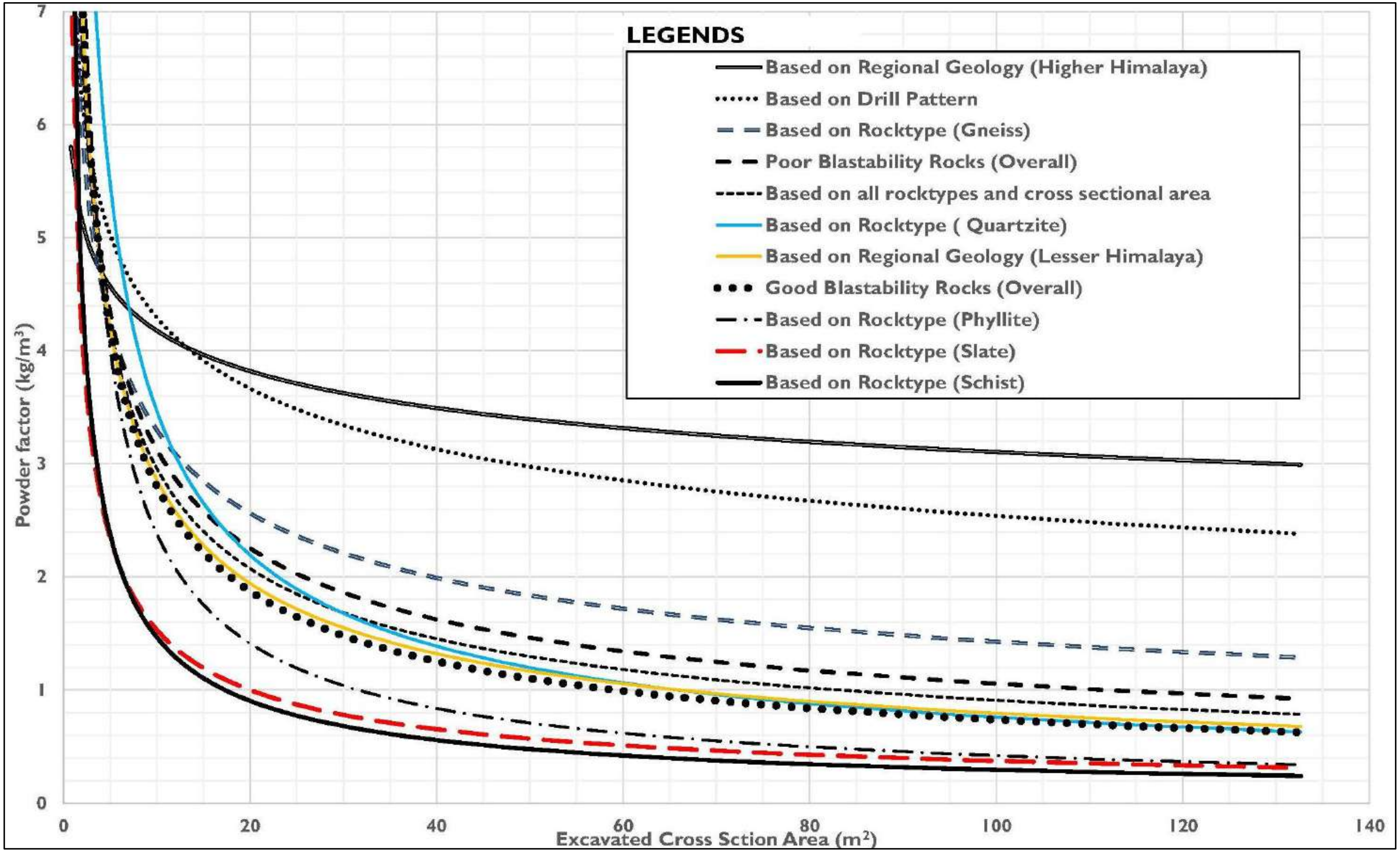


Figure 6-11 Recommended estimation of explosive material for underground excavation by considering different methods/factors namely rock type, rock quality, blastability, regional geology, and a typical blasting pattern

Table 6-9 Average powder factor for different cross sectional area based on all the rock types, good blastability rocks, poor blastability rocks, blastability, based on Regional Geology, common rock types of Nepal Himalaya, and on typical blasting pattern

Diameter of Typical Circular Section (m)	Cross Sectional Area (m^2) of Typical Circular Section	Recommended powder factor																					Recommended Range of computed Powder Factor
		Based Rock Type						Based on Blastability		Based on Rock Quality										Based on Regional Geology		Based on Typical Blasting Pattern	
										For Good Blastability Rocks					For Poor Blastability Rocks								
		All rocks of Nepal Himalaya	Gneiss	Schist	Phyllite	Slate	Quartzite	Good Blastability Rocks	Poor Blastability Rocks	Rock Class I	Rock Class II	Rock Class III	Rock Class IV	Rock Class V	Rock Class I	Rock Class II	Rock Class III	Rock Class IV	Rock Class V	Higher Himalaya	Lesser Himalaya		
1	0.79	10.92	8.33	8.64	16.2	7.31	18.6	10.39	12.26	32.88	27.13	21.44	15.86	5.59	16.99	16.05	15.15	14.34	18.1	5.8	11.76	7.67	3.88-32.62
1.5	1.77	7.2	6.2	4.91	8.78	4.44	10.9	7.09	7.66	18.58	15.53	12.49	9.48	3.88	11.30	10.50	9.72	8.95	9.44	5.22	7.49	6.37	3.66-18.52
1.6	2.01	6.74	5.92	4.49	7.97	4.1	10	6.67	7.11	16.96	14.21	11.47	8.74	3.66	10.59	9.82	9.05	8.3	8.52	5.14	6.97	6.19	3.46-16.92
1.7	2.27	6.33	5.66	4.12	7.27	3.81	9.23	6.3	6.62	15.57	13.07	10.58	8.09	3.46	9.96	9.21	8.47	7.74	7.73	5.06	6.52	6.02	3.29-15.55
1.8	2.54	5.97	5.43	3.81	6.67	3.55	8.56	5.97	6.2	14.37	12.08	9.8	7.52	3.29	9.41	8.68	7.96	7.24	7.05	4.98	6.12	5.87	3.13-14.35
1.9	2.83	5.65	5.22	3.53	6.15	3.32	7.97	5.67	5.82	13.32	11.22	9.12	7.03	3.13	8.91	8.20	7.5	6.8	6.46	4.92	5.76	5.72	2.99-13.31
2	3.14	5.36	5.03	3.29	5.7	3.12	7.45	5.4	5.49	12.39	10.45	8.52	6.58	2.99	8.46	7.77	7.09	6.41	5.95	4.85	5.44	5.59	2.86-12.38
2.1	3.46	5.1	4.85	3.07	5.29	2.94	6.98	5.16	5.18	11.57	9.77	7.98	6.19	2.86	8.05	7.39	6.72	6.05	5.51	4.79	5.15	5.47	2.74-11.57
2.2	3.8	4.86	4.69	2.88	4.93	2.78	6.57	4.94	4.91	10.83	9.17	7.5	5.83	2.74	7.69	7.03	6.39	5.74	5.11	4.73	4.89	5.35	2.64-10.84
2.3	4.15	4.65	4.54	2.71	4.61	2.63	6.19	4.73	4.67	10.18	8.62	7.07	5.51	2.64	7.35	6.72	6.08	5.45	4.76	4.68	4.66	5.25	2.54-10.18
2.4	4.52	4.45	4.4	2.55	4.33	2.49	5.85	4.55	4.44	9.58	8.13	6.68	5.22	2.54	7.04	6.42	5.8	5.18	4.44	4.63	4.44	5.14	2.45-9.59
2.5	4.91	4.26	4.28	2.41	4.07	2.37	5.55	4.38	4.24	9.05	7.69	6.33	4.96	2.45	6.76	6.15	5.55	4.94	4.16	4.58	4.24	5.05	2.36-9.06
2.6	5.31	4.1	4.15	2.28	3.84	2.26	5.27	4.22	4.05	8.56	7.29	6.01	4.72	2.36	6.50	5.91	5.32	4.72	3.91	4.53	4.06	4.96	2.26-8.57
2.7	5.72	3.94	4.04	2.16	3.62	2.16	5.01	4.07	3.87	8.12	6.92	5.71	4.5	2.28	6.26	5.68	5.1	4.52	3.68	4.49	3.9	4.88	2.16-8.13
2.8	6.15	3.8	3.94	2.06	3.43	2.06	4.78	3.93	3.71	7.71	6.58	5.44	4.3	2.21	6.03	5.47	4.9	4.33	3.47	4.45	3.74	4.8	2.06-7.73
2.9	6.6	3.66	3.84	1.96	3.25	1.98	4.56	3.8	3.57	7.34	6.27	5.19	4.11	2.14	5.82	5.27	4.72	4.16	3.28	4.41	3.6	4.72	1.96-7.36
3	7.07	3.54	3.74	1.87	3.09	1.9	4.36	3.68	3.43	7.00	5.98	4.96	3.94	2.08	5.63	5.09	4.55	4	3.11	4.37	3.47	4.65	1.87-7.01
3.1	7.54	3.42	3.66	1.78	2.94	1.82	4.18	3.57	3.3	6.68	5.72	4.75	3.78	2.01	5.44	4.91	4.38	3.85	2.95	4.33	3.34	4.58	1.78-6.70
3.2	8.04	3.31	3.57	1.71	2.81	1.75	4	3.47	3.18	6.39	5.47	4.55	3.63	1.96	5.27	4.75	4.23	3.71	2.8	4.3	3.23	4.51	1.71-6.41
3.3	8.55	3.21	3.49	1.64	2.68	1.69	3.85	3.37	3.07	6.12	5.25	4.37	3.49	1.9	5.11	4.60	4.09	3.58	2.67	4.26	3.12	4.45	1.64-6.14
3.4	9.07	3.11	3.42	1.57	2.56	1.63	3.7	3.27	2.96	5.87	5.04	4.2	3.36	1.85	4.96	4.46	3.96	3.46	2.54	4.23	3.02	4.39	1.57-5.88
3.5	9.62	3.02	3.35	1.51	2.45	1.57	3.56	3.19	2.87	5.63	4.84	4.04	3.24	1.81	4.82	4.33	3.84	3.34	2.43	4.2	2.92	4.33	1.51-5.65
3.6	10.17	2.93	3.28	1.45	2.35	1.52	3.43	3.1	2.77	5.42	4.66	3.89	3.12	1.76	4.68	4.20	3.72	3.24	2.32	4.17	2.83	4.28	1.45-5.43
3.7	10.75	2.85	3.21	1.39	2.26	1.47	3.31	3.02	2.69	5.21	4.48	3.75	3.02	1.72	4.56	4.08	3.61	3.13	2.22	4.14	2.74	4.22	1.39-5.22
3.8	11.34	2.78	3.15	1.34	2.17	1.42	3.19	2.95	2.61	5.02	4.32	3.62	2.92	1.68	4.44	3.97	3.51	3.04	2.13	4.11	2.66	4.17	1.34-5.03
3.9	11.94	2.7	3.09	1.3	2.08	1.37	3.08	2.88	2.53	4.84	4.17	3.5	2.82	1.64	4.32	3.87	3.41	2.95	2.04	4.08	2.59	4.12	1.30-4.85
4	12.56	2.63	3.04	1.25	2.01	1.33	2.98	2.81	2.46	4.67	4.03	3.38	2.73	1.6	4.21	3.76	3.32	2.86	1.96	4.06	2.52	4.08	1.25-4.68
4.1	13.2	2.57	2.98	1.21	1.93	1.29	2.89	2.74	2.39	4.51	3.89	3.27	2.65	1.57	4.11	3.67	3.23	2.78	1.88	4.03	2.45	4.03	1.21-4.52
4.2	13.85	2.5	2.93	1.17	1.86	1.25	2.8	2.68	2.32	4.36	3.77	3.17	2.57	1.53	4.01	3.58	3.14	2.71	1.81	4.01	2.38	3.99	1.17-4.37
4.3	14.51	2.44	2.88	1.13	1.8	1.22	2.71	2.62	2.26	4.22	3.65	3.07	2.49	1.5	3.92	3.49	3.06	2.63	1.74	3.98	2.32	3.94	1.13-4.23
4.4	15.2	2.39	2.83	1.1	1.74	1.18	2.63	2.57	2.2	4.08	3.53	2.98	2.42	1.47	3.83	3.41	2.99	2.56	1.68	3.96	2.26	3.9	1.10-4.09
4.5	15.9	2.33	2.79	1.06	1.68	1.15	2.55	2.51	2.14	3.96	3.42	2.89	2.35	1.44	3.74	3.33	2.91	2.5	1.62	3.94	2.21	3.86	1.06-3.97
4.6	16.61	2.28	2.74	1.03	1.62	1.12	2.48	2.46	2.09	3.83	3.32	2.81	2.29	1.41	3.66	3.25	2.85	2.43	1.57	3.91	2.15	3.82	1.03-3.91
4.7	17.34	2.23	2.7	1	1.57	1.09	2.41	2.41	2.04	3.72	3.23	2.73	2.23	1.38	3.58	3.18	2.78	2.37	1.51	3.89	2.1	3.79	1.00-3.89
4.8	18.09	2.18	2.66	0.97	1.52	1.06	2.34	2.36	1.99	3.61	3.13	2.65	2.17	1.36	3.51	3.11	2.72	2.32	1.46	3.87	2.06	3.75	0.97-3.87
4.9	18.85	2.14	2.62	0.94	1.48	1.04	2.28	2.32	1.94	3.51	3.05	2.58	2.11	1.33	3.43	3.04	2.65	2.26	1.41	3.85	2.01	3.72	0.94-3.85
5	19.63	2.09	2.58	0.92	1.43	1.01	2.22	2.27	1.9	3.41	2.96	2.51	2.06	1.31	3.37	2.98	2.6	2.21	1.37	3.83	1.96	3.68	0.92-3.83
5.1	20.42	2.05	2.54	0.89	1.39	0.99	2.16	2.23	1.85	3.32	2.88	2.45	2.01	1.29	3.30	2.92	2.54	2.16	1.33	3.81	1.92	3.65	0.89-3.81
5.2	21.23	2.01	2.51	0.87	1.35	0.97	2.11	2.19	1.81	3.23	2.81	2.39	1.96	1.26	3.24	2.86	2.49	2.11	1.29	3.79	1.88	3.62	0.87-3.79
5.3	22.05	1.97	2.47	0.85	1.31	0.94	2.06	2.15	1.77	3.14	2.73	2.33	1.91	1.24	3.17	2.80	2.44	2.06	1.25	3.77	1.84	3.58	0.85-3.77
5.4	22.89	1.94	2.44	0.82	1.28	0.92	2.01	2.12	1.73	3.06	2.66	2.27	1.87	1.22	3.11	2.75	2.39	2.02	1.21	3.75	1.8	3.55	0.82-3.75
5.5	23.75	1.9	2.41	0.8	1.24	0.9	1.96	2.08	1.7	2.98	2.60	2.21	1.83	1.2	3.06	2.70	2.34	1.98	1.18	3.74	1.77	3.52	0.80-3.74

Diameter of Typical Circular Section (m)	Cross Sectional Area (m^2) of Typical Circular Section	Recommended powder factor																						Recommended Range of computed Powder Factor
		Based Rock Type						Based on Blastability		Based on Rock Quality										Based on Regional Geology		Based on Typical Blasting Pattern	
										For Good Blastability Rocks					For Poor Blastability Rocks								
		All rocks of Nepal Himalaya	Gneiss	Schist	Phyllite	Slate	Quartzite	Good Blastability Rocks	Poor Blastability Rocks	Rock Class I	Rock Class II	Rock Class III	Rock Class IV	Rock Class V	Rock Class I	Rock Class II	Rock Class III	Rock Class IV	Rock Class V	Higher Himalaya	Lesser Himalaya		
5.6	24.62	1.86	2.38	0.78	1.21	0.88	1.91	2.04	1.66	2.91	2.53	2.16	1.78	1.18	3.00	2.65	2.29	1.94	1.14	3.72	1.73	3.5	0.78-3.72
5.7	25.5	1.83	2.35	0.76	1.18	0.86	1.87	2.01	1.63	2.84	2.47	2.11	1.74	1.16	2.95	2.60	2.25	1.9	1.11	3.7	1.7	3.47	0.76-3.70
5.8	26.41	1.8	2.32	0.75	1.15	0.84	1.83	1.98	1.6	2.77	2.42	2.06	1.71	1.14	2.90	2.55	2.21	1.86	1.08	3.69	1.67	3.44	0.75-3.69
5.9	27.33	1.77	2.29	0.73	1.12	0.83	1.79	1.95	1.56	2.70	2.36	2.02	1.67	1.13	2.85	2.51	2.17	1.82	1.05	3.67	1.63	3.41	0.73-3.67
6	28.26	1.74	2.26	0.71	1.09	0.81	1.75	1.92	1.53	2.64	2.31	1.97	1.63	1.11	2.80	2.46	2.13	1.79	1.02	3.65	1.6	3.39	0.71-3.65
6.1	29.21	1.71	2.23	0.69	1.06	0.79	1.71	1.89	1.5	2.58	2.25	1.93	1.6	1.09	2.76	2.42	2.09	1.75	1	3.64	1.57	3.36	0.69-3.64
6.2	30.18	1.68	2.21	0.68	1.04	0.78	1.67	1.86	1.48	2.52	2.20	1.89	1.57	1.08	2.71	2.38	2.05	1.72	0.97	3.62	1.55	3.34	0.68-3.62
6.3	31.16	1.65	2.18	0.66	1.01	0.76	1.64	1.83	1.45	2.46	2.16	1.85	1.54	1.06	2.67	2.34	2.02	1.69	0.95	3.61	1.52	3.31	0.66-3.61
6.4	32.15	1.63	2.16	0.65	0.99	0.75	1.6	1.8	1.42	2.41	2.11	1.81	1.51	1.05	2.63	2.30	1.98	1.66	0.92	3.59	1.49	3.29	0.65-3.59
6.5	33.17	1.6	2.13	0.64	0.97	0.73	1.57	1.78	1.4	2.36	2.06	1.77	1.48	1.03	2.58	2.27	1.95	1.63	0.9	3.58	1.47	3.27	0.64-3.58
6.6	34.19	1.58	2.11	0.62	0.94	0.72	1.54	1.75	1.37	2.31	2.02	1.74	1.45	1.02	2.55	2.23	1.92	1.6	0.88	3.56	1.44	3.24	0.62-3.56
6.7	35.24	1.55	2.09	0.61	0.92	0.71	1.51	1.73	1.35	2.26	1.98	1.7	1.42	1.01	2.51	2.19	1.88	1.57	0.86	3.55	1.42	3.22	0.61-3.55
6.8	36.3	1.53	2.06	0.6	0.9	0.69	1.48	1.7	1.33	2.21	1.94	1.67	1.39	0.99	2.47	2.16	1.85	1.55	0.84	3.54	1.4	3.2	0.60-3.54
6.9	37.37	1.5	2.04	0.59	0.88	0.68	1.45	1.68	1.3	2.17	1.90	1.64	1.37	0.98	2.43	2.13	1.82	1.52	0.82	3.52	1.37	3.18	0.59-3.52
7	38.47	1.48	2.02	0.57	0.86	0.67	1.43	1.66	1.28	2.12	1.86	1.61	1.34	0.97	2.40	2.10	1.8	1.49	0.8	3.51	1.35	3.16	0.57-3.51
7.1	39.57	1.46	2	0.56	0.85	0.66	1.4	1.63	1.26	2.08	1.83	1.58	1.32	0.95	2.37	2.07	1.77	1.47	0.78	3.5	1.33	3.14	0.56-3.50
7.2	40.69	1.44	1.98	0.55	0.83	0.65	1.37	1.61	1.24	2.04	1.79	1.55	1.3	0.94	2.33	2.04	1.74	1.45	0.76	3.49	1.31	3.12	0.55-3.49
7.3	41.83	1.42	1.96	0.54	0.81	0.64	1.35	1.59	1.22	2.00	1.76	1.52	1.27	0.93	2.30	2.01	1.72	1.42	0.75	3.47	1.29	3.1	0.54-3.47
7.4	42.99	1.4	1.94	0.53	0.79	0.63	1.32	1.57	1.2	1.96	1.73	1.49	1.25	0.92	2.27	1.98	1.69	1.4	0.73	3.46	1.27	3.08	0.53-3.46
7.5	44.16	1.38	1.92	0.52	0.78	0.62	1.3	1.55	1.18	1.93	1.70	1.46	1.23	0.91	2.24	1.95	1.67	1.38	0.71	3.45	1.25	3.06	0.52-3.45
7.6	45.34	1.36	1.9	0.51	0.76	0.61	1.28	1.53	1.17	1.89	1.67	1.44	1.21	0.9	2.21	1.92	1.64	1.36	0.7	3.44	1.23	3.04	0.51-3.44
7.7	46.54	1.34	1.88	0.5	0.75	0.6	1.26	1.51	1.15	1.86	1.64	1.41	1.19	0.89	2.18	1.90	1.62	1.34	0.69	3.43	1.22	3.02	0.50-3.43
7.8	47.76	1.33	1.87	0.49	0.73	0.59	1.24	1.49	1.13	1.82	1.61	1.39	1.17	0.88	2.15	1.87	1.59	1.32	0.67	3.41	1.2	3.01	0.49-3.41
7.9	48.99	1.31	1.85	0.48	0.72	0.58	1.21	1.48	1.11	1.79	1.58	1.37	1.15	0.87	2.12	1.85	1.57	1.3	0.66	3.4	1.18	2.99	0.48-3.40
8	50.24	1.29	1.83	0.48	0.71	0.57	1.19	1.46	1.1	1.76	1.55	1.34	1.14	0.86	2.10	1.82	1.55	1.28	0.64	3.39	1.16	2.97	0.48-3.39
8.5	56.72	1.22	1.75	0.44	0.64	0.53	1.1	1.38	1.02	1.62	1.43	1.24	1.05	0.81	1.97	1.71	1.45	1.19	0.58	3.34	1.09	2.89	0.44-3.34
9	63.59	1.15	1.68	0.4	0.59	0.49	1.02	1.31	0.96	1.49	1.32	1.15	0.98	0.77	1.86	1.61	1.36	1.12	0.53	3.29	1.02	2.82	0.40-3.29
9.5	70.85	1.08	1.62	0.37	0.55	0.46	0.95	1.24	0.9	1.38	1.22	1.07	0.91	0.73	1.76	1.52	1.28	1.05	0.49	3.25	0.96	2.75	0.37-3.25
10	78.5	1.03	1.56	0.35	0.5	0.43	0.89	1.18	0.85	1.28	1.14	1	0.86	0.7	1.68	1.44	1.21	0.99	0.45	3.2	0.91	2.68	0.35-3.20
11	94.99	0.93	1.45	0.31	0.44	0.38	0.78	1.08	0.76	1.12	1.00	0.88	0.76	0.64	1.52	1.31	1.09	0.88	0.39	3.12	0.82	2.57	0.31-3.12
12	113.04	0.85	1.36	0.27	0.38	0.35	0.7	1	0.69	0.99	0.89	0.78	0.68	0.59	1.39	1.19	0.99	0.8	0.34	3.06	0.74	2.47	0.27-3.06
13	132.67	0.79	1.29	0.24	0.34	0.31	0.63	0.92	0.63	0.89	0.80	0.7	0.61	0.55	1.29	1.10	0.91	0.73	0.3	2.99	0.68	2.38	0.24-2.99
Recommended Trend line equation		9.643x^-0.513	7.627x^-0.364	7.299x^-0.697	13.481x^-0.753	6.299x^-0.614	15.848x^-0.66	9.271x^-0.472	10.654x^-0.58	27.726x^-0.704	22.967x^-0.688	18.25x^-0.66	13.6x^-0.634	5.011x^-0.451	15.403x^-0.503	14.14x^-0.523	13.27x^-0.548	12.456x^-0.581	14.905x^-0.802	5.622x^-0.129	10.278x^-0.556	7.257x^-0.228	

6.2.7 Validation of estimation of explosive material for underground excavation based on various factors recommended by this guideline

Validation is crucial in any estimation work because it ensures that the estimates are accurate, reliable, and fit for purpose. Figure 6-10 shows that the average powder factor of the total explosive consumption for the given cross sectional area of underground excavation of various 18 hydropower projects lies within the range of powder factors recommended by this guideline as presented in Table 6-9 and Figure 6-11. In order to establish a certain factor of safety during the estimation of explosive materials, this guideline has considered a contingency provision for various recommended typical curves based on under-estimation and over-estimation of the collected data as discussed below (Annex -12 and Table 6-11)

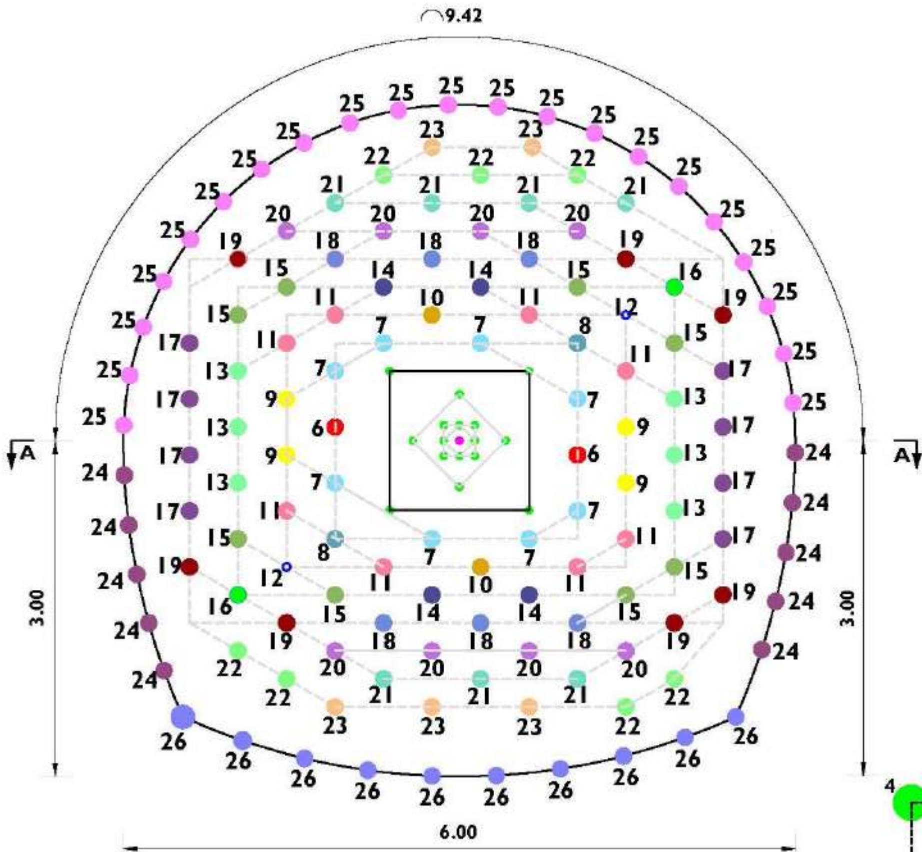
a) Table 6-11 shows that there is an average of 8.44% under-estimation of explosive material based on the typical curve of overall rock type recommended by this guideline. Thus, the guideline recommends at most 10% contingency provision if the hydropower developer selects the estimation based on any rock types presented in Table 6-9 and Figure 6-11.
b) Similarly, there is an average of 7.35% and 7.42% under-estimation of explosive material based on the typical curve of good blastability and poor blastability respectively as recommended by this guideline. Thus, the guideline recommends at most 10% contingency provision if the hydropower developer selects the estimation based on blastability presented in Table 6-9 and Figure 6-11.
c) There is an average of 8.58% under-estimation of explosive material based on the typical curve of Lesser Himalaya (Regional Geology) as recommended by this guideline. Thus, the guideline recommends at most 10% contingency provision if the hydropower developer selects the estimation based on Lesser Himalaya (Regional Geology) presented in Table 6 9 and Figure 6 11. However, there is 5.97% over-estimation of explosive material based on the typical curve of Higher Himalaya (Regional Geology) as recommended by this guideline. Thus, the guideline recommends no contingency provision if the hydropower developer selects the estimation based on Higher Himalaya (Regional Geology) presented in Table 6-9 and Figure 6-11.
d) There is 35.84% over-estimation of explosive material based on the typical curve of blasting pattern as recommended by this guideline. Thus, the guideline recommends no contingency provision if the hydropower developer selects the estimation based on blasting pattern presented in Table 6-9 and Figure 6-11.
e) Lastly, if the hydropower developer selects the estimation based on rock quality presented in Table 6-9 and Figure 6-11, this guideline recommends no contingency provisions, since the estimation based on rock quality will be based on the comprehensive geological baseline report of the given hydropower project having higher degree of confidence during the estimation of the explosive materials.

6.3 Details of estimation of ignition system

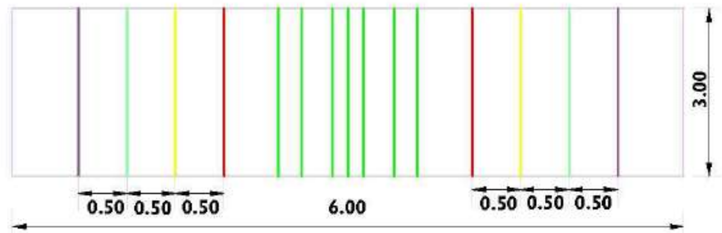
Based on the primary data and information collected during the site visits (Section 2.1.1), secondary data and information collected during the questionnaire survey (Section2.1.2) and residential workshop (Section 2.1.4), the average number of detonators required for 1 kilogram of the explosive (emulsion) used is 1.64 while the average length of the detonating cord required per kilogram of the explosive (emulsion) used is 0.66 meter were computed. Similarly, based on typical blasting pattern design recommended by this guideline (Section 6.2) the average number of detonators required for 1 kilogram of the explosive (emulsion) used is 0.63 while the average length of the detonating cord required per kilogram of the explosive (emulsion) used is 0.87 meter were computed. According to the DoR Norm (2077) for the road tunnel excavation, the powder factor, detonators number and detonating cord for different rock classes is as presented in the Figure 6-10. According to Table 6-12, the number of detonators per unit kilogram of explosive is 1.45 while detonating cord length is 3.64 m per unit kilogram of explosive. (DoR Norms, 2077). Thus, this guideline recommends the estimation of the ignition systems for underground excavation as presented in Table 6-13. Meanwhile, this guideline recommends the firing sequence for any drilling and blasting operation by using an example for the diameter of 6.0 m horseshoe shaped tunnel as presented in the Figure 6-13. Please refer to the downloadable link Templates for estimation of explosive materials for estimating the explosive materials and ignition system for both surface and underground excavation based on the above discussions.

Table 6-10 Validation of The Guideline Estimation Curve

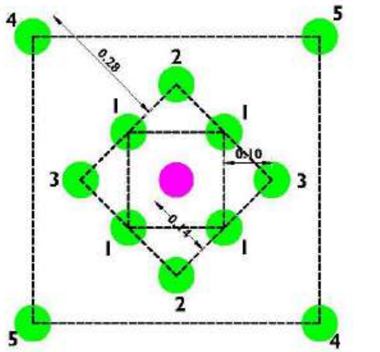
	Name of Projects	Component	Tunnel Length from drilling and Blasting data	Excavated Cross Section Area	Average Powder Factor based on the total explosive consumption for the given tunnel	Range of Powder factor recommended by this guideline	Remarks
1	Ghar Khola	HRT	419.15	8.45	2.91	1.64-6.14	
2	Kabeli(21.9 MW)	HRT	2488.2	10.94	3.96	1.39-5.22	
3	Lower Likhu HEP	HRT	4705.31	22.71	1.42	0.82-3.75	
4	Lower Solu HEP (82 MW)	High Pressure Tunnel	1274.44	14.28	4.19	1.13-4.23	
5	Mai Khola Hydroelectric Project	HRT	2115.48	15.83	1.09	1.06-3.97	
6	Mathilo Mailung HPP	HRT	2216.598	7	4.63	1.87-7.01	
7	Mistri Khola HEP	HRT	2224.73	16.67	3.83	1.03-3.91	
8	Nilgiri Khola HEP-1	HRT	2741.28	10.42	5.18	1.39-5.22	
9	Nilgiri Khola HEP-2	HRT	4920.78	10.42	3.95	1.39-5.22	
10	Nyasim HEP	Approach Tunnel	274.1	11.56	3.32	1.30-4.85	
11	Seti Khola HEP	HRT	1817.45	33.65	2.08	0.64-3.58	
12	Solukhola Dudhkoshi	HRT	514.33	17.01	3.54	1.00-3.89	
13	Super Kabeli Khola Cascade HEP(12 MW)	HRT	1298.69	10.93	3.99	1.39-5.22	
14	Tanahu Hydropower project	Left Bank Grouting Gallery	185.45	20.49	2.83	0.89-3.81	
15	Thulo Khola HEP	Headrace Tunnel	2792.5	11.81	2.81	1.30-4.85	
16	Upper Khudi Hydropower project	Headrace tunnel	57.47	7.65	5.98	1.78-6.70	
17	Upper Rahughat	Headrace Tunnel	83.5	15.32	2.45	1.34-5.03	
18	UT-1	Headrace Tunnel	722.43	46.39	2.45	0.50-3.43	



Typical Blasting Pattern



Typical Blasting Profile at Section A-A



Typical Blasting Pattern of Cut Hole (In Detail)

Legends For Different Types of Blast Holes along with Details of Explosive Materials used					
Descriptions	Symbol	Label	Emulsion (Kg)	Total Emulsion (Kg)	Detonators (No.)
Cut Holes		D1, D2, D3, D4, D5	1.05	16.8	16
Stopping Holes		D6	1.8	3.6	2
		D7	1.8	14.4	8
		D8	1.8	3.6	2
		D9	1.8	7.2	4
		D10	1.8	3.6	2
		D11	1.8	14.4	8
		D12	1.8	3.6	2
		D13	1.8	10.8	6
		D14	1.8	7.2	4
		D15	1.8	14.4	8
		D16	1.8	3.6	2
		D17	1.8	14.4	8
		D18	1.8	10.8	6
		D19	1.8	3.6	7
		D20	1.8	3.6	8
		D21	1.8	12.6	7
		D22	1.8	12.6	7
		D23	1.8	9	5
Contour Holes		D24	1.8	18	10
		D25	1.8	37.8	21
Lifter Holes		D26	1.8	18	10

Details of Typical Blasting Pattern for 6m dia. Horse Shoe Shaped Tunnel

Total Drill Holes (No.)	150
Empty Holes (No.)	1
Loading Holes (No.)	149
Detonator (No.)	149
Emulsion (Kg)	249.3

Cross-Sectional Area (m^2)	29.85
Assumed Pull Length (m)	3
Volume of Section (m^3)	89.55
Explosive Consumption (Kg / m^3)	2.78

Figure 6-12 An example for firing sequence in a typical delay pattern for 6.0m diameter horse-shoe shaped tunnel following the principle of rectangularity

Table 6-11 Contingency Table for the estimation of explosive based on different factors

Types of Typical Curve	Computed Contingency as per the over-estimation/under-estimation of the collected data	Recommended Contingency (%)
Based on Overall Rock type	8.44 %	At most10%
Based on Blastability		
Good Blastability	7.35%	At most 10%
Poor Blastability	7.42%	At most10%
Based on Regional Geology		
Lesser Himalaya	8.58%	At most 10%
Higher Himalaya	-5.97%	None
Based on Blasting and Drilling Pattern	-35.84%	None
Based on Specific Rock type		At most10%
Based on Rock Quality		None

Note: The recommended contingency for surface excavation is at most 10%

Table 6-12 Estimation of explosive materials for underground blasting proposed by DoR

S.N.	RMR	Rock Class	Powder factor (kg/m^3)	Detonators No. (per kg explosive)	Detonating cord, m (per kg explosive)
1	81-100	Class-I	2.88	1.45	3.64
2	61-80	Class-II	2.532		
3	41-60	Class-III	2.482		
4	21-40	Class-IV	2.613		
5	<20	Class-V	2.75		

Table 6-13 Recommended estimation of the ignition systems for the underground excavation

Type of Ignition System	Estimation based on primary and secondary data collected	Estimation based on typical blasting pattern recommended	Estimation based on Norms of DoR	Recommended range by this guideline
Detonators number per kg of the explosive used (nos.)	1.64	0.63	1.45-1.46	0.63-1.64
Detonating cord length per kg of the explosive use (m)	0.66	0.87	3.64-3.65	0.66-3.64 (Note: 3.64 is the maximum value observed in primary data collected)

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

7.1.1 For Explosive Materials Estimation

a) In order to get the recommendation for the procurement of explosive materials for the hydropower project, the prospecting hydropower project must provide the estimation based on the details mentioned in a Blasting Assessment Report (BAR) discussed in Section 3.1.5 of this guideline in pursuant to the estimation sheet presented in Table 3-1. The estimation of the explosive materials must be carried out having the technical specification as discussed in Section 3.1.8.

b) Explosive material estimation should be done by calculating the exact rock excavation volume by assuming an appropriate powder factor for the given excavated cross-sectional area based on various factors. For the estimation of explosive materials for the hydropower projects of Nepal, this guideline recommends to assess the actual dimensions of all the project components and compute the exact rock excavation (both surface and underground) volume considering the requirements mentioned in Section 3.1.1. Please refer to the downloadable link Templates for estimation of explosive materials for estimating the explosive materials and ignition system for both surface and underground excavation.

c) The estimation of the explosive materials should be based on the geology of Nepal as discussed in Section 3.1.2. For the assumption of the powder factor of explosives as discussed in Section 3.1.3 regarding surface excavation, this guideline recommends to apply the ranges of powder factor mentioned in Figure 6-1 and consider the requirements mentioned in Section 3.1.6. Meanwhile, for the assumption of the powder factor of explosives as discussed in Section 3.1.3 regarding underground excavation, this guideline recommends to apply the ranges of powder factors presented in Figure 6-11 and Table 6-9 as well as consider the requirements mentioned in Section 3.1.7. Please refer to the downloadable link Templates for estimation of explosive materials for estimating the explosive materials and ignition system for both surface and underground excavation.

d) In order to compare and assess the recommended typical curve for estimation of explosive material for underground excavation based on rock type, blastability, rock quality, regional geology, and typical blasting pattern for the prospecting hydropower projects of Nepal, this guideline has prepared a master curve and master table in Figure 6-11 and Table 6-9 respectively. For the estimation of explosive materials for underground excavation in any hydropower projects in Nepal, this guideline recommends to select at least two typical curves as presented in Figure 6-11 and Table 6-9.

e) Contingency provision for the recommended typical curves regarding the estimation of explosive materials have been carried out in order to establish certain factor of safety during the estimation of explosive materials which has been presented in Annex-12 and Table 6-11.

f) Similarly, for the assumption required for the estimation of ignition system (detonators and detonating cord), this guideline recommends to apply the recommended range of values as mentioned in the Table 6-13 for boulder blasting, surface excavation as well as underground excavation. Please refer to the downloadable link Templates for estimation of explosive materials for estimating the explosive materials and ignition system for both surface and underground excavation.

g) This guideline does not recommend the use of plain detonators and safety fuses during any drilling and blasting operations in a hydropower project. Thus, the estimation of ignition system should not include estimates of plain detonators and safety fuses.

h) It should be noted that the production of electric detonator has been prohibited in the neighboring countries. So, the availability of the electric detonator is in question. Thus, this guideline recommends the use of "State-Of-The-Art" initiation system such as non-electric (shock tube) or electronic detonators for explosive detonation and blasting works as an elimination measure as discussed in Section 4.2.12.1.

i) However, this guideline also allows the estimation of explosive materials-based norms prepared by the Department of Roads (DoR) of Nepal if any prospecting hydropower project opt to estimate it accordingly.

j) With the advancement of new technology, equipment, and explosives developed in the future, the drilling and blasting operations will tend to be more effective and efficient requiring less consumption of explosive materials for the given rock excavation volume. Thus, this guideline suggests to revise the recommended typical curve for estimation of explosive material for underground excavation in every 10 years.

k) In the estimation, the total amount of explosive materials needed should be broken down by year, taking into account transportation and storage needs. Additionally, a yearly dispatch schedule should be created in the BAR.

7.1.2 For Explosive Materials Usage

a) For maintaining the proper usage of the explosive material, the hydropower project must prepare a Daily Blasting Work Sheet. For this purpose, this guideline recommends a typical work sheet for every drilling and blasting operation in a hydropower project as presented in the Table 3-29. Similarly, this guideline recommends a typical format of record keeping of the data related to the drilling and blasting operations as presented in the Table 3-30 for reference.

b) There is currently a provision to provide monthly explosive material usage to the Nepal Army by the concerned hydropower project. Similarly, there is provision to provide the explosive material usage to the respective CDO in every 3 months duration. This guideline recommends to provide the explosive material usage in every 3 months duration notarized by the Nepal Army to DoED by including it in the regular trimonthly progress report which need to be submitted by every hydropower projects.

c) If additional explosive materials is required to complete the construction of hydropower project due to any reasons, the concerned hydropower project must include the explosive material usage record as presented in the Table 3-30 in the request application along with updated BAR for procurement of explosive materials

7.1.3 For Explosive Materials Handling

a) All the personnel associated with the explosive material handling should strictly follow all the provisions mentioned in the Explosive Act (2018) and the Explosive Regulation (2020) of Nepal.

b) This guideline recommends the overall responsibilities of authorized personnel regarding different activities associated with explosive material handling as mentioned in Table 3-31.

c) This guideline recommends the requirements of a licensed Master Blaster and or Magazine Keeper regarding explosive material handling in any hydropower projects of Nepal in Section 3.3.2..

d) This guideline recommends that the blasting and explosive management plan must be prepared in Section 3.3.3 and included in the Blasting Assessment Report (BAR) as discussed in Section 3.1.5 by any hydropower project in order to ensure proper handling of the explosive materials.

e) In order to identify alert level for surface and underground blasting activities, a specific trigger (TARP) should be proactively developed to address escalating levels of risk by every hydropower project in Nepal. A typical TARP to identify alert level for surface and underground blasting activities has been presented in Table 3-32 for reference.

f) This guideline recommends the work planning procedure and control requirement in any drilling and blasting operation by any hydropower project in Nepal in Section 3.3.5.
g) This guideline recommends to fulfill the requirements discussed in Section 3.3.6 during any drilling and blasting operation by a hydropower project.
h) This guideline recommends to fulfill the requirements for explosive charging as discussed in Section 3.3.7 during any drilling and blasting operation by a hydropower project.
i) For proper handling of the explosive material with regards to tying-in of blasting circuit, this guideline recommends to fulfill the requirements as discussed in Section 3.3.8 during any drilling and blasting operation by a hydropower project.
j) During the environmental study as per Environment Protection Regulation (2077), identification of the most suitable disposal method should be considered based on the nature of the explosive and its hazards, and any hazards associated with the disposal method or created during the disposal process. The disposal plan for surplus, defective and expired explosives, and used packing material has been depicted in Figure 3-43 for reference.
k) This guideline recommends the misfire waiting period when a misfire is suspected to any persons entering the drilling and blasting location until:
    1. For 30 minutes if safety fuse and blasting caps are used; or
    2. For 15 minutes if any other ignition system (detonators among others) are used.
l) This guideline recommends the misfire handling procedures as discussed in Section 3.3.11.1.
m) For proper handling of the explosive material with regards to training requirement for safeguards for personnel, this guideline recommends to fulfill the requirements as discussed in Section 3.3.12.

7.1.4 For Explosive Material Transportation

a) This guideline recommends to ensure the activities as discussed in Section 3.4 for the safe handling of explosives during transportation.
b) All the safety precautions specified in Section 4.4.1 of this guideline should be applied during transportation with security aided by Nepal Army.
c) This guideline recommends referring to the Section 4.4.1 and Section 4.4.3 for elimination measures to be adopted during explosives transportation.
d) Delivery, Acquisition and Inventory of Explosive Material has been discussed in Section 3.4.1 separately.
e) A sample Request for Information (RFI) for delivery and acquisition of the explosive material from UT-1 HEP (216 MW) has been presented in the Annex-9 for reference. The hydropower project must include a daily blasting work sheet as mentioned in Section **3.2** and Table 3-29 of this guideline in the above mentioned RFI.
f) The hydropower developer should prepare inventory records of used explosive quantity in the format as mentioned in the Table 3-34 and this inventory information should be communicated to the Ministry of Home Affairs and respective CDO at an interval of three months.

7.1.5 For Explosive Material Storage

a) An Environmental Assessment Report of the hydropower project submitted for getting the generation license from the DoED must include the details of the bunker facilities and setup of the onsite explosive magazine based on the requirements envisaged by the Environment Protection Regulation (2077) of Nepal. The details in the environmental report must include drawings to indicate the location and arrangement of the magazine. The security measures and safe operation regulation and procedure shall be proposed in pursuant to the prevailing laws and guidelines of Nepal.

b) This guideline recommends the requirements regarding proper planning and siting of bunker facilities in Table 3-36.

c) This guideline recommends the requirements for quantity and separation distance within storage spaces of explosive magazine in pursuant to IATG 06.20 - Storage space requirements: Based on the storage space requirements mentioned in Section 3.5.3, only 45% of storage capacity of the bunker facilities should be utilized as the storage space of explosive materials considering hand held handling provision. However, this guideline recommends using optimum space available in the bunker facilities in coordination with the Nepal Army as per the requirement of each specific hydropower projects.

d) Based on Section 3.5.4, this guideline recommends a maximum field storage of 100 tonne by weight in a bunker facility having dimension of 14 m (l)X 7 m (b) X3.7 m (h) of a hydropower project in Nepal. If the explosive material requirement of the hydropower project during construction is more than 100 tonne, then the project must construct another bunker facilities with regards to the explosive material storage requirement stated in Section 3.5.2 and Section 3.5.3.

7.1.6 For Explosive Material Procurement

a) For the procurement of the explosive materials, this guideline recommends to follow Rule 11 of the Explosive Regulation (2020).

b) The procurement of the explosives should be made by the licensed company of the concerned HPP either through the main civil contractor or any explosive manufacturers/suppliers hired by the given project.

c) The Hydropower project must submit the blasting assessment report as mentioned in the Section 3.1.5 for getting recommendation of procurement of explosive materials from the DoED.

d) If additional procurement of explosive material is necessary then also the hydropower project must submit an updated BAR (including inventory information about explosives mentioned in Table 3-34 and explosive consumption record sheets as mentioned in Table 3-29 and Annex-8 to DoED for getting further recommendation.

e) A hydropower project generally should follow the procedure for the procurement of the explosive materials as discussed in Section 3.6.2.

f) In order to shorten the duration of explosive procurement, procedures mentioned above, this guideline recommends to avoid duplicate works of getting consent from both DoED and MoEWRI, if the procurement procedure has been initiated through DoED. Based on the discussions made in the residential workshop for the preparation of this guideline as mentioned in Section 2.1.4, the time taken for the procurement process can be shortened by at least two weeks if the duplicate work is avoided. However, it should be noted that this recommendation does not apply for the hydropower project of Nepal in which explosive procurement procedure has been initiated directly by the MoEWRI.

g) When the manufacturers or suppliers of the estimated explosive material are unable to provide the approved quantity of explosive materials (including explosives and ignition system), this guideline recommends to request the change the detail information of the vendors through an application to the DoED or equivalent institution if there is no change in the estimated quantity of the explosive materials to be procured. However, if hydropower project desires to change the vendor of the explosive materials with change in estimated quantity, then, the project must follow explosive procurement procedure discussed in Section 3.6.2.

7.1.7 For Operational Health and Safety Regarding Explosive Materials

a) This guideline presents the framework for the operational health and safety regarding explosive materials in the following topics in the sub sections of Chapter 4.

1) General requirement for drilling and blasting operation;
2) Major hazards and risks and its elimination measures;
3) Blasting safety for surface blasting; and
4) Explosive stored in site magazine and site transportation.

7.1.8 For Formalizing Inspection and Monitoring of Explosive Materials

a) This guideline recommends the framework for formalized inspection and inventory process of the explosive material as presented in Table 3-34 of Section 3.4.1 for reference.

b) Similarly, this guideline recommends a checklist for the inspections of the bunker site and the explosive materials presented in Annex-10 which should be carried out by the hydropower project at the site in presence of designated Nepal Army authority and designated magazine keeper.

c) In accordance to the approved environmental study report and the submitted blasting assessment report (BAR), the hydropower project should review the environmental performance of the project and prepare and submit the inspection report to DoED in every six months. The blasting and explosive management monitoring report should include the activities mentioned in Table 5-1.

d) Third party audit of the blasting and explosive management inspection report should be undertaken annually to assess compliance and adequacy of internal audits undertaken regarding the storage, transportation, handling and usage of the explosive materials. The consultant appointed for the exercise should be qualified in the subject area and should provide a time bound corrective action plan.

e) The corrective and preventive action should be carried out based on the recommended actions required to be taken mentioned in the audited blasting and explosive management inspection report as mentioned in Section 5.1.1 and Section 5.1.2 of this guideline.

f) This guideline recommends the overall responsibilities of each specific personnel exposed to explosive material handling, storage, and transportation as mentioned in the Table 3-31 of this guideline. Regarding the inspection responsibilities of the explosive materials, this guideline recommends to prepare blasting and explosive management inspection report (Section 5.1.1 and Section 5.1.2).

7.2 RECOMMENDATIONS

a) This guideline recommends to revise and update various aspects regarding the explosive materials discussed in this guideline in every 10 years in pursuant to the data obtained from various hydropower projects regarding the explosive material consumption records recommended in this guideline as well as based on sophisticated technology, equipment, and explosive materials developed in the near future.

b) This guideline recommends to consider the time lapse required for the procurement of the explosive materials while preparing the construction schedule of any Hydropower Project in Nepal.

c) This guideline recommends that there should be no provision of setting certain proportion of explosive materials to be procured from any manufacturers/suppliers (Including Nepal Army). The explosive materials should be considered as a goods and any hydropower project can procure the exact estimated quantity from any desired manufacturers or suppliers.

7.2.1 Recommendations for Amendment of Explosive Act (2018) and Explosive Regulation (2020)

a) Explosive materials procurement procedures should be shortened by avoiding duplicate works of getting consent from both DoED (or related department) and MoEWRI (or related Ministry) if the procurement procedure has been initiated through DoED (or related department). Based on the discussions made in the residential workshop for the preparation of this guideline as mentioned in Section 2.1.4, the time taken for the procurement process can be shortened by at least two weeks if the duplicate work is avoided. However, it should be noted that this recommendation should not apply for the construction project of Nepal in which explosive procurement procedure has been initiated directly by the MoEWRI (or related Ministry).

b) Definition of the explosives has been provided in the Explosive Act (2018) and Explosive Regulation (2020) which has been mentioned in Section 3.1.3 of the guideline. However, it will be appropriate to classify the explosive as mentioned in Figure 3-6 and at least commercial/industrial explosives should be considered as a construction material in the act.

c) A separate and independent nodal organization for regulating various activities related to the commercial explosive materials should be formed by the GoN in order to formalize the explosive consumption during the construction of various infrastructure projects in Nepal.

d) The legislation should mention that estimation of the explosive materials should be based on the geological condition of the given construction project.

e) The use of plain detonators and safety fuses during any drilling and blasting operations should be totally prohibited in a hydropower project of Nepal.

f) It should be noted that the production of electric detonator has been prohibited in the neighboring countries. So, the availability of the electric detonator is in question. Thus, use of electric detonators during any drilling and blasting operations should be totally prohibited in a hydropower project of Nepal and the use of "State-Of-The-Art" initiation system such as non-electric (shock tube) or electronic detonators for explosive detonation and blasting works should be recommended.

g) The procurement of the explosives should be made by the licensed company of the concerned HPP either through the main civil contractor or any explosive manufacturers/suppliers hired by the given project.

h) Procurement of the raw materials for the manufacture of explosive materials should be carried out following the procurement act of Nepal in order to ensure its continuous supply and attract private investment in the manufacturing.

i) Presently, there are no private investment in the manufacturing of the explosive materials in Nepal. So, this guideline recommends to encourage the private investment in the manufacturing of the explosive materials by maintaining a balance between economic incentives, public safety and regulatory oversight following all the security provisions prevailing in Nepal.

j) For getting recommendation for the procurement of explosive materials, the prospecting construction project must provide the estimation in a Blasting Assessment Report (BAR) discussed in Section 3.1.5 of this guideline. The estimation of the explosive materials must be carried out having the technical specification as discussed in Section 3.1.8.

k) This guideline recommends that the blasting and explosive management plan must be prepared in Section 3.3.3 and included in the Blasting Assessment Report (BAR) as discussed in Section 3.1.5 by any hydropower project in order to ensure proper handling of the explosive materials.

l) In order to identify alert level for surface and underground blasting activities, a specific trigger (TARP) recommended by this guideline should be included in the Act in order to address escalating levels of risk by every construction project in Nepal.

m) For maintaining the proper usage of the explosive material, the legislation should have the provision of maintaining Daily Blasting Work Sheet as recommended by this guideline for every construction project requiring explosive materials for rock excavation.

n) This Act should recommend the work planning procedure and control requirement in any drilling and blasting operation by any hydropower project in Nepal.

o) The number of security strength from Nepal Army shall be limited to a minimum for escorting during the transportation of commercial explosives only (but not to other types of explosives) in order to minimize the economic burden of the hydropower developer.

p) The Act should eliminate unnecessary or repetitive steps in the procurement process in order to streamline the process, making it more efficient and effective.

8 REFERENCES

Select portions of the following references were used in developing this guideline. The listed references are intended to acknowledge author and documents used in this guideline. Listed reference do not indicate alternate methods for estimation, usage, handling, transportation, and storage of the explosive materials and its managerial strategies.

AECOM India Private Limited. (2022). Environment and Social Management System ManA1:A28ual for Lower Solu Hydropower Project.

ICI Australia Operations Pty Ltd (1980) Handbook of blasting table, Metric edition

Bhotekoshi 5 Hydroelectric Project (62MW), Detail Project Report (DPR), Volume I: Main Report (2019).

Dangerous Substances (Explosives) Regulation 2004.

Deere D.U. (1963), "Technical description of rock cores for engineering purposes", Rock Mechanics and Engineering Geology, Vol-1, p18.

Deere, D.U. 1989. Rock quality designation (RQD) after 20 years. U.S. Army Corps Engrs Contract Report GL-89-1. Vicksburg, MS: Waterways Experimental Station

Department of Road (2077), Norms for Rate Analysis of Road Tunnel Construction

Department of Road (2075), Norms for Rate Analysis of Road and Bridge Works

Detail Design of Inkhu Khola Small Hydropower Project, 2018

Detail Design of Lower Hongu Khola Small Hydropower Project, 2018.

Detail Design of Siwa Khola Small Hydropower Project, 2019

Detail Engineering Design of Inkhu Khola Small Hydropower Project, Final Interim Report, (2018).

Detailed Engineering Design of Middle Kaligandaki Hydrolectric Project (66.3 MW) Myagdi District, Updated Feasibility Study Report Volume I: Main Report (2023).

Detailed Engineering Design of Mistri-2 Hydropower Project, Myagdi District, Updated Feasibility Study Report Volume I: Main Report (2023).

Dhital, M. R. (2015). Geology of the Nepal Himalaya: regional perspective of the classic collided orogen. Springer.

Environmental Protection Works, ICB No: ICB/BRIBP/PHU-01-W, Final Report, 2016.

Exploratory Drilling & It's Associated In-Situ Test and Laboratory Tests of Upper Mugu Karnali Hydropower Project, Final Report, 2023.

Feasibility and Environmental Study of Seti River-6 (SR-6) Storage Project, Achham and Doti, Nepal, Final Consolidated Report Volume III: Appendices Part III: Geological Mapping & Geotechnical Investigation & Construction Material Survey (2022)

Feasibility and IEE Study of Bheri Khola Hydropower Project, 2019.

Feasibility and IEE Study of Nyaurigad Hydropower Project, 2019.

Feasibility and Initial Environmental Examination Study of Dotigad Hydropower Project

Feasibility and Initial Environmental Examination Study of Dudhkoshi-4 Hydropower Project.

Feasibility and Initial Environmental Examination Study of Inkhu Khola Hydropower Project.

Feasibility and Initial Environmental Examination Study of Jawa Khola Hydropower Project Jumla District, Final Feasibility Study Report Volume-1 (B) Main Report, (2019)

Feasibility and Initial Environmental Examination Study of Loti Karnali (Darma) Hydropower Project

Feasibility and Initial Environmental Examination Study of Lower Chameliya Hydropower Project.

Feasibility Study & EIA of Inkhu Khola Small Hydropower Project, Final Report Main Report, Volume 1, (2014).

Feasibility study and EIA of the Sankhuwa Khola I Hydropower Project, 2018.

Feasibility Study and Environment Impact Assessment (EIA) Study of Bharbhung Storage Hydropower Project Dolpa District, Interim Design Report Volume IV B (Part 1) Annex C4: Geotechnical Investigation, (2024)

Feasibility Study and Environment Impact Assessment (EIA) Study of Dadagau-Khalanga Bheri Hydropower Project, Jajarkot District, Final Field Report, Volume III-Part A: Geotechnical Baseline Report (2024).

Feasibility Study and Environment Impact Assessment of Kankai Multi-Purpose Project Jhapa and Ilam Districts, Final Report VOLUME –2B, (2022).

Feasibility Study and Environmental Impact Assessment (EIA) Arun 4 HPP, 2022.

Feasibility Study and Environmental Impact Assessment (EIA) Lower Arun HPP, 2023.

Feasibility Study and Environmental Impact Assessment (EIA) Study Dudhkoshi-5 Hydropower Project

Feasibility Study and Environmental Impact Assessment (EIA) Study of Hima Khola HPP, 10.8 MW, Jumla (2024).

Feasibility Study and Environmental Impact Assessment (EIA) Study of Kaligandaki 2 Storage Project.

Feasibility Study and Environmental Impact Assessment (EIA) Study of Kawadi-1 Hydropower Project, Bajura and Humla District, Final Report, Volume-III Annextures, Annex E: Geotechnical Investigations Report (2023).

Feasibility Study and Environmental Impact Assessment (EIA) Study of Khimti Those Siwalaya Storage Hydropower Project Dolakha-Ramechhap District, Interim Design Report Annex -6: Geotechnical Investigation Report (2023).

Feasibility Study and Environmental Impact Assessment (EIA) Study of Khokhajor Storage Hydropower Project

Feasibility Study and Environmental Impact Assessment (EIA) Study of Lower Badigad Storage Hydropower Project Gulmi District, Final Field Report Volume III Part C: Geotechnical Baseline Report, (2024).

Feasibility Study and Environmental Impact Assessment (EIA) Study of Lower Humla Karnali Cascade Hydropower Project, Interim Design Report, Volume I-B, Geological and Geotechnical Study (2024).

Feasibility Study and Environmental Impact Assessment (EIA) Study of Naumure Multipurpose Project.

Feasibility Study and Environmental Impact Assessment (EIA) Study of Sunkoshi-2 Hydropower Project Volume III: Appendices, Part III: Geological Baseline Report for SU-2 (2023)

Feasibility Study and Environmental Impact Assessment (EIA) Study of Sunkoshi-3 Hydropower Project, Final Consolidated Report Volume III Appendices Part III Geological Baseline Report, (2023)

Feasibility Study and Environmental Impact Assessment (EIA) Study of Super Budhigandaki Hydroelectric Project, Gorkha District, Final Report, Volume-III Annextures, Annex E: Geotechnical Investigations Report (2024).

Feasibility Study and Environmental Impact Assessment (EIA) Study of Tom Dogar (Budhigandaki) Hydroelectric Project Gorkha District, Final Report, Volume-III Annextures, Annex E: Geotechnical Investigations Report and Lab Test Results, (2024).

Feasibility Study and Environmental Impact Assessment (EIA) Study Sharda Babai Storage Hydropower Project

Feasibility Study and Environmental Impact Assessment Study of Humla Karnali Hydropower Project, Draft Final Report Volume I: Main Report, (2024).

Feasibility Study and Environmental Impact Assessment Study of Sankhuwa Khola Hydropower Project (SKHPP), Draft Final Report, (2018).

Feasibility Study and IEE Study of Kawadi Khola HP, 2018

Feasibility Study and Initial Environment Examination Study of Kawadi Khola Hydropower Project, Final Field Report Geotechnical Investigation Report, (2018).

Gansser A (1964) Geology of the Himalayas. Interscience, New York, 289 pp

Geotechnical Investigation of Bagmati Small HPP, Kulekhani, Final Report, 2015.

Geotechnical Investigation of Budiganga Small Hydropower project 20 MW.

Geotechnical Investigation of Machha Khola HPP, Final Report, 2021.

Geotechnical Investigation of Madi Khola HPP Final Report.

Geotechnical Investigation of Mahadev Khola Impounding Project, Nagarkot, Final Report, 2016.

Geotechnical Investigation of Melamchi Drinking Water Project, Final Report, 2014.

Geotechnical Investigation of Myagdi Khola Hydropower Project, Final Report, 2022.

Geotechnical Investigation of Namlan Khola Hydropower Project, Final Report, 2023.

Geotechnical Investigation of Simbuwa Khola Hydropower Project, Final Report, 2021.

Geotechnical Investigation of Tamor Mewa Hydroelectric Project, Final Report, 2021.

Geotechnical Investigation of Upper Chameliya Hydropower Project, Final Report, 2021.

Geotechnical Investigation of Upper Solu HPP, Final Report, 2016.

Geotechnical Investigation Report on Design and Build of Dhap Dam, Access Road And

Geotechnical Report on Core Drilling of Nilgiri Khola Hydroelectric Project, 2013.

Ghose A.K. (1988), "Design of drilling and blasting subsystems – A rockmass classification approach", Mine Planning and Equipment Selection, Balkema.

Gokhale, B.V (2010) Rotary drilling and blasting in large surface mine CRC Press.

Gupta R. N. (1996), "A Method to Assess Charge Factor Based on Rock Mass Blastability in Surface Mines", Proceedings of National Seminar on Drilling and Blasting, MINTECH Publications, Bhubaneswar, pp42-46.

Handbook no 8, Rock Blasting

Hansen D. W. (1968), "Drilling and Blasting Techniques for Morrow Point Power Plant", Proceedings Ninth Symposium of Rock Mechanics, Golden, Colorado, pp347-360.

Heinen R. H. & Dimock R.R. (1976), "The Use of Sonic Measurements to Determine the Blastability of Rocks", Proceedings Second Conference on Explosive and Blasting Techniques, Luisville, Kentucky, pp234-248.

Indian Standard Safety Code for blasting and related Drilling operations.

J. P. Ashby, "Production blasting and the development of open pit slopes," in Proceedings of the 3rd International Conference on Stability in Open Pit Mining, Vancouver, B.C, 1981.

Jiang Han, Xu Weiya and Xie Shouyi (2000), "Artificial Neural Network Method of Rockmass Blastability Classification", Geocomputation 2000, downloaded from http://www.geocomputation.org/2000/GC060.Gc060.htm

Johannessen, O., 1991. Rock Caverns. Norwegian University of Science and Technology (NTNU).

Kabeli-A Hydroelectric Project (37.6 MW), Geotechnical Baseline Report (GBR), (2011).

Kaligandaki Tinau Diversion Multipurpose Project, Final Report on Geotechnical Investigation (2019).

Karadogan, A., Kahriman, A., & Ozer, U. (2014). A new damage criteria norm for blast-induced ground vibrations in Turkey. Arabian Journal of Geosciences, 7, 1617-1626.

Khimti-2 Hydropower Project, Final Report on Geotechnical Investigation, (2017).

Kimathanka Arun Hydro Electric Project (KAHEP), Geological Mapping and Geotechnical Investigations and Construction Material Survey, (2019)

Langefors U, KihilstrÖm B (1978) The modern technique of rock blasting, 3rd edn. Wiley, New York. ISBN 0-470-99282-4

Langefors U. and Kihlstrom B., (1978), "The Modern Technology of Rock Blasting", John Wiley & Sons Inc, New York, p438.

Lilly P. (1986), "An Empirical Method of Assessing Rockmass Blastability", Large Open Pit Mine Conference, Newman, Australia, October, pp89-92.

Lower Barun Khola Hydropower Project (132 MW), Sankhuwasabha District, Geotechnical Investigation Report, Final Report, (2019).

Mascle G, Pêcher A, Guillot S, Rai SM, Gajurel AP (2012) The Himalaya–Tibet collision. Nepal Geological Society and Société Géologique de France, London, 264 pp

Nepal Water and Energy Development Company Private Limited. (2021). Blasting and Explosive Management Plan.

NTNU, 1995. Project Report 2A-95 TUNNELLING – Blast Design, NTNU. Department of Civil and Transport Engineering, Trondheim.

Ocak, I., & Bilgin, N. (2010). Comparative studies on the performance of a roadheader, impact hammer and drilling and blasting method in the excavation of metro station tunnels in Istanbul. Tunnelling and Underground Space Technology, 25(2), 181-187

Satici, Ö., & Hindistan, A. (2006). Drilling and blasting as a tunnel excavation method. Middle East Technical University, Department of Geological Engineering: Ankara, Turkey, 24.

Singh, S. P., & Xavier, P. (2005). Causes, impact and control of overbreak in underground excavations. Tunnelling and Underground Space Technology, 20(1), 63-71.

Solu Khola (Dudh Koshi) Hydroelectric Project, Detailed Project Report (Final), Volume I (Main Report) (2017)

Super Lower Bagmati Hydropower Project, Report on Geological, Geotechnical Investigations & Tunnel Support Design (2023).

Terzaghi, K. 1946. Rock defects and loads on tunnel supports. In Rock tunneling with steel supports, (eds R. V. Proctor and T. L. White) 1, 17-99. Youngstown, OH: Commercial Shearing and Stamping Company.

Updating Feasibility Study, Detailed Engineering Survey & Design and Environmental Impact Assessment Study of Nalgad Hydropower Project (417 MW), Jajarkot District, Nepal, Updated Feasibility Study Final Report, (2022)

Zare, S. (2007). Prediction model and simulation tool for time and costs of drill and blast tunnelling.

Zou, D. (2017). Theory and technology of rock excavation for civil engineering (p. 699). Singapore: Springer Singapore.

*** The revision dates of all test methods referenced in this manual are those dates current on the publishing date of this guideline.

This page intentionally left blank

Prepared by:
Joint Venture of:

HYDRO-CONSULT ENGINEERING

Hydro-Consult Engineering Limited (HCE)

ENVIRONMENT RESOURCE ERMC MANAGEMENT

Environment Resource Management (P) Ltd. (ERMC)

FBC

Full Bright Consultancy (FBC)

Address: Gangadevi Marga, Buddhanagar, Kathmandu, Nepal