National Defence **B-GL-320-012/FP-004**

ENGINEER FIELD MANUAL

VOLUME 12
HORIZONTAL CONSTRUCTION

PART 4
PITS AND QUARRIES
(ENGLISH)
(Supersedes B-CE-320-012/FP-004 dated 1983-06-01)

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FOREWORD

1. B-GL-320-012/FP-004, Engineer Field Manual, Volume 12, Horizontal Construction, Part 4, Pits and Quarries is issued on the authority of the Chief of the Defence Staff.

2. This publication is effective upon receipt and supersedes B-CE-320-012/FP-004 dated 1983-06-01. It is the primary reference authorized on this subject matter.

3. Suggestions for change shall be forwarded through normal channels to Headquarters Mobile Command, Attention: Senior Staff Officer Field Engineer.

RECORD OF CHANGES

Identification Change		Date Entered	Signature
Ch No.	Date		

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CHAPTER 1

INTRODUCTION

GENERAL

1. Military engineer responsibilities and tasks may include construction projects that require large quantities of soil and rock for hit, base courses, surfacing and other earthworks. In peace time projects in isolated areas and certainly during wartime operations, the supply of this material may also be an engineer responsibility. Therefore military engineers should understand the principles of pit and quarry operations.

AIM

2. The aim of this publication is to provide a manual for military engineers on some pit and quarry operations.

SCOPE

3. The scope of this publication includes:

   a. site selection factors and procedures;

   b. planning and operation of quarries;

   c. drilling and blasting;

   d. planning and operation of pits;

   e. selection of equipment; and

   f. excavation in frozen ground.

DEFINITIONS AND CLASSIFICATIONS

4. Definitions. Pits and quarries are sites which have been developed for the purpose of providing select materials and aggregate for use in construction.

   a. Pits are sites from which unconsolidated earth and rock particles can be removed generally without blasting.

   b. Quarries are sites where open excavations have been made for the purpose of removing rocks, usually by cutting or blasting, for construction.

5. **Classification.** Pits and quarries are generally classified according to the type of material contained in them and the methods used to excavate and process the material. See Figure 1-1.

REFERENCES

6. This publication makes reference to several publications for the elaboration of a method, detail or standard. These publications should be read in conjunction with this manual. Annex A to this manual lists the referenced publications as well as publications which provide additional information.

TYPE	MATERIAL	PRIMARY USE	OPERATING EQUIPMENT
PIT: Borrow	Select soil other than sand and gravel.	Fill for embankments and subgrades.	Scraper, dozer, ripper, power shovel, front loader, or dragline, and dump trucks.
Sand and gravel (Bank or hill)	Sand and gravel with clay	Base courses, sub bases and fills	Scrapers or power shovel, front loader, or hand tools and dump trucks.
Alluvial	Clean sand and gravel	Aggregates for concrete and bituminous mixes and free-draining, non-frost susceptible fills.	Power shovel, front loader, dragline, or clamshell and dump trucks.
Miscellaneous (Dumps)	Slag, mine tailings, cinders, etc.	Surfacing, fills and aggregates.	Power shovel, front loader, or hand tools and dump trucks.
QUARRY: Hard rock	Hard, tough rocks like granite, felsite, grabbo, diorite, basalt, quartzite, and some sandstones, limestones and dolomites.	Aggregates for base courses, surfacing, concrete and bituminous mixes, free-draining fills and stone for rip-rap, embankments and marine structures.	Rock drill, blasting materials and machine, power shovel, front loader, dump trucks, and crushing, screening (and washing) plant.
Medium rock	Moderately hard, tough rocks like most sandstones, limestones, dolomites and marbles.	Base courses and surfacing on roads and airfields and aggregates for some concrete and bituminous mixes.	Rock drill, blasting materials and machine, power shovel, front loader, dump trucks, and crushing, screening (and washing) plant.
Soft rock	Cement-like materials such as limestone, coral, caliche, tuff and laterite or weak rock like disintegrated granite and some sandstones or conglomerates.	Fills and base courses and surfacing for roads and airfields.	Ripper, power shovel, front loader and earthmoving equipment.

Figure 1-1 Classificaton of Pits and Quarries

CHAPTER 2

SELECTION OF PIT OR QUARRY SITES

SECTION 1

INTRODUCTION

GENERAL

1. The selection of a pit or a quarry site is dependent on many physical and operational factors. Although a site may appear to be ideal by means of its physical factors (quality and quantity of suitable material) it may not be viable because of the operational factors (distance from task site, equipment and manpower, tactical situation). The weight assigned to each factor may be significant to military pit or quarry operations.

AIM

2. The aim of this chapter is to outline the factors that should be considered in site selection.

SCOPE

3. The scope of this chapter covers:

   a. the operational factors peculiar to the operation or the physical limitations of the area of concern. Some factors may not be significant; however, they are presented in order to cover as broad a situation as possible; and

   b. investigation procedures to assist the engineer in site selection.

SECTION 2

GEOLOGICAL FACTORS

GENERAL

1. Geological factors are important in locating a possible source of material for the required task. This section includes the following:

   a. a review of various types of landforms which are possible sources of material;

   b. a review of material quality;

   c. a review of geological maps; and-.

   d. a review of soil maps.

2. The recognition of geological features is valuable in locating possible pit and quarry sites. Structural features are useful in quarry site selection while landforms are useful for pit site selection.

GEOLOGICAL FEATURES - QUARRIES

3. General. The structural features useful in quarry site selection are folds, joints and faults. These features are identified by their strike and dip. The significance of these features is discussed throughout the text. Strike and dip (see Figure 2-2-1) are-horizontal and vertical trends and are defined as follows:

Strike

Strike is the direction of a horizontal line in the plane of a rock feature. It is a direction or bearing determined by means of a compass and is always given with reference to north.

Dip

Dip is the angle of inclination of a rock feature relative to the horizontal. The dip angle and direction is always measured at right angles to the strike.

These terms are important in site selection because they determine the direction the quarry develops. They are also significant in the determination of the width and depth of the quarry. The quarry face is generally perpendicular to the strike, that is, the quarry face moves in the direction of the strike.

4. Fold. A fold is a bend, flexure or wrinkle in a rock bad. There are essentially three types of folds. These are monoclines, anticlines and synclines.

   a. Monocline. A monocline is a double flexure connecting strata at one level with the same strata at another level. See Figure 2-2-2.

b. **Anticline.** An anticline is a local arch of rock strata. The limbs, or two sides of the fold, dip away from each other. Most anticlines are inclined. This is called the plunge of the fold. See Figure 2-2-3.

c. **Syncline.** A syncline is a local arch of rock strata where the limbs, or two sides of the fold, dip toward each other. See Figure 2-2-4.

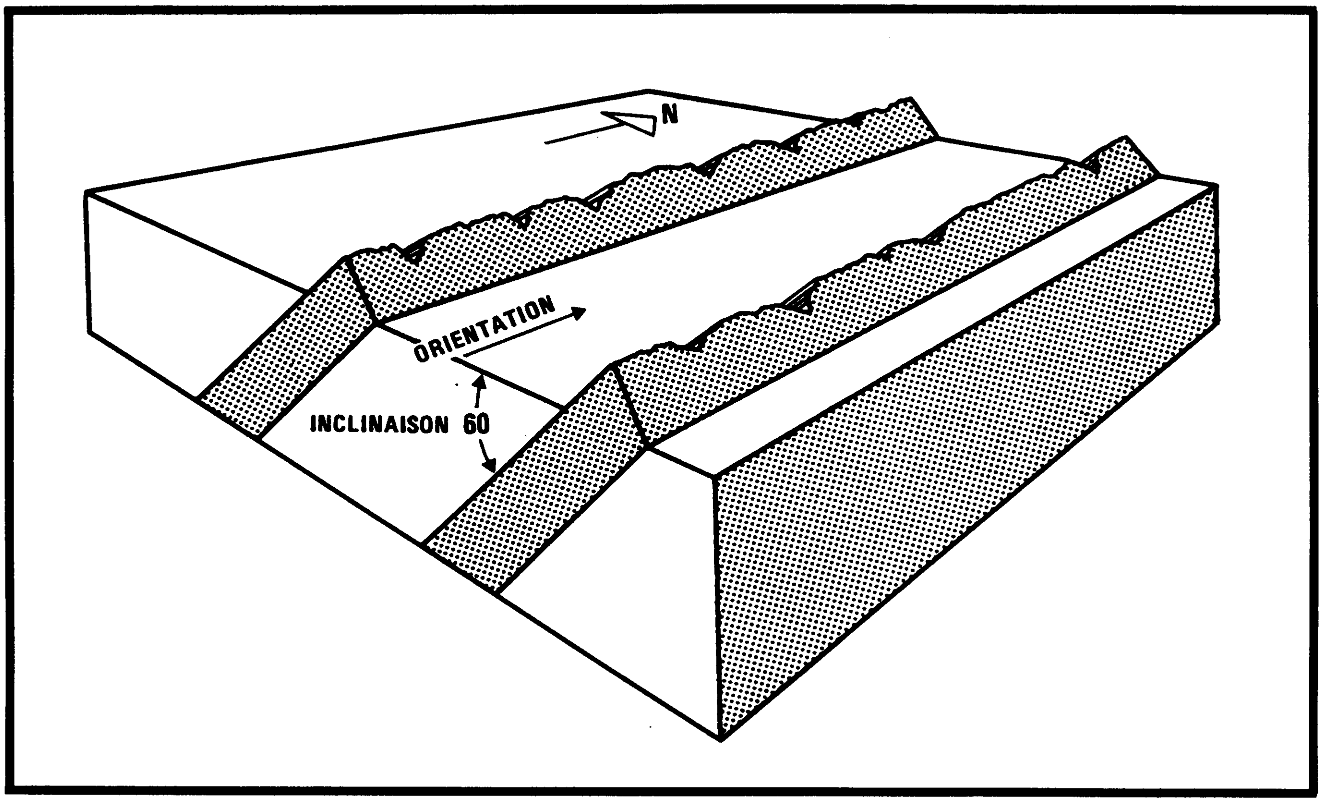


Figure 2-2-1 A Strike and Dip of Sedimentary Strata Shown Here Dipping Toward the West at 60 Degrees with the Strike Running North-South.

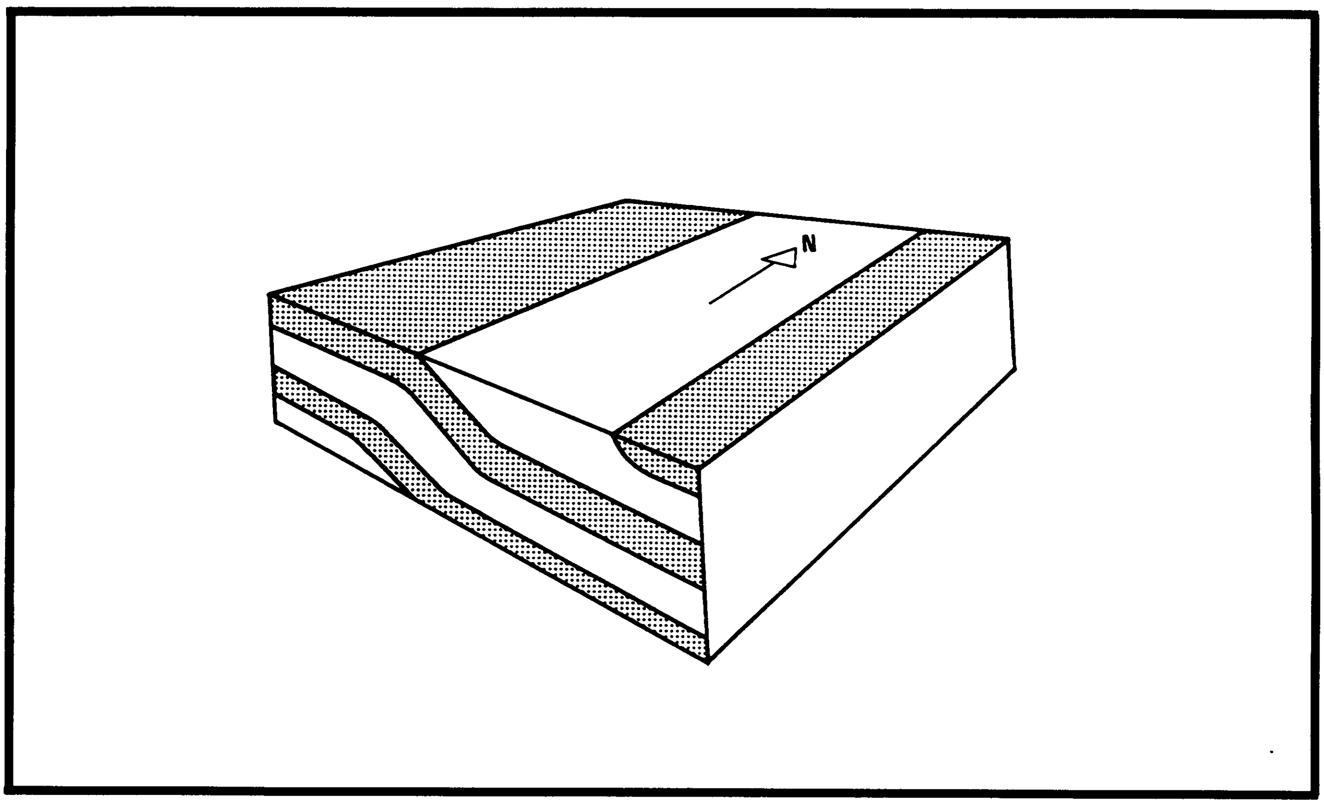


Figure 2-2-2 Monocline with North-South Strike

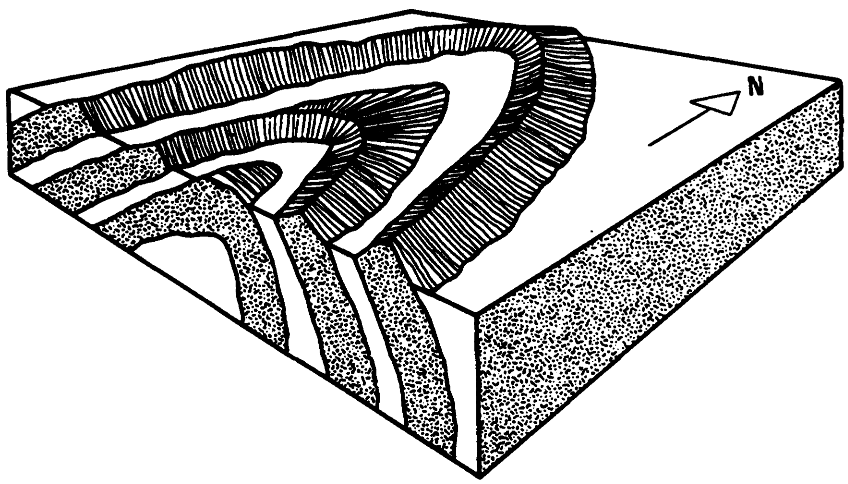


Figure 2-2-3 Plunging Anticline. The Folded, Sedimentary Structure has Dips Pointing Away from One Another and Plunges Toward the North

Some folds may be recognized from maps, from aerial photos or on the ground. The size of the limbs and the amount of material between the limbs are factors to be considered in quarry site selection. For example, the larger the limb, the greater the yield of material; and the greater the distance between the limbs, the greater the amount of overburden material to be removed. The position of the fold may also affect quarry operations. For example, it may be more desirable to work the quarry floor on a slant parallel to a dipping bed. This will have to be assessed with consideration given to equipment capabilities and drainage. If a bed dips into a hill there will be a problem with the removal of progressively more overburden. A moderately tilted bed may be worked along the strike as a long shallow quarry whereas it may be possible to work the quarry as a steep walled cut for a very steeply dipping rock outcrop. Values describing the size of limbs, or bedding thickness are found in Annex A to this chapter.

5. Joint. A joint is a fractured surface in a rock mass where no slippage has occurred. Joints normally occur in sets and are usually parallel to one another. These sets may run vertically, horizontally or at some angle. Values describing fracture spacing are found in Annex A to this chapter. Joints are undesirable in quarry operations when blasting is being used because they tend to reduce fragmentation (See Chapter 4). However, when ripping is being used to fragment rock, joints are desirable because they aid in breaking the rock (See Chapter 3). Joints also permit water to flow, therefore, drainage may become a problem in the quarry. Vertical joints may create a safety problem during quarry operations. They may act as slip planes permitting slides of unsupported rock masses on exposed sides of quarries. Water, ice or saturated clay from the overburden may compound the problem by serving as a lubricant on the slide surface.

6. Fault. A fault is a fracture where the sections on each side of the break have moved relative to each other. If movement is in the direction of the dip, it is called a dip-slip fault. If the movement is predominately horizontal, it is called a strike-slip fault. An oblique-slip fault has movement along both strike and dip. A fourth type of fault, the hinge fault, is identified by a displacement that dies out

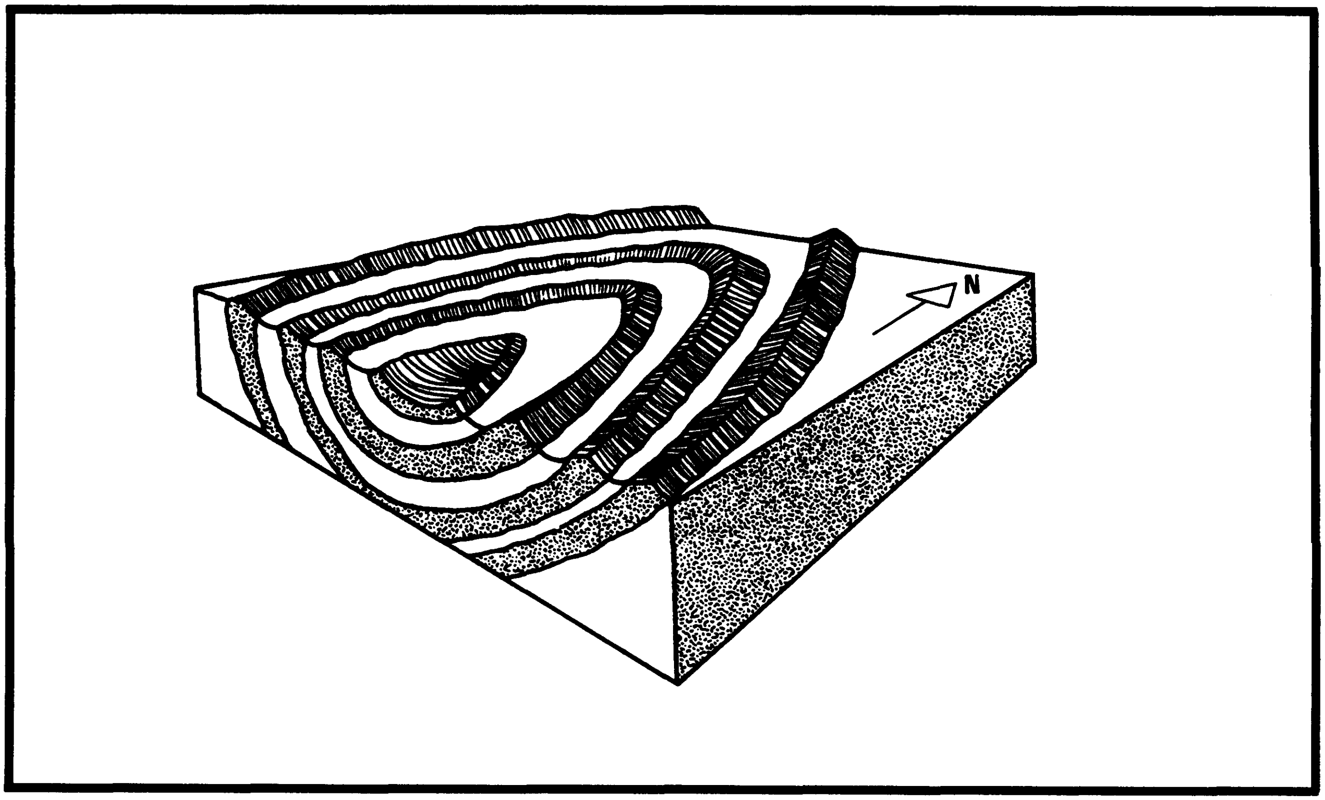


Figure 2-2-4 Plunging Syncline. The Folded, Sedimentary Structure has Beds Dipping Toward One Another. The Direction of the Strike Varies, and the Syncline is Plunging Toward the South.

perceptibly along a strike and ends at a definite point. Values describing fracture spacing are found in Annex A to this chapter. Faults may affect quarry operations. Faults that have dislocated a bed of limited thickness may create a problem in following the desired rock in the quarry. Faults may also create a safety and a drainage problem similar to that described for joints in paragraph 5 of this section. Like joints, faults are undesirable in blasting operations but they are desirable for ripping operations.

GEOLOGICAL FEATURES - PITS

7. General. The geological features that are useful for pit selection are glacial landforms and fluvial (water laid) landforms. Glacial landforms are either glacial till deposits such as ground moraines, moraines and drumlins or glacio-fluvial deposits such as eskers, kames and outwashes. Fluvial landforms are divided into: river associated forms such as flood plains and deltas; alluvial forms such as alluvial fans, valley fill or continental alluvium; or marine formations such as coastal plains and beach ridges. These landforms offer a variety of pit material of varied quality. Paragraph 8 describes the glacial features and paragraph 9 describes the fluvial. The type and suitability of material found in each feature is summarized in Figure 2-2-18.

8. Glacial Landforms:

a. Ground Moraines. Ground moraines consist of glacial drift or till materials in heterogeneous mixtures of clay, silt, sand, gravel and boulders which are unstratified, unconsolidated and unsorted. There are many variations of ground moraine landforms. They range from flat and dissected plains to undulating topography.

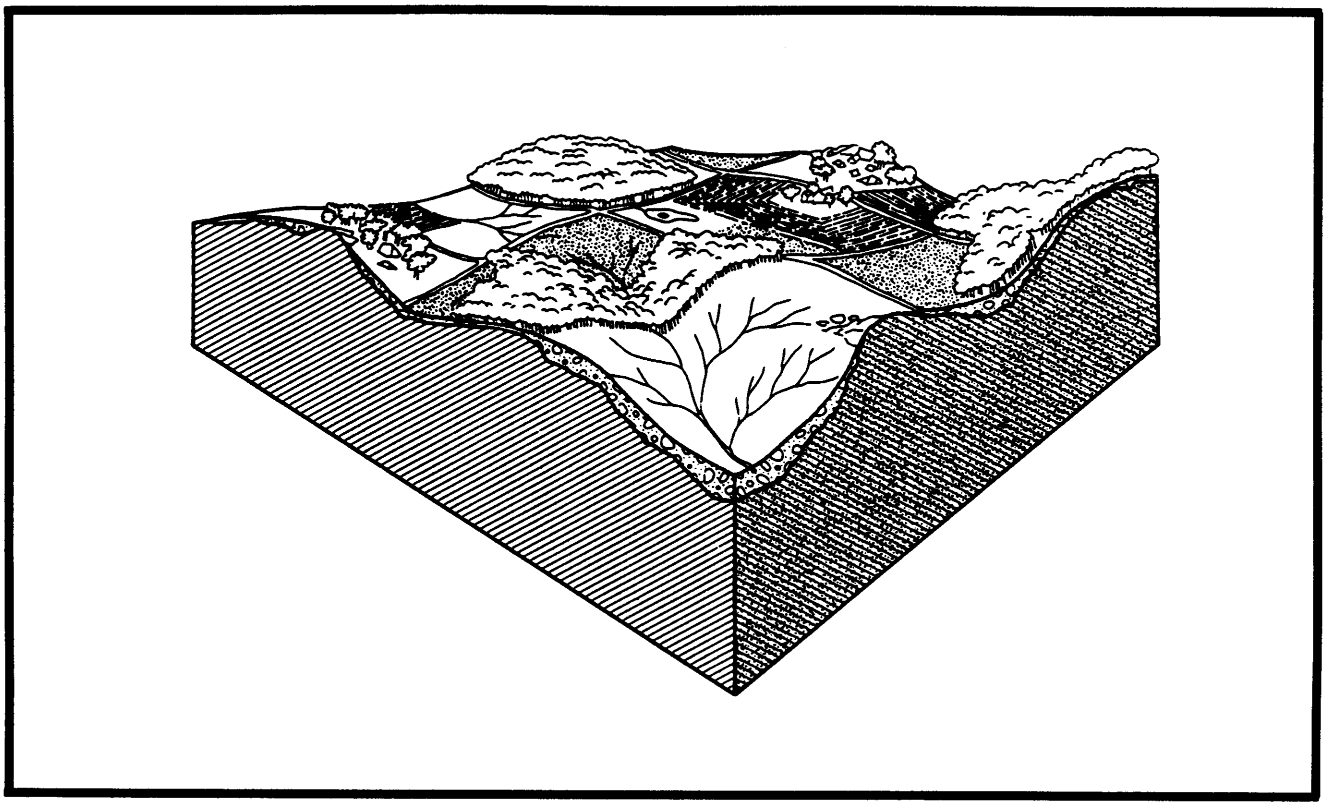


Figure 2-2-5 Ground Morraine

b. Moraines. Moraines consist of heterogeneous, unconsolidated to moderately consolidated, unstratified to partly stratified mixtures of clay, silt, sand, gravel, cobbles and boulders. The topography is usually undulating and rugged. The drainage is variable with many ponds and swamps found in the depressions at various elevations.

c. Drumlins. Drumlins consist of heterogeneous glacial drift which may include some lens-like layers of sand and gravel. Drumlins are hills that are smooth, oval and cigar shaped. They typically measure 800 to 1600 metres long, 150 to 500 metres wide and 20 to 60 metres high. Drumlins show no drainage patterns because they are well drained.

d. **Eskers.** Eskers are snake-like ridges of poorly to moderately well-stratified sands and gravels. They are typically 800 to 1600 metres long, less than 60 metres wide, less than 30 metres high and have sideslopes of approximately 30 degrees. Like drumlins, eskers show no drainage patterns.

e. **Kames.** Kames are individual or groups of conical hills, mounds or knobs which contain poorly stratified sands and gravels. They usually extend less than 120 metres in any one direction, are less than 15 metres high and have sideslopes of approximately 30 degrees.

f. **Outwash.** Outwash landforms consist of stratified silts, sands and gravels. They are recognized as flat plains with depressions and pits. These pits may be filled with water and may have steep slopes. The well-graded granular soils of outwashes do not allow sufficient run-off for the creation of an integrated drainage system.

9. **Fluvial Landforms.** There are many varied and complex landforms created by the fluvial process. In the process, water transports eroded sediments and rock debris from other landforms, sorts the materials and eventually deposits them.

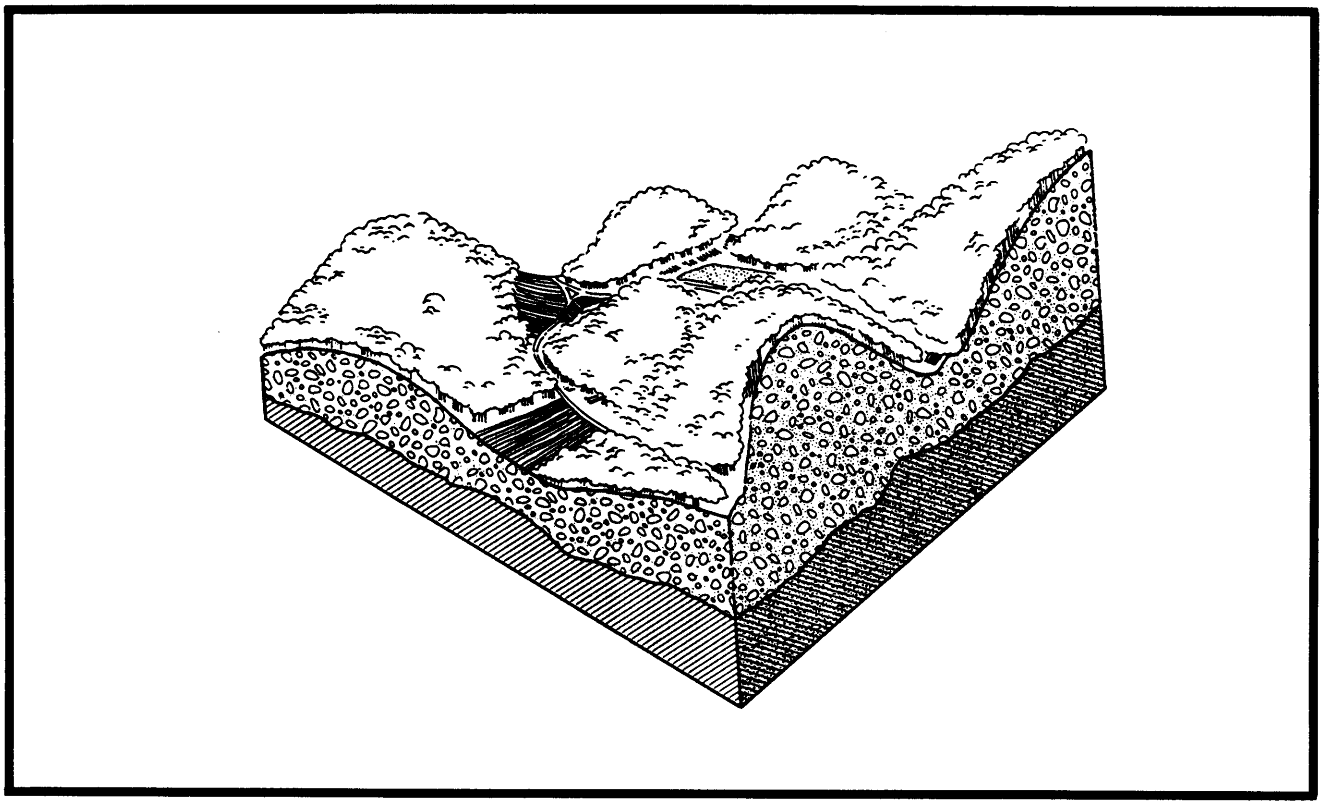


Figure 2-2-6   Morraine

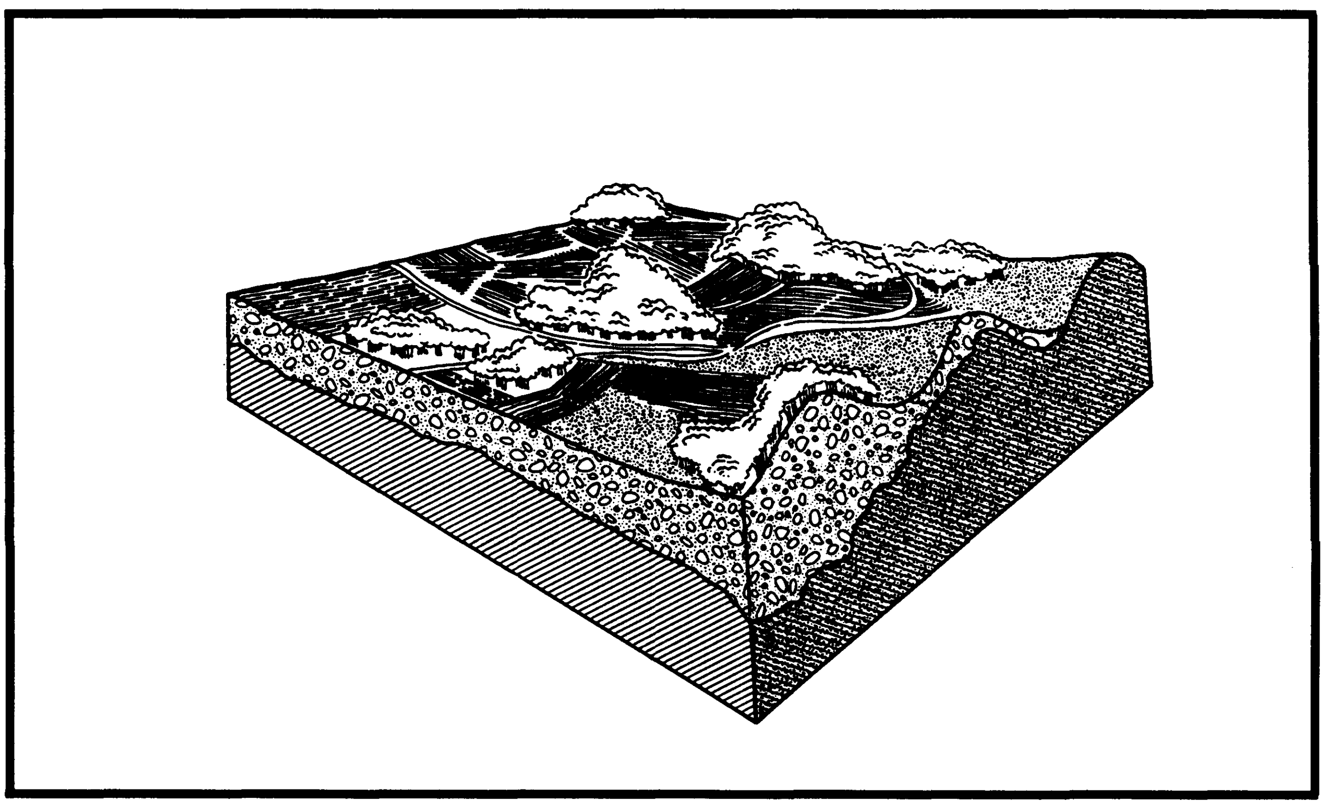


Figure 2-2-7   Drumlin

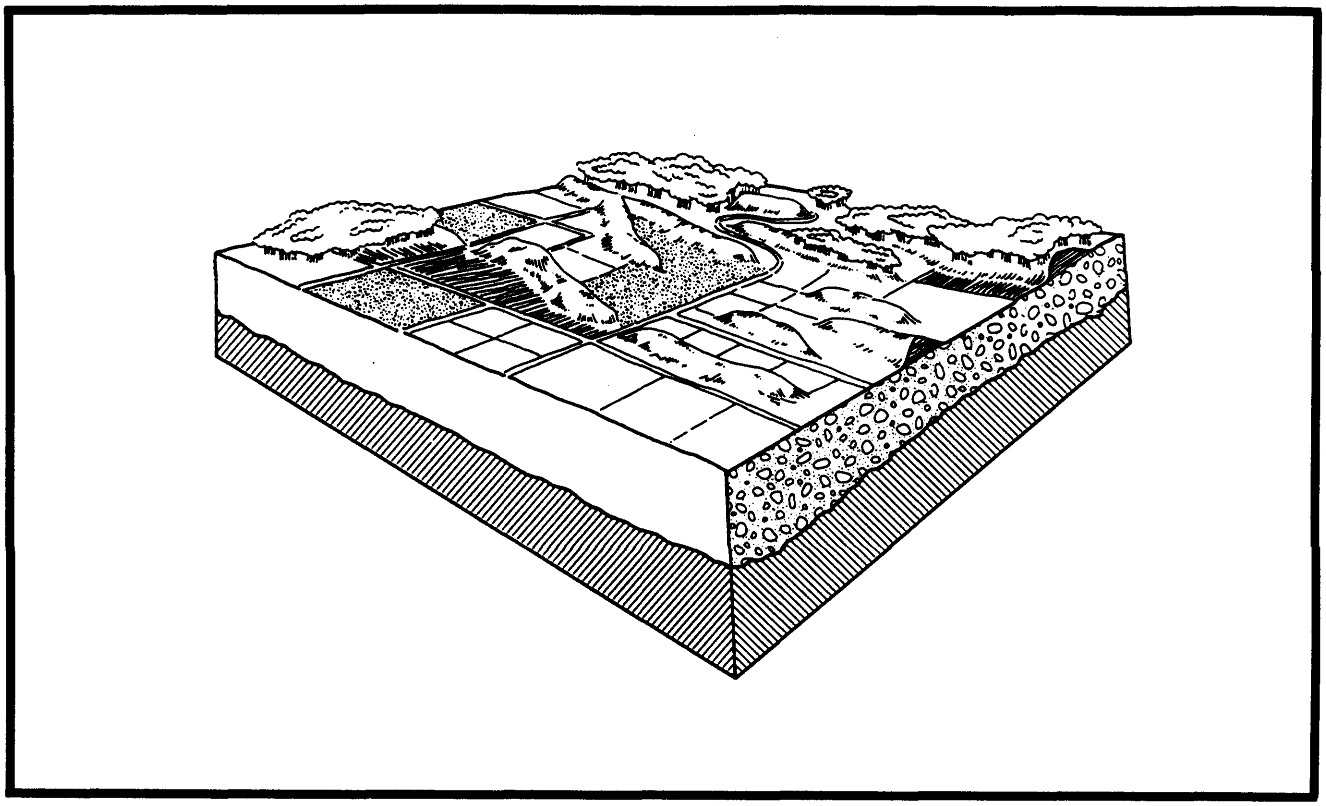


Figure 2-2-8 Eskers

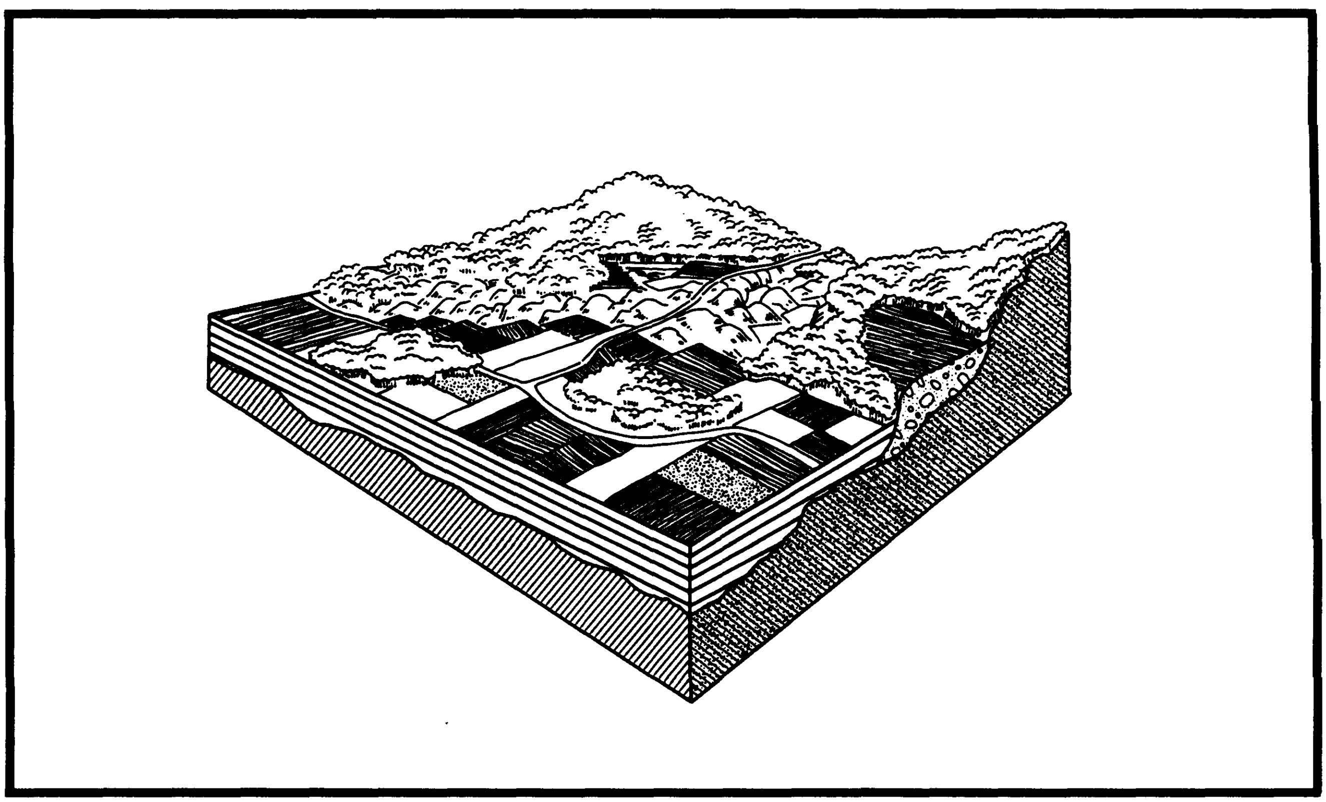


Figure 2-2-9 Kames

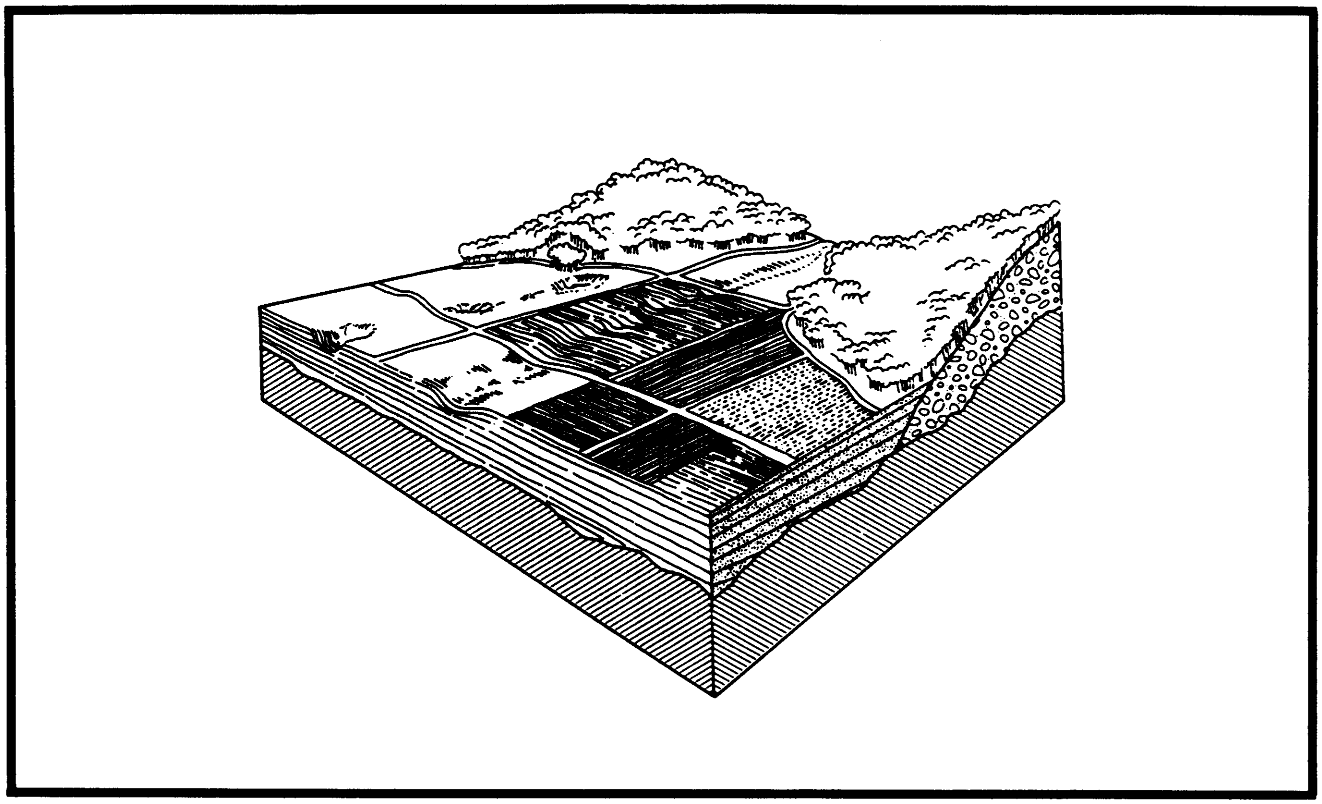


Figure 2-2-10 Outwash

a. **Flood Plains.** Flood plains are formed by the deposition of sediments carried by streams and deposited during floods. Flood plains are characteristically flat, but they may have surface irregularities caused by meanders or channels.

b. **Deltas.** Deltas are deposits of sediments and debris where a stream or river encounters a large body of water like an ocean or lake. They usually appear as arcs, estuaries or in the shape of a bird's foot and contain many drainage channels.

c. **Alluvial Formations.** Alluvial formations consist of sediments of loaded streams which have changed gradient and velocity abruptly as they emerge from steep valleys onto relatively flat surfaces. These formations may appear as gently sloping fan-shaped formations (alluvial fans), flat valley bottoms filled with deposited material (valley fill) or as broad, flat plains covering vast regions (continental alluvium). See Figures 2-2-13, 2-2-14. and 2-2-15.

d. **Coastal Plains.** Coastal plains are stratified layers of gravel, sand, silt and clay that have been exposed where the land surface has uplifted or the ocean level has gone down. Young coastal plains are flat and softly undulating with many swamps and organic deposits found in depressions. They exhibit a parallel, regional drainage pattern. Old coastal plains are highly dissected but do not have steep slopes. They have fine-textured deposits and tree-like drainage patterns.

e. **Beach Ridges.** Beach ridges consist of sandy or gravelly materials deposited by the action of waves. They represent previous shoreline elevations of oceans or lakes. They can be easily identified by their parallel ridges. Because of their porous soil, beach ridges do not facilitate the formation of run-off drainage systems.

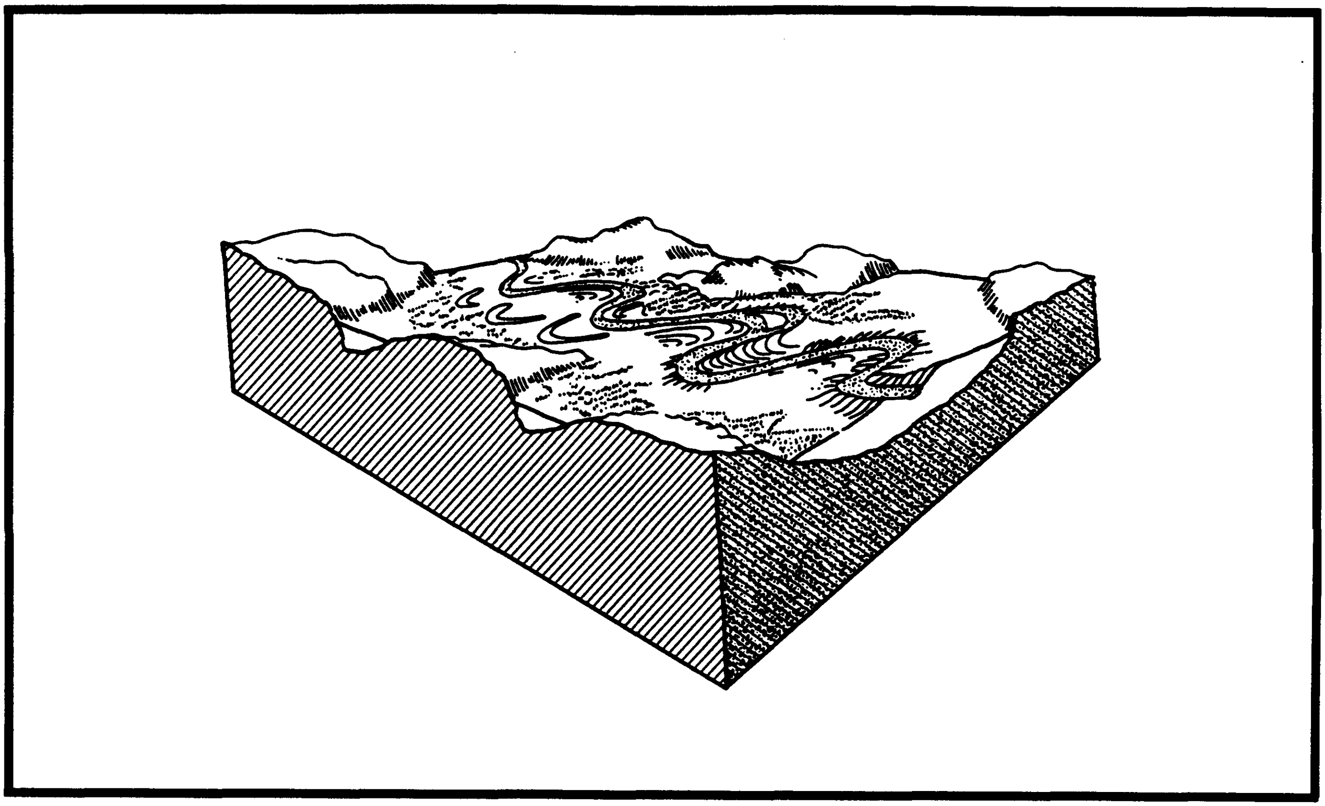


Figure 2-2-11 Flood Plain

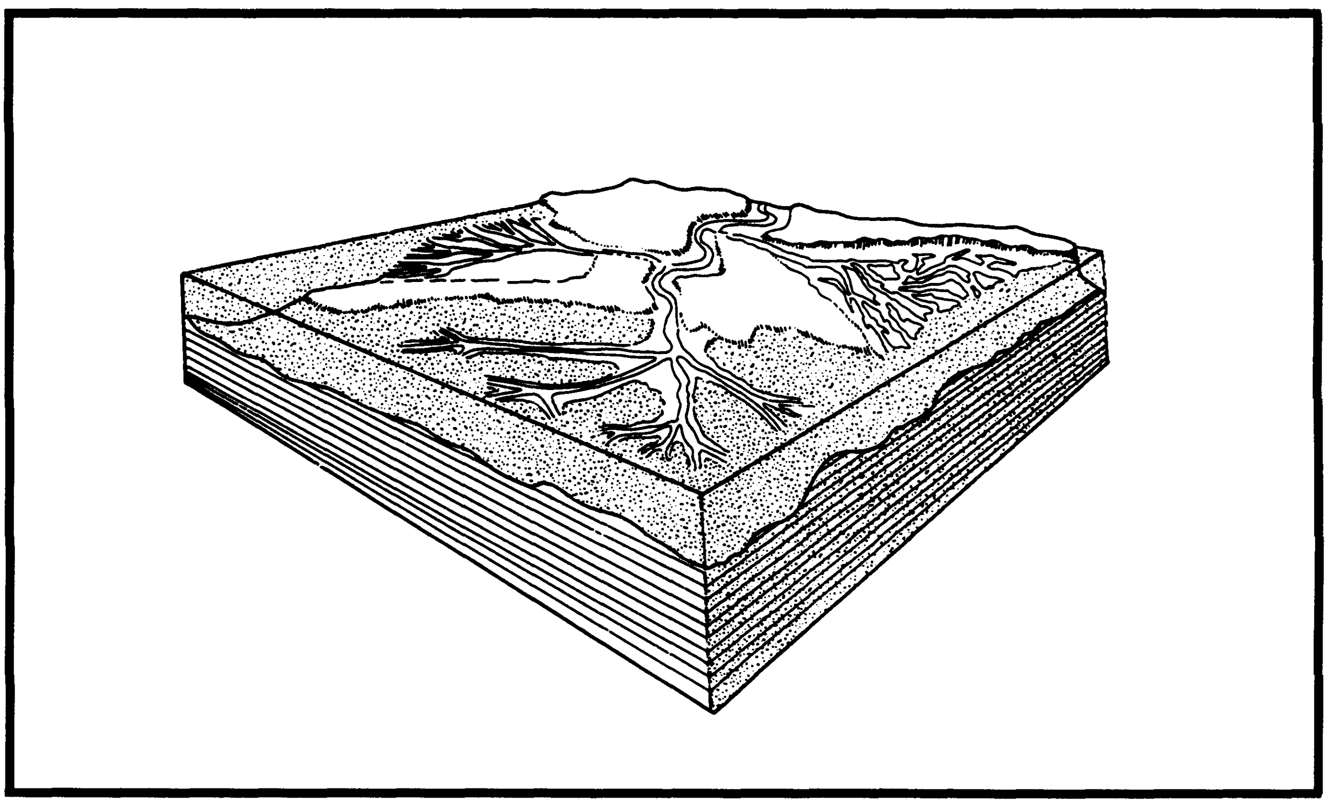


Figure 2-2-12 Delta

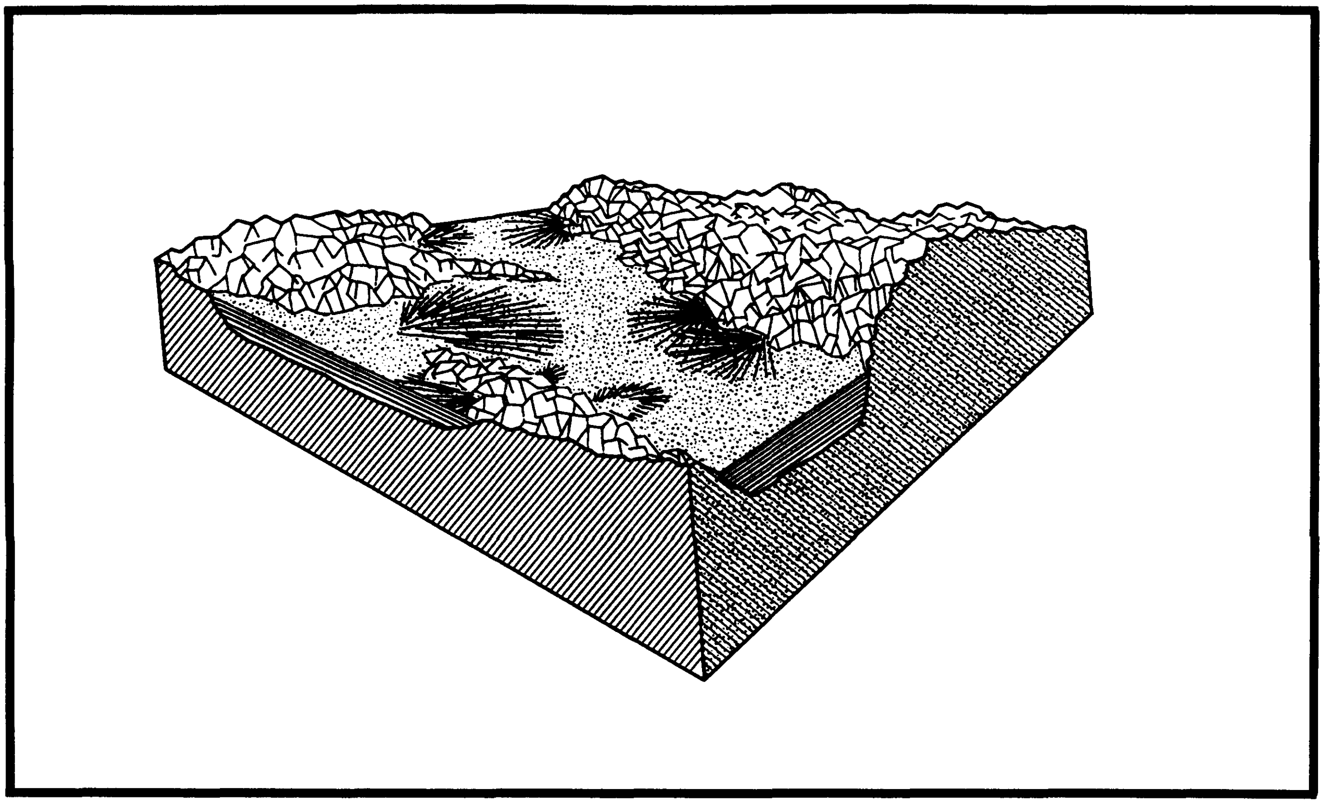


Figure 2-2-13 Alluvial Fan

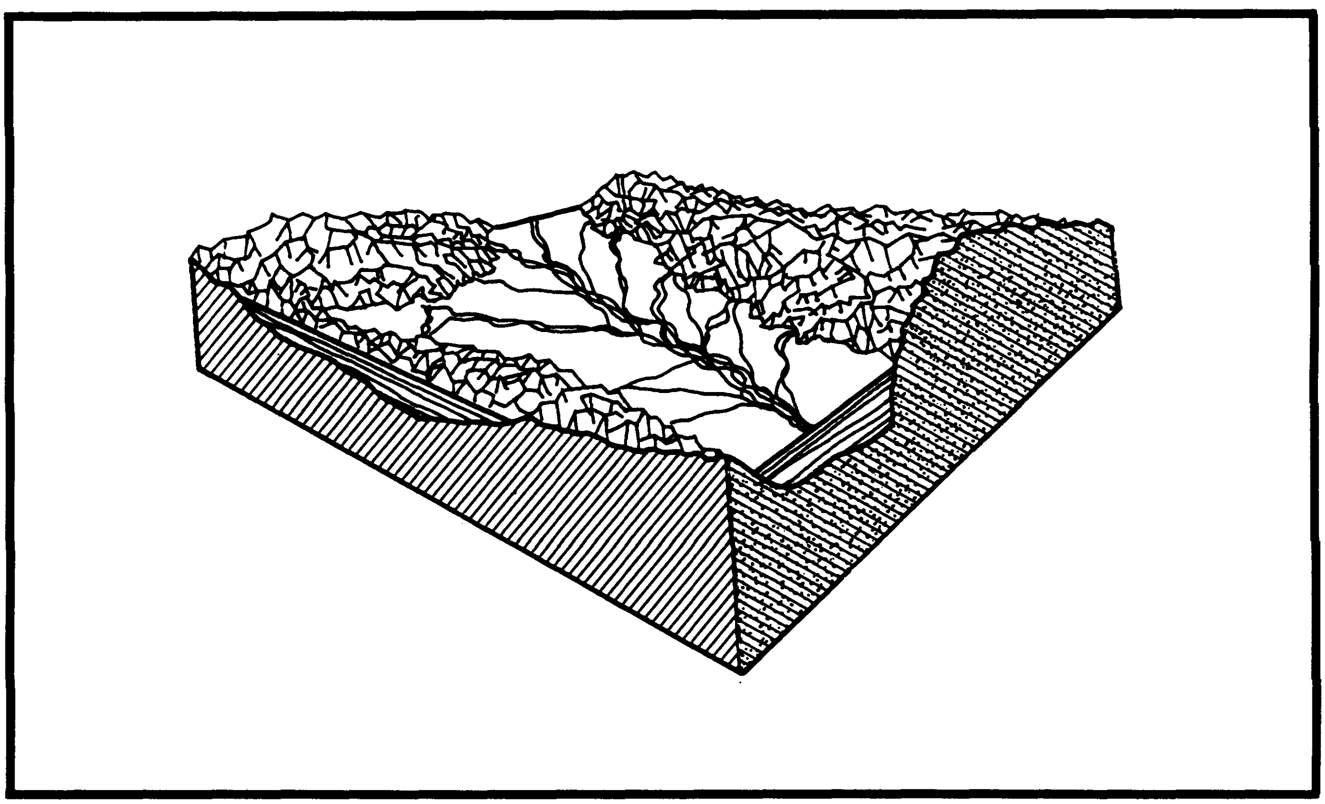


Figure 2-2-14 Valley Fill

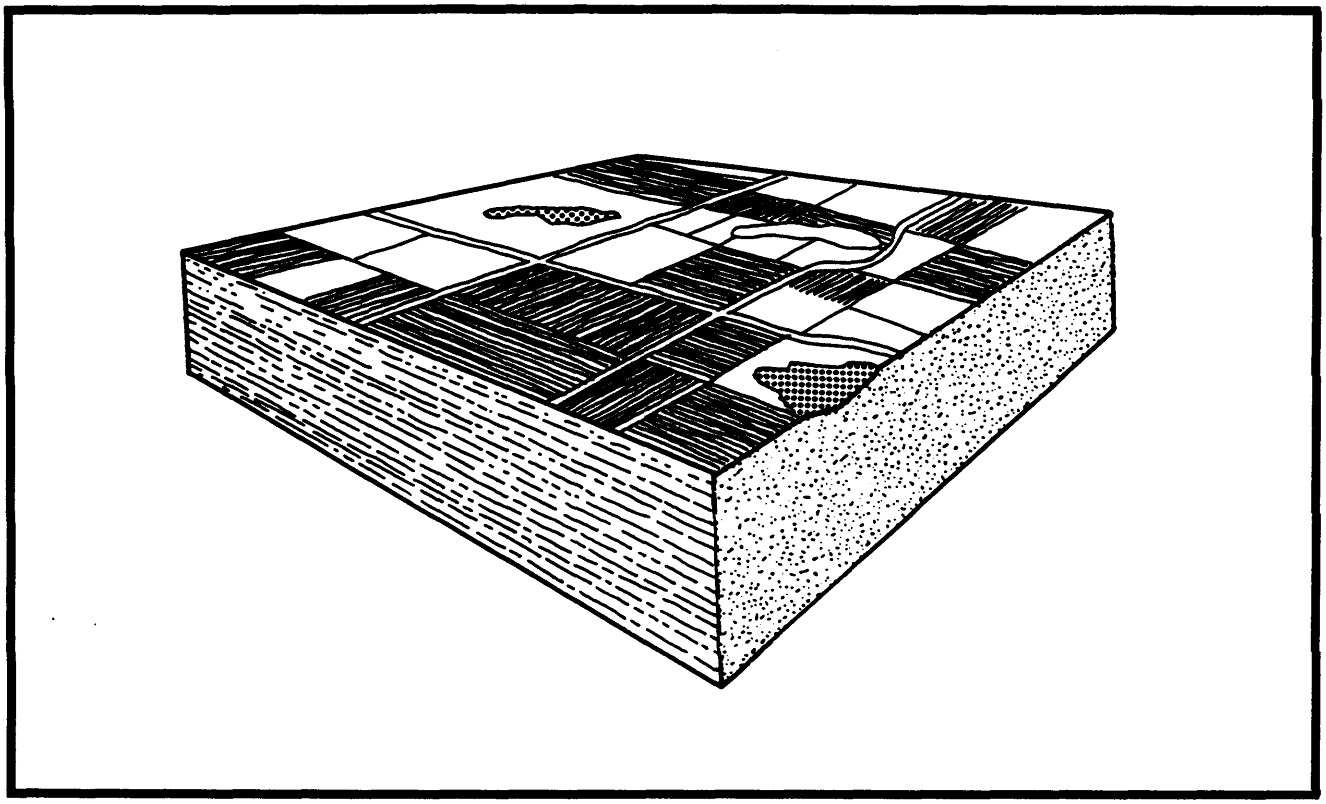


Figure 2-2-15 Continental Alluvium

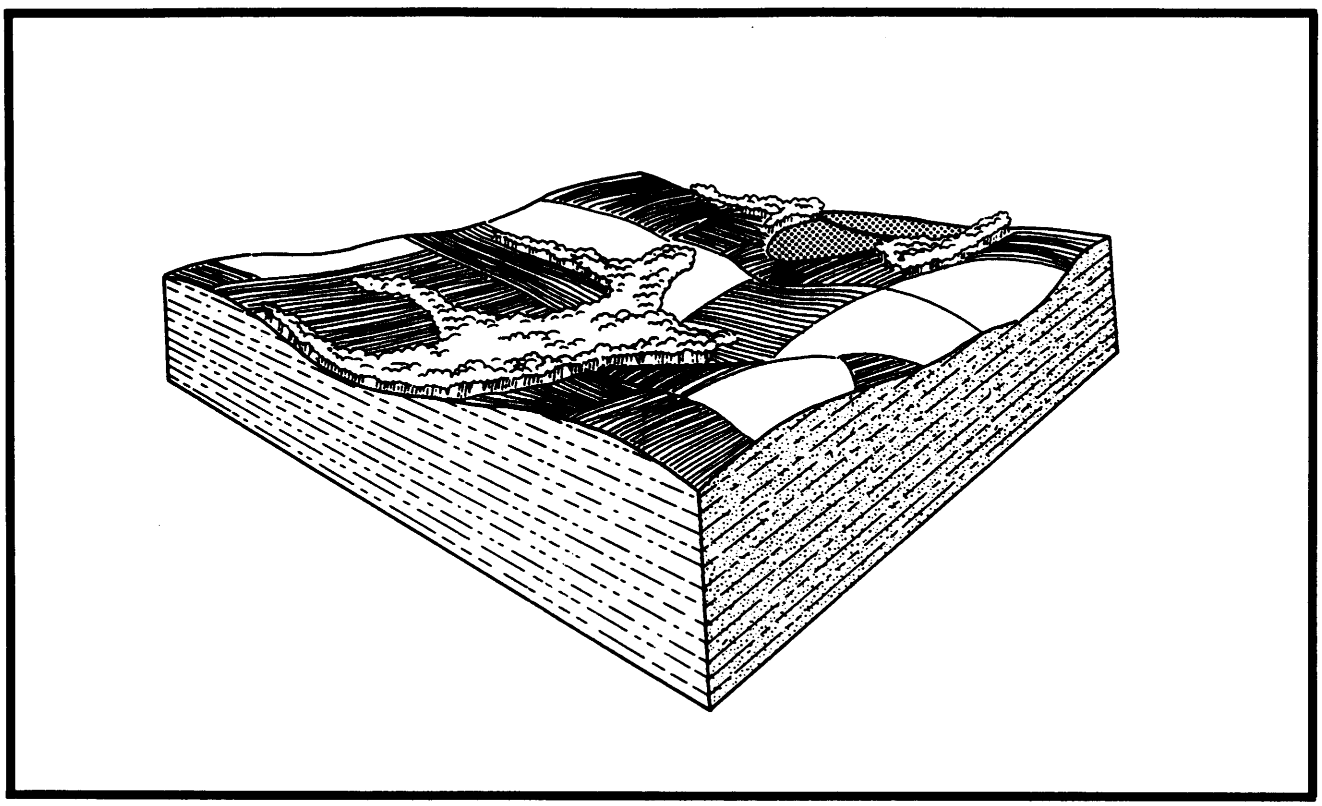


Figure 2-2-16 Coastal Plain

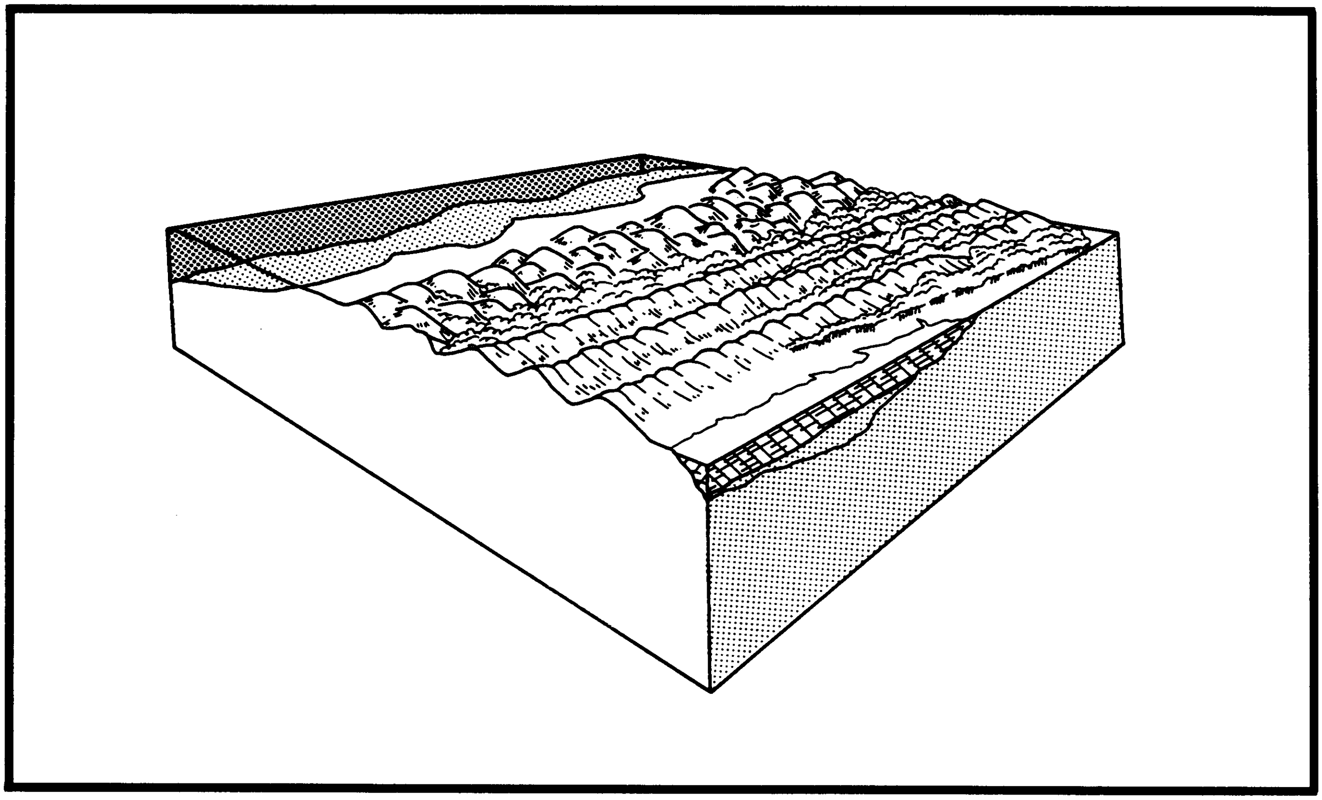


Figure 2-2-17 Beach Ridges

SERIAL	LANDFORM	SAND	GRAVEL	AGGREGATE	SURFACING	
1	Ground Moraines	Unsuitable	Unsuitable	Unsuitable	Excellent to Fair	G
2	Moraines	Good to Unsuitable	Good to Unsuitable	Good to Unsuitable	Excellent to Fair	E P
3	Drumlins	Unsuitable	Unsuitable	Unsuitable	Good to Fair	G
4	Eskers	Good to Poor	Excellent	Excellent	Unsuitable	E
5	Kames	Excellent	Excellent	Good	Unsuitable	E F
6	Outwash	Excellent	Excellent	Good	Unsuitable	E
7	Flood Plains	Excellent	Poor	Unsuitable	Excellent to Fair	E P
8	Deltas	Good to Poor	Good to Unsuitable	Poor	Excellent to Fair	G
9	Alluvial Formations	Excellent to Poor	Excellent to Poor	Excellent to Poor	Good	E F
10	Coastal Plains	Excellent to Fair	Fair	Fair to Poor	Excellent to Poor	E G
11	Beach Ridges	Excellent	Excellent to Unsuitable	Excellent to Poor	Excellent	E

Figure 2-2-18 Type and Suitability of Pit Material from Glacial and Fluvial Landforms

MATERIAL QUALITY

10. **General.** The intended use of the material is the most important consideration in the determination of the quality required. The specifications for materials to be used as fills and subgrades are generally not as stringent as those for crushed rock, surfacing, base courses or pavements. These specifications are not discussed in detail in this manual. Paragraphs 11 to 17 review the properties that most commonly influence the selection of quarry or pit material. Annex A to this chapter outlines field and laboratory tests that exist for evaluating the suitability of a sample of material in terms of these properties.

11. **Toughness.** Toughness is the resistance a rock has to crushing or breaking under impact. It is desirable for aggregate that is used on or near the surface of roads or airfields to be tough enough to withstand the impact of passing traffic. The materials listed in Figure 2-2-19 with a toughness of 1.0 to 3.0 are suitable as aggregate for base courses, surfacing, and concrete and bituminous mixtures. Toughness also has an influence on rock crushing production. For example, crusher production decreases as rock toughness increases. Figure 2-2-19 describes the relationship between toughness and crusher production. Toughness is also related to the unconfined compressive strength of rock. Compressive strength values are described in Annex A to this chapter.

ROCK TYPE	TOUGHNESS	APPROXIMATE CRUSHER PRODUCTION FACTOR*
Limestone	1.0	1.00
Dolomite	1.0	1.00
Marble	1.0	1.00
Hornblende gneiss	1.0	0.95
Biotite granite	1.2	0.90
Andesite	1.2	0.90
Granite gneiss	1.2	0.90
Slate	1.2	0.90
Calcareous sandstone	1.5	0.90
Granite	1.5	0.85
Chert	1.5	0.80
Gabbro	1.6	0.80
Altered basalt	1.7	0.80
Biotite gneiss	1.9	0.80
Coarse quartzite	1.9	0.80
Rhyolite	2.0	0.80
Felsite	2.0	0.80
Hornblende granite	2.1	0.80
Diorite	2.1	0.80
Hornblende schist	2.1	0.80
Fresh basalt	2.3	0.75
Altered Diabase	2.4	0.75
Sandstone	2.6	0.70
Fine quartzite	2.7	0.70
Diabase	3.0	0.65

* Includes maintenance factor

Figure 2-2-19 Relative Toughness of Rocks

12. **Hardness.** Hardness is the resistance of rock to scratching or abrasion. Hardness is not related to the toughness, that is, the ease with which the rock can be broken. Hardness is an important quality for aggregate used in road and airfield construction because if the aggregate cannot resist abrasion it may wear into dust. Aggregates should normally have a hardness of between 5 and 7 on the Moh Scale. (See Annex A, paragraph 3 to this chapter). A material with a hardness greater than 7 may cause excessive wear and/or damage to a crusher or other heavy equipment while material softer than 5 may be too soft for long-term wear.

13. **Durability.** Durability is the resistance of rock to disintegration due to the effects of temperature extremes or alternating cycles of freezing and thawing or wetting and drying. Materials used in exposed construction, particularly pavements and marine structures, must be able to resist hot jet exhaust, water and ice without deterioration.

14. Chemical Stability. Chemical stability is the resistance of rock to chemical reactions. Rocks that contain impure forms of silica should not be used as concrete aggregates. They react with alkalies in Portland cement to form a water-absorbing gel that may expand and crack or disintegrate hardened concrete.

15. Crushed Shape. The shape of an aggregate contributes to its ability to compact well, to interlock to resist displacement and to distribute loads. Rocks which break into irregular bulky fragments provide the best aggregates for construction. Rocks which break into elongated pieces, slabs, sheets or flakes are weak due to their thin dimension and do not compact well. Round aggregates do not interlock well, but they are easy to place and distribute loads well.

16. Density. Density is the weight per unit volume. Density affects loading and hauling costs and the selection of such specialized materials as rip rap, jetty stone and lightweight aggregates. Among rocks of the same type, density is often a good indicator of the toughness and durability of the rock. Generally the denser the rock the tougher and more durable it is.

17. Grain Size Distribution. Grain size distribution is the relative amount of different grain sizes in a sample of material. The gradation of material provides an indication of the compactability of the material. Well-graded material is best for compaction.

GEOLOGICAL MAPS

18. General. Geological maps show the distribution of the earth's materials. These maps are excellent aids in finding pit and quarry locations. Detailed geological studies have not been completed for all parts of the world. However, Canadian provinces, through their departments responsible for energy and mining, the United States Geological Survey (USGS), and many foreign nations, through similar agencies, publish geological maps and reports.

19. Information Provided on Geological Maps. Geological maps show the distribution of the different rocks and their ages. They also indicate the known locations of minerals in the area. Information on existing pits, mines and quarries, in addition to geological features such as folds and faults, will be found on these maps. The strikes and dips of these features and rock outcrops can also be found on a geological map. The amount of detail found on a geological map is related to the amount of geological activity (mining or quarrying) and the amount of geological study completed in the area.

20. **Geological Map Symbols.** Although there is no universally accepted set of standard symbols, many symbols are commonly used on these maps by the various agencies.

a. **Rock Identification.** Some maps have symbols to identify rocks while others use a colour code. Symbols that commonly identify rocks are found in Figure 2-2-20.

b. **Structural Symbols.** Commonly used structural symbols found on a geological map are shown in Figure 2-2-21.

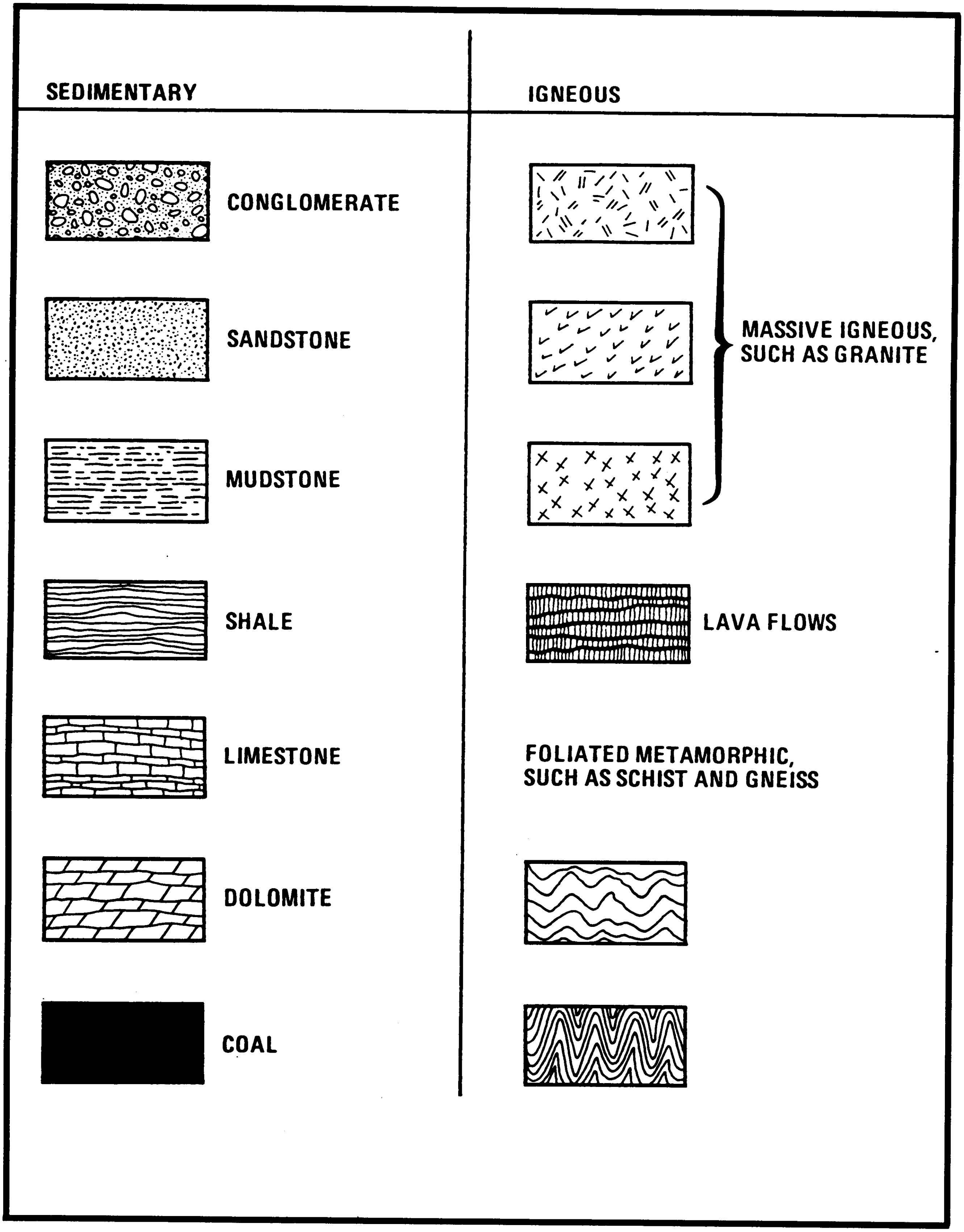


Figure 2-2-20 Commonly Used Rock Identification Symbols on Geological Maps

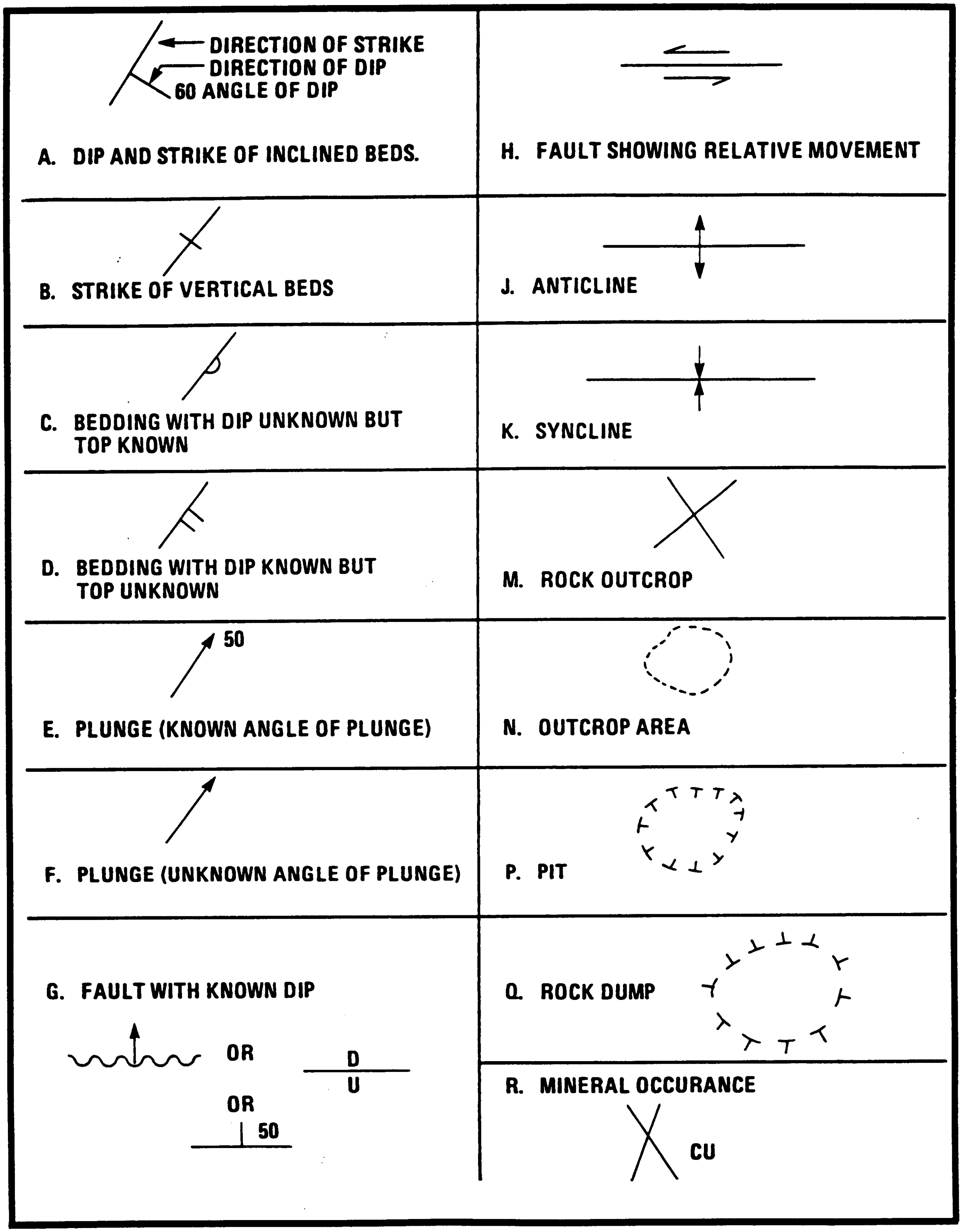


Figure 2-2-21 Commonly Used Structural Symbols on Geological Maps

21. **Geologic Cross-section.** A geologic cross-section is a diagram showing a side view of the earth's crust across a specified section. The cross-section may be a projection from a geological map or produced from information obtained from borehole samples. Figure 2-2-22 is an example of a geologic cross-section projected from a geological map.

SOIL MAPS

22. **General.** Soil maps present information on the distribution of soil and classify it by thickness, texture, drainage or other characteristics. They may also provide data which reflect local geological conditions. It is best to use soil maps in conjunction with geological information. Soil maps are useful in providing an indication of the type of overburden that may have to be removed.

23. **Availability of Soil Maps.** Soil maps and reports are usually produced through the Canadian provincial government departments responsible for energy and mining or the federal Department of Agriculture, and by the US Department of Agriculture or by similar agencies in many foreign nations.

SUMMARY

24. Geological favors are important to pit and quarry site selection. Folds are desirable features in quarry site selection, while extensive joints and faults are undesirable for blasting but desirable for upon, Glacial and fluvial landforms contain materials such as sand, gravel, aggregate, surfacing material and fill material that range from unsuitable to excellent material for construction. Geological and soil maps provide information useful in site selection such as the distribution of different rocks, information on existing pits and quarries and drainage information.

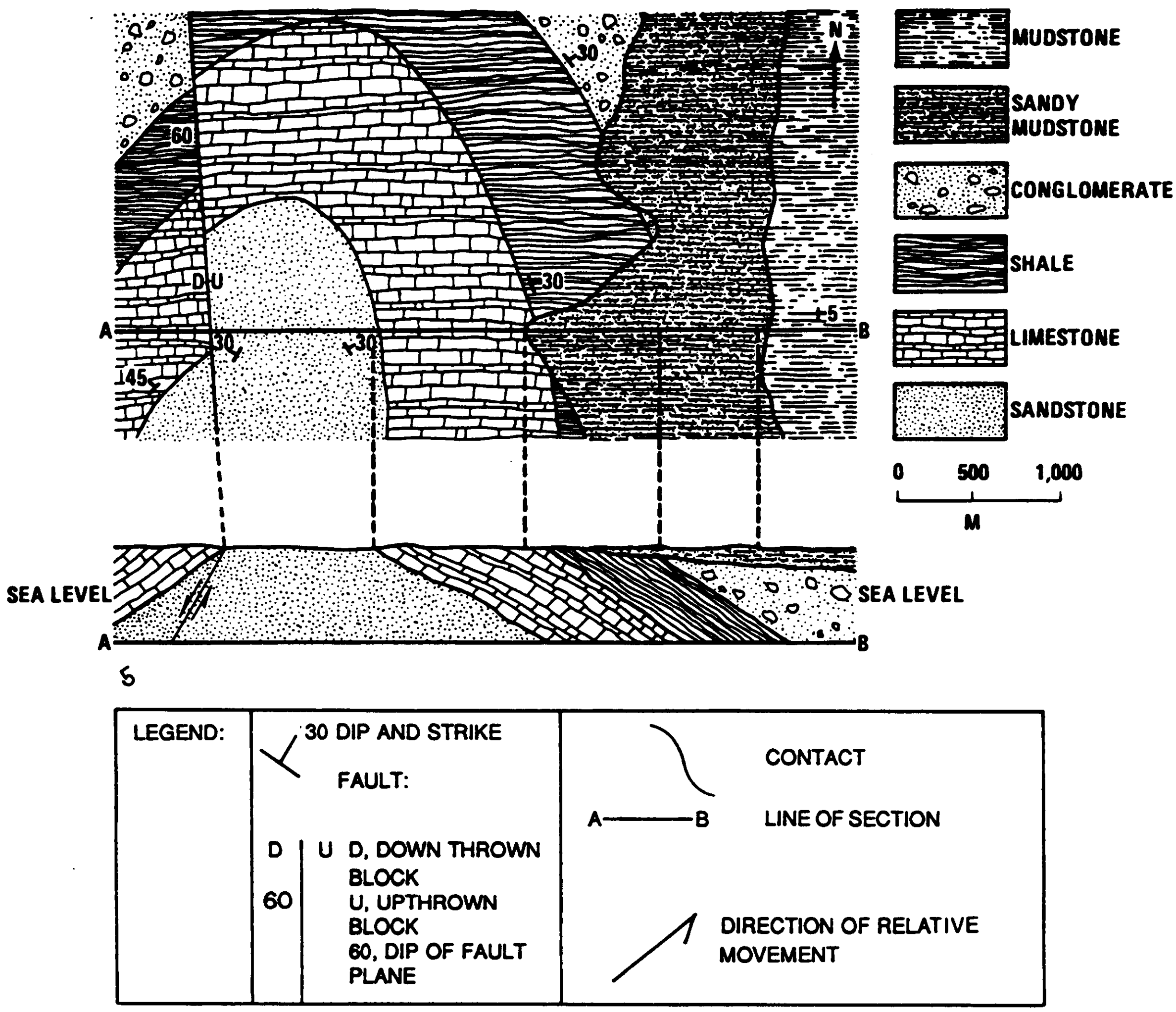


Figure 2-2-22 Construction of a Geologic Cross-section From a Geological Map

SECTION 3

TOPOGRAPHY

GENERAL

1. Topography provides a great deal of information useful to site selection. Much of this information is found in topographic maps and aerial photos.

TOPOGRAPHIC MAPS

2. Topographic maps provide two types of information useful for site selection: terrain features for locating sources and man-made features to support the operation.

3. Terrain Features. Topographic maps indicate terrain features such as elevations, slopes, road and railway cuts, pits, mines, quarries, drainage patterns, vegetation and clearings. A close inspection of these features can provide valuable clues as to the nature of the rocks, degree of weathering, soils and drainage, and suggest areas for the operation of the pit or quarry as well as areas for the storage of material.

4. Man-made Features. Topographic maps provide information about man-made features that are useful in the selection of a pit or quarry. This information includes routes of transportation (roads, railways, airstrips and docking facilities used in the transportation of equipment and personnel), established communication lines, built-up areas (for supplies and other facilities as well as offices which may have valuable records), utilities (power and pipelines), and wells (water, gas, oil).

5. Limitations. The value of the information from a topographic map depends on the age, scale and contour intervals of the map.

AERIAL PHOTOGRAPHS

6. Aerial photographs present a picture of the land on which vegetation, roads, drainage, rock outcrops, excavations and many other features, such as those found on a topographic map, can be identified. Aerial photographs can provide geological and operational information.

7. Geological and Other Information. Aerial photographs can provide hints on the nature of the soil and rock. This information is derived from the drainage patterns as well as the vegetation and land use.

- **a. Drainage Patterns.** Drainage patterns that usually indicate bedrock features such as jointing, fracturing and tilting are those with right angle intersections of gullies, sharp angular bends, straight line runs or parallel gullies. See Figure 2-3-1. Drainage patterns for pit materials are described in Section 2 of this chapter.

- **b. Vegetation.** The presence or absence of vegetation is not necessarily an indicator of bedrock. However, the occurrence of trees in agricultural areas generally indicates land that is not suitable for cultivation. This may be due to land that is poorly drained, steep, dry or rocky. The type of vegetation cover is important in the consideration of overburden removal. Large diameter trees require more effort to remove and indicate thick overburden. A large amount of vegetation also requires more effort to remove. Aerial photographs provide a better appreciation of these factors than topographic maps. Aerial photographs also show cleared areas for possible storage areas better than topographic maps.

c. **Land Use.** The use of land is a valuable indicator of possible rock. Railroads and major highway alignments give important clues to rock conditions since they typically follow the path of least construction cost. Cuts can provide information on the nature of the subsurface material. Roads shown on aerial photographs can be considered for haul routes in the operation of the site.

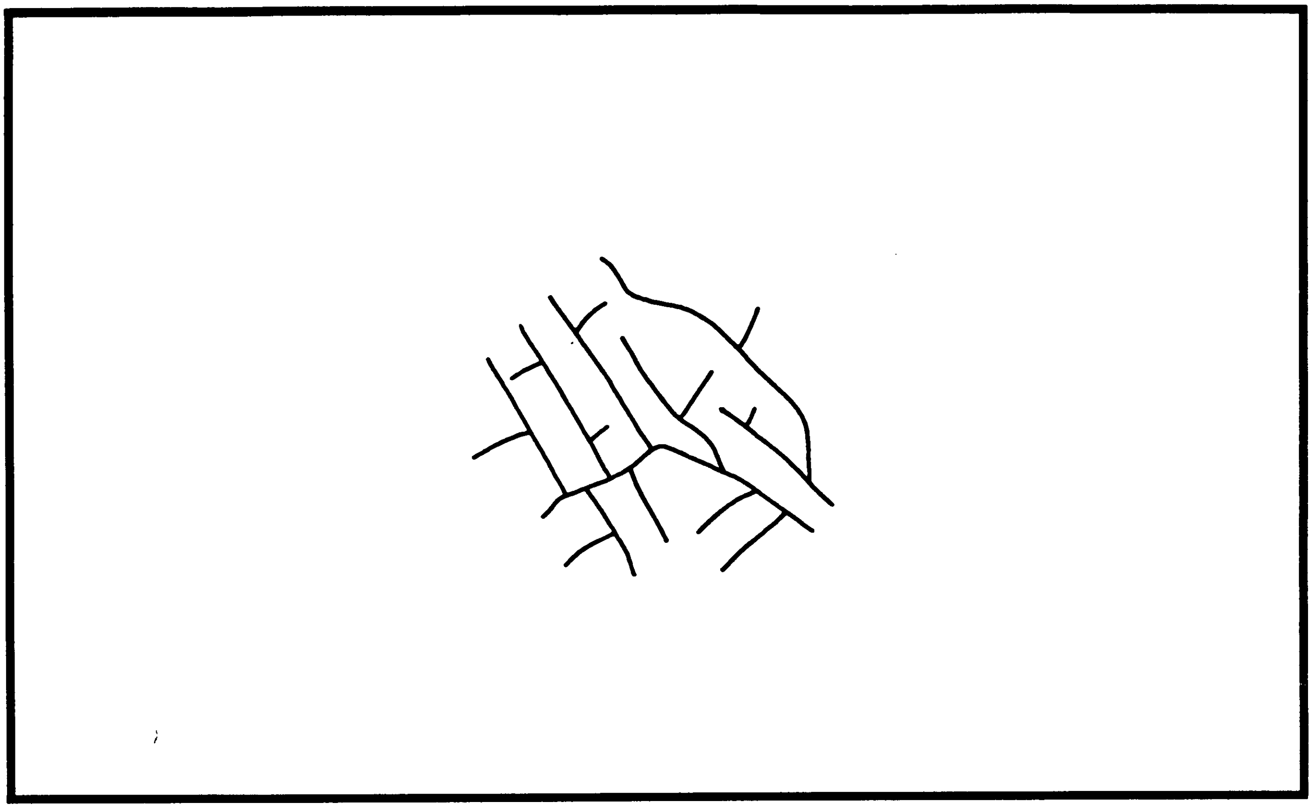


Figure 2-3-1 Drainage Pattern Showing Right Angle Intersections, Sharp Angular Bends, Straight Lines and Parallel Lines Typical in Bedrock Features

8. **Limitations.** The value of aerial photographs is dependent on their age and scale. A lack of experience or training in aerial photograph interpretation will limit the amount of detail that can be derived as well as the accuracy of conclusions made by interpretation. Aerial photographs should be limited to preliminary investigations and should always be followed by ground reconnaissance.

SECTION 4

OPERATIONAL FACTORS

GENERAL

1. Operational factors play a significant role in site selection. This section outlines the operational factors that should be considered.

LOCATION

2. General. The location of a site is important in its relationship to its surroundings. The effect of location on the operation of a pit or quarry can be assessed relative to the construction site, the transportation routes, the site's proximity to built-up areas, utility and communication facilities, and site facilities.

3. Construction Site. The pit or quarry should ideally be as close as possible to the construction site. This reduces the time and cost of material transportation to the construction site.

4. Transportation Routes. Routes from the source to the construction site must be of suitable quality, or must be easily upgraded, to carry the anticipated loads and should be as direct as possible. For large operations, consideration should be given to rail and water transportation routes. When large quantities are shipped by rail a siding should be laid from the site to the main railroad. Routes from the site to its administrative support area should also be suitable. This could involve docks and airstrips for resupply of equipment and personnel by sea and air.

5. Proximity to Built-up Areas. The proximity of built-up areas should be evaluated in terms of blasting operations and administrative support. Structures close to the quarry may be affected by the blast or the flyrock. If the operation of the pit or quarry depends to any degree on local support for food, water, petroleum, oil and lubricants (POL), labour, equipment, maintenance or communications, then the capability of the area to provide this support should be evaluated in terms of reliability, time, cost and distance.

6. Utilities and Communications. The availability of utilities at the site can significantly reduce site development and operational cost. This includes power, water (for human consumption and for washing concrete aggregate and equipment and telephones.

7. Site Facilities. The site itself should be evaluated for facilities it may be able to provide. This includes buildings for offices, accommodations, messing facilities or maintenance facilities. Hardstanding areas, excavations, roads, utilities, existing equipment, and the space available for equipment, plant and material storage should also be considered.

LOCAL WATER FACTORS

8. Ground and surface water may present problems to operations. Because quarries and borrow pits are worked dry, water seepage tests should be performed and the location of the ground water table established to assess the amount of drainage required. In most cases water can be drained by pumping equipment. Extensive drainage projects such as stream diversions or lake drainage should be considered only for extended operations

or where no other sites are available. Gravel pits containing little or no clay can be worked wet if proper equipment, such as draglines, is available.

OVERBURDEN AND SLOPE

9. Overburden. A site requiring a minimum of grubbing, clearing and stripping of vegetation and overburden is desirable. It is usually impractical to operate a site where the depth of overburden exceeds one-third the thickness of usable material or 5 metres. For some types of construction, such as roadway embankments, the overburden may be removed, mixed with sand or gravel and used as a fill.

10. Slopes. Sloping ground is desirable in pit and quarry operations. In quarries, gravity aids equipment in moving material progressively downhill from face to crusher, crusher to storage bin and bin to truck. Other effects of slopes that must be considered include the drainage of precipitation or seepage, road construction and site access, and the positioning of processing and support facilities.

EQUIPMENT AND PERSONNEL

11. The availability of engineer equipment and trained personnel is a major factor to be considered in site evaluation. Equipment determines the extent and the method of operation. The amount of training and experience personnel have is also important. It may be necessary to institute special training programs to meet acceptable standards of safety, maintenance and production.

ENVIRONMENTAL

12. General. The effects of the environment on operations and the effect of operations on the environment should be considered.

13. Environment on Operations. Although it is unlikely there are significant differences in weather between various possible sites, weather effects should be evaluated. If the weather history indicates significant rainfall, then drainage will affect the operation of the pit or quarry. If the weather history indicates a significant lack of rainfall, then dust created by the operation of the site will have to be controlled. If temperatures are excessively hot or cold, special attention would have to be given to both personnel and equipment.

14. Operations on the Environment. Quarry operations produce large amounts of noise, dust, vibration and traffic. This may have an adverse effect on local personnel, installations, the water supply or roads. Blasting may limit the use of the air space over a site or endanger local structures. In some cases the suitability of a site may be influenced by its impact on the local economy or by the cost of restoring the site to a natural condition after operations have ended. In peacetime, government environmental regulations may be very restrictive to quarry operations.

TACTICAL

15. Tactical factors may restrict pit and quarry operations in wartime. There may be restrictions on the use of certain areas and routes as well as blasting restrictions due to air zoning. Blasting and operation time restrictions may be imposed because of noise and light restrictions. There may also be camouflage requirements and restrictions due to proximity to other operational units. The tactical restrictions and their duration must be

understood by the engineer before a great deal of time is spent on reconnaissance of a site that may be constrained too severely.

SECURITY

16. Pit and quarry sites are particularly vulnerable to enemy operations in wartime. Any major item of equipment destroyed at the site may halt the entire operation (and the project it supports) until a replacement is received. In both wartime and peacetime, consideration must be given to the problems of pilferage, vandalism and accidental injury to trespassers.

SUMMARY

17. Operational factors are very important in site selection. At times they may be even more important than geological factors and their impact must be carefully assessed in site selection. These factors include such things as location, local water, overburden and slope, and environmental factors. They also include human operational factors such as equipment and personnel, and tactical and security factors.

SECTION 5

SITE SELECTION - INVESTIGATION PROCEDURES

GENERAL

1. The process used to arrive at a final site selection for a pit or quarry involves preliminary planning and site investigation. The investigation process should start as early as possible.

PRELIMINARY PLANNING

2. General. Preliminary planning involves all work in the site selection process before any on-site investigation and varies according to time limitations. As many sources of data as possible should be used in this stage.

3. Understanding the Requirement and the Limitations. From the outset an understanding of all parameters in the stated requirement for the pit or quarry as well as all imposed limitations is essential. Specifically, the following information must be known:

> **a. Purpose.** It must be known what the material will be used for (eg, concrete aggregate, pavement aggregate, roads, airfields, or railways, bases or sub-bases) in order to define the desired quality.
>
> **b. Size.** It must be known what volume of material is required or the scope of the project(s) to be supported in order to determine how large a site is required.
>
> **c. Time.** It must be known by when the site must be selected, when it has to be operating and for how long it must operate.
>
> **d. Restrictions.** All restrictions pertinent to the investigation, selection and operation of the pit or quarry must also be known.

4. Accumulation of Data. Once the task has been fully defined and understood, the next step is to collect and study all available information relative to potential site locations. A thorough study of this information saves time by limiting the areas to be investigated to those having definite possibilities. The following are sources of data that should be explored:

> **a. Intelligence Sources.** Intelligence reports used for long range planning from higher formation engineer staff may contain information on soil types, rock formations and the locations of existing pits and quarries. Local government agencies or offices may also have records with useful information.
>
> **b. Maps and Photos.** A study of all available geologic, soil and topographic maps as well as aerial photos and foreign maps may provide valuable information. Sections 2 and 3 of this chapter describe the information that can be derived from these sources.

c. **Local Inhabitants.** The local inhabitants, particularly surveyors, contractors, engineers, farmers, teachers and government officials may provide a great deal of useful data on local geology and engineering problems. They are normally a quick source of information on local rock and soil types and on locations of readily available rock and soil exposures.

d. **Miscellaneous Records.** Miscellaneous records from drilling, mining, petroleum and engineering companies, and government departments may provide geologic and engineering data for many areas which have been explored or developed for commercial or industrial purposes, or may provide zoning regulations.

5. Air Reconnaissance. Once an appreciation of the area of concern is made, an air reconnaissance should be conducted because it provides a clear picture of the information derived from the data study.

6. Formulation of Field Reconnaissance Plan. Once all data has been assembled and evaluated, field reconnaissance priorities should be established as follows:

a. **Known Sites.** These are sites that are currently in use or have previously been used as pits or quarries and that are close enough to the construction site to warrant further investigation.

b. **Probable Sites.** These are sites which available data indicates probably contain desirable construction material.

c. **Possible Sites.** These are sites which data indicates possibly contain construction material.

SITE INVESTIGATION

7. General. Site investigation involves gathering all facts peculiar to each site in terms of geological factors and operational factors. Preliminary planning provides a familiarity of each site. Site Investigation confirms this information and provides new information to ensure a complete appreciation of the site.

8. Geological Investigation. Geological investigation examines the rock at the site to determine the quality of material.

a. **Structure.** Site investigations should devote special attention to the geological structure of potential sites. The shape and arrangement of geological features can influence operational costs. Thin, broad deposits may require excessive stripping and frequent equipment relocations. Layers or masses of waste material within a deposit may create problems in recovering and processing the desirable materials. The spacing and orientation of rock layers and fractures should be carefully evaluated because of their influence on rock distribution, fragmentation and slides.

(1) **Rock Distribution.** The orientation and thickness of rock bodies determine their distribution. Steeply inclined rock formations may quickly slope to depths when excavation or overburden removal becomes impractical. Therefore, large areas may have to be stripped to secure enough rock where deposits are thin and flat-lying.

(2) **Rock Fragmentation.** Many weak, thinly layered or closely fractured rocks can be excavated by ripping instead of blasting (see Chapter 3, Section 4, paragraphs 2 to 8). This method of excavation is most effective where the equipment can work in the dip direction of the rock layers or fractures. Where drilling and blasting are required, inclined rock layers or open fractures may divert drill bits, producing misaligned drill holes. Drill steels may even bind, stick or break off. Open fractures and layers of weak rock may reduce blasting efficiency by allowing the force of the blast to dissipate before the surrounding rock has been property fragmented. Further, the spacing of rock layers and fractures may control the size and shape of the excavated rock fragments and could possibly reduce their suitability for construction or increase processing costs.

(3) **Rock Slides.** Massive rock slides may occur where unconfined rock masses overlie inclined rock layers or fractures. The risk of such slides is greatest over smooth, continuous, water-or-clay-lubricated surfaces which dip steeply toward natural or man-made excavations.

b. **Subsurface Exploration.** As much site information as possible should be obtained from intelligence sources and surface observations to minimize Subsurface investigation requirements. Where subsurface exploration is needed, the following exploration methods may be used:

(1) **Geologic Mapping.** This consists of recording geologic observations and interpretations on map or photo overlays and cross-sections. Many valid inferences can be made on the subsurface distribution of geologic materials and fractures from observations of their exposures and trends. Usually, data is obtained from soil and rock outcrops exposed by erosion or excavation. (See Chapter 2, Section 2, paragraphs 18 to 21.)

(2) **Probing.** This method usually consists of driving a steel rod into the ground and noting the variations in penetration resistance. Rods for this purpose may be of any diameter, but round or hexagonal rods between 1.6 and 2.2 centimetres (5/8 and 7/8 inch) in diameter are usually used. They may be pointed or have a driving point attached. Probing is generally used to determine the presence or absence of bedrock or gravel deposits within acceptable depths determined by equipment capabilities. Resistance to penetration can be roughly interpreted in terms of the character of the material penetrated. Probing is not always reliable because a penetration refusal, interpreted as bedrock, may actually prove to be a cobble, boulder or cemented soil layer. Probing should never be used in other than preliminary exploration and should always be checked with other investigative methods.

(3) **Wash Boring.** This consists of forcing a wash pipe or hollow drill rod through overburden by chopping and jetting as water is pumped through the boring device. Usually a chopping bit is attached to the bottom end of a wash pipe. Displaced soil is washed to the surface where it may be caught in a container for sampling and testing. Wash borings are used mainly to advance holes through overburden materials prior to penetration testing or drive sampling. They may also be used to obtain a borehole though overburden to prepare for rock drilling. This method cannot be used as a final analysis for determining subsurface conditions. It should be used only as an expedient prior to final evaluation of an area.

(4) **Auger Drilling.** Manual or mechanical augers may be used in soil or very weak rock to

determine the depth and thickness of deposits, obtain disturbed samples for testing and advance boreholes for penetration tests or drive sampling.

(5) **Drive Sampling.** This consists essentially of driving a hollow tube into soil or soil-like materials in order to obtain samples for evaluation. Normally this exploration method is used in conjunction with wash boring or auger drilling in fine-grained soils.

(6) **Pneumatic Drilling.** This method uses percussion-type rock drills. Bedrock conditions may be interpreted from drill penetration rates and the color of cuttings from the hole. These explorations are useful in supplementary investigations for searching out shallow cavities and soft zones after overburden has been stripped from the rock.

(7) **Core Drilling.** This method involves cutting and recovering core samples from rock using hollow drill bits and sample tubes which are not usually available to troop units.

(8) **Geophysical Measurements.** Much data can be obtained on the nature and distribution of subsurface materials from measurements of their resistance to the passage of sound waves or electric currents. Such geophysical measurements require careful, experienced interpenetration and must be correlated with data from other sources. The sophisticated electronic equipment required for geophysical exploration will not usually be available to field troops.

(9) **Test Pits and Trenches.** These are excavations made by hand or power tools to expose subsurface materials. They have their greatest use in connection with soil exploration and testing. They may also be used to study the character of overburden and the position, character and condition of bedrock surfaces, Test pits and trenches are the most reliable and widely used of all subsurface exploration techniques.

c. **Rock Quality Tests.** Rock quality tests should be performed on site samples. Both field and laboratory tests for rock properties are found in Annex A to this chapter.

9. Quantity of Material.

a. **General.** The quantity of material available at a site must be carefully estimated. A margin of safety must be included for unforeseen difficulties that may arise which can reduce the estimated output. These unforeseens may include excessive seepage or decreased material quality. All other factors being equal, it is better to select a site containing more material than is required.

b. **Calculations.** The volume of material available at a site is estimated by selecting a reference plane, such as the quarry floor or bottom of a pit, and computing the volume of these segments. The thickness of a deposit is measured at right angles to the reference plane. Unusable materials such as weathered rock and overburden should be subtracted from the volume of the deposit. Likewise, allowance should be made for that portion of the desired material which might have to be spoiled after screening or washing. The following formula may be used:

EQ2-5-4a

$$Q_p = Q_t \left(1 - \frac{W}{100}\right)$$

where:

Qp = Volume of product available
Qt = Total quantity of available material in deposit
W = Percent of spoil or by-product expected after processing.

The total quantity of available material may be calculated by two methods:

(1) Hasty Method. Take cross-sections at right angles to a convenient base line; determine the average cross-sectional area of the deposit; then determine the estimated volume by multiplying the average cross-sectional area by the length of the deposit. See Figure 2-5-1. Use the equations:

A = H x B
V = L x A

where:

A = area of cross-section V = volume of material
B = length of base of cross section L = depth of deposit
H = height of cross-section

(2) Deliberate Method. Divide a plan of the deposit into a system of squares or rectangles and triangles 5 to 20 metres on a side. Then determine the difference in elevation between the ground surface and the excavation level at the corners of each square, rectangle or triangle. Compute the average excavation depth for each geometric area. Then compute the volume under each area and total these volumes. It should be remembered that the surface of the usable material or floor will seldom be level. This should be taken into account in the computations by averaging their depths. When the depth of excavation is uniform or has been averaged throughout the pit, the total volume may be computed using the following equation (see Figure 2-5-2):

EQ2-5-4b

$$V = N(abd) + \frac{M(a'bd)}{2}$$

where:

V = Volume of material in cubic metres
N = Number of squares or rectangles involved

a, a', b = Length of sides in metres

d = Average depth in metres

M = Number of triangles involved

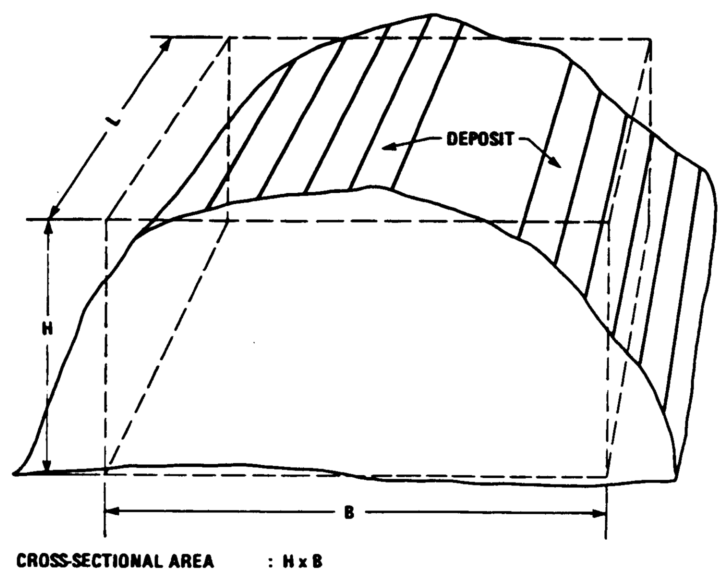


Figure 2-5-1 Volume Calculation - Hasty Method

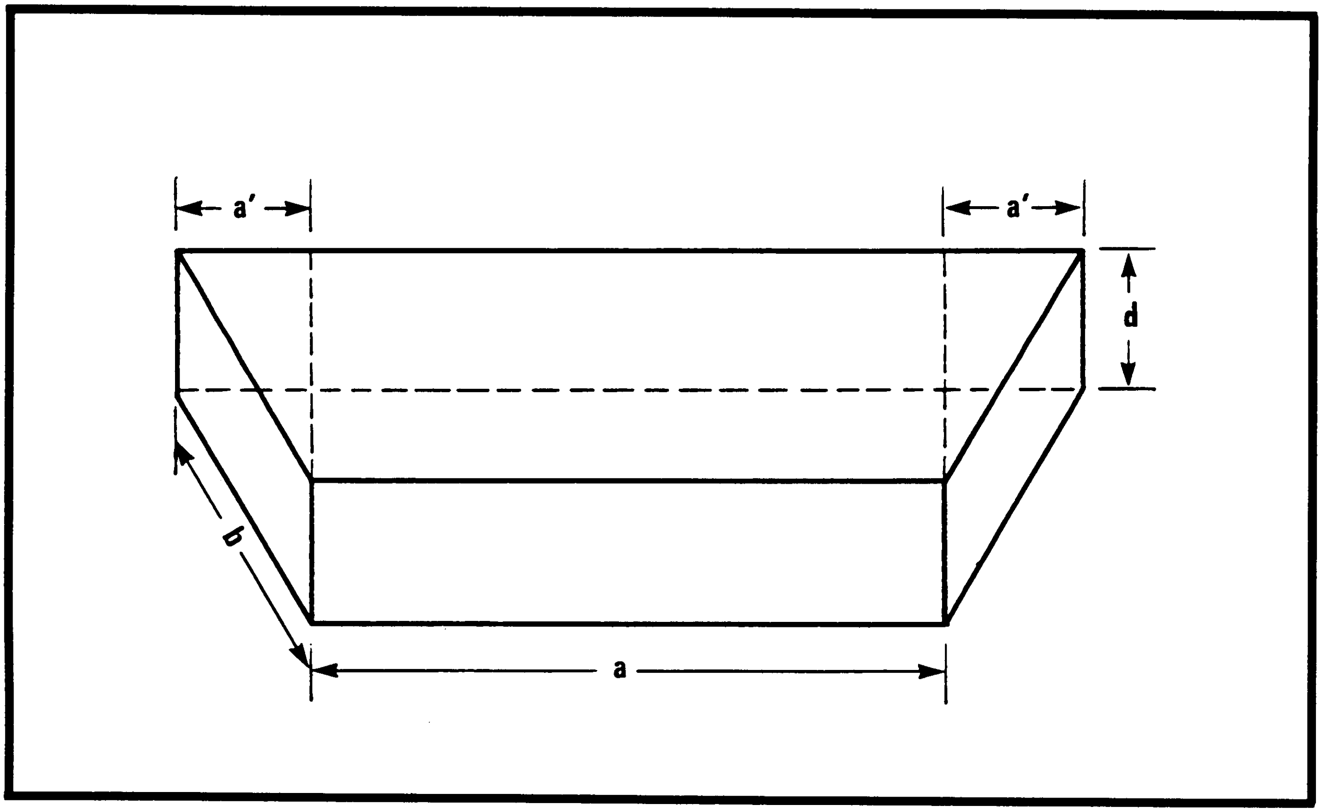


Figure 2-5-2 Volume Calculation - Deliberate Method

c. **Weight-Volume Relationships.** Loosened rock occupies a greater volume after excavation than solid rock does before excavation. The weight and volume relationships of materials should be measured during site investigation to accurately determine the potential yield. The quantity of broken rock is generally 1.5 times the quantity of solid rock. The estimated tonnage in place is 2.6 tons per cubic metre. Estimates of quantity of rock available are more easily made from the face of existing quarries than from new developments and are generally more accurate.

10. Operational Factors Investigation. The site should also be evaluated in terms of the operational factors listed in Section 4 of this chapter.

11. Site Investigation Report. A final report of the site investigation should be completed. This report should contain all information determined from the site as well as conclusions and recommendations. Annex B to this chapter provides a sample outline for a site investigation report.

SUMMARY

12. The process of site selection involves preliminary planning and site investigation. Preliminary planning ensures that the requirement is understood, that data is accumulated, that an air reconnaissance is conducted and that a field reconnaissance plan is formulated before the actual site is visited. Site investigation includes a geological investigation of rock structure and quality, determination of material quantity and investigation of the operational factors that may influence the site.

SECTION 6

SITE SELECTION

GENERAL

1. Final site selection is made after all preliminary and site investigation data have been collected, analyzed and evaluated. The weight assigned to each factor in the decision making process depends on the particular situation. The most important factor in selection, however, must be the requirement for the site to meet the desired quality and quantity of material. If more than one site satisfies these requirements, the ultimate choice is based on the evaluation of the other geographical and operational factors. Choose the site which best meets the defined requirements within the stated limitations.

ANNEX A, CHAPTER 2
FIELD AND LABORATORY TESTS ON ROCK

1. Toughness:

a. **Field Test.** Toughness may be estimated in the field by attempting to break a fragment of the rock with a hammer. Tough rocks are difficult to break whereas soft rocks are broken easily. A large boulder of very tough rock causes the hammer to rebound with a ringing sound. Some rocks, when they break, disintegrate into a powder. Resistance to powdering is desirable.

b. **Laboratory Tests.** The standard laboratory test for toughness is provided by the American Society for Testing and Materials (ASTM). The test procedure is described as follows:

(1) Test pieces may be either cylinders or cubes, 25 mm in diameter and 25 mm in height, cut perpendicular to the cleavage of the rock. Cylinders are recommended as they are cheaper and more easily made.

(2) The test machine shall consist of a 50-kg anvil placed on a concrete foundation. The hammer shall be a 2 kg weight. The hammer shall be dropped upon an intervening 1 kg plunger that rests on the test piece. The lower or bearing surface of this plunger shall be a spherical shape having a radius of 1 cm. The plunger shall be made of hardened steel, and pressed firmly upon the test piece by suitable springs. The test piece shall be adjusted so that the center of its upper surface is tangent to the spherical end of the plunger.

(3) The test shall consist of a 1 cm fall of the hammer for the first blow, and an increased fall of 1 cm for each succeeding blow until failure of the test piece occurs. The number of blows necessary to destroy the test piece is used to represent the toughness of the material. The centimetre-grams of energy applied may also be used to represent the toughness.

2. Compressive Strength. The laboratory test that covers the procedures for determining compressive strength is ASTM Test C170-50 Compressive Strength of National Building Stone. Compressive strength may be described by the following values:

Very strong	over 220 MPa
Strong	110 to 220 MPa
Intermediate	60 to 110 MPa
Weak	28 to 60 MPa
Very Weak	less than 28 MPa

3. Hardness:

a. **General**. Hardness is usually measured using the Moh scale found in Figure 2A-1. The harder the material the higher is its number on the scale. Any material will scratch another of equal or lesser hardness. A relative classification of rocks is found in Figure 2A-2.

Mineral	Hardness	Description
Diamond	10	Very hard
Corundum	9	Very hard
Topax or beryl	8	Very hard
Quartz	7	Very hard
Feldspar	6	Hard
Apatite	5	Moderately hard
Fluorite	4	Moderately hard
Calcite	3	Soft
Gypsum	2	Very soft
Talc	1	Very soft

Figure 2A-1 Moh's Scale of Hardness

Soft	Medium	Hard	Very Hard
Asbestos rock	Limestone	Granite	Iron Ore (Taconite)
Gypsum rock	Dolomite	Quartzite	Granite
Slate	Sandstone	Iron ore	Granite gravel
Talc		Traprock	Traprock
Soft Limestone		Gravel	

Figure 2A-2 Hardness of Rocks

b. **Field-Test.** Hardness may be measured using the common expedients given in Figure 2A-3. If, for example, a rock can scratch the blade of a knife, it has a hardness of 5.5 or greater. A rock which can be scratched by a copper coin has a hardness of 3.0 or less.

Expedient	Hardness
Porcelain	7.0
Steel file	15
Window glass	5.5
Knife blade	5.0
Copper coin	3.0
Finger nail	2.5

Figure 2A-3 Hardness Expedients

c. **Laboratory Test**

(1) The standard laboratory test for hardness is the Dorry Hardness Test using a Dorry machine. A stone cylinder 25 cm in diameter is obtained by a diamond core drill from the material to be tested. The cylinder is weighed and placed in the machine so that one end of it rests on a horizontal cast-iron grinding disc at a pressure of 25 gram per square centimetre. The disk is revolved 1000 times, during which standard crushed quartz sand about 1.5 mm in diameter is automatically fed onto the disk. The cylinder is then removed and weighed and the coefficient of hardness, expressed in grams, is obtained by the formula: 20 - 1/3 the loss in weight. In order to get reliable results, two cylinders are generally used and each one is reversed end for end during the test.

(2) Another test is ASTM test C535-69 Resistance to Abrasion. It measures the resistance to abrasion of large size coarse aggregate by use of the Los Angeles abrasion machine.

4. **Durability.** Durability may be estimated in the field from observations of the effects of weather on natural exposures of the rock.

5. **Chemical Stability.**

a. **Field Tests.** Potential alkali-aggregate reactions may be anticipated in the field by identifying the rock and comparing it to known reactive types or by investigating structures in which the aggregate has been used. Generally, light-colored or glassy volcanic rocks, cherts, flints and clayey rocks should be considered reactive unless proven otherwise.

b. **Laboratory Tests.** A detailed laboratory test to evaluate the suitability of aggregate suspected to produce alkali-silica or alkali-carbonate reactions in concrete is found in Canadian Standards Association CAN3-A23.2-M-77 Test A23.2-14A Alkali-Aggregate Reaction.

6. **Crushed Shape:**

a. **Field Test.** The shape of rocks can be evaluated in the field by inspecting samples in the area or by breaking some samples. Figure 2A-4 describes various shapes.

b. **Laboratory Tests.** A detailed laboratory test that outlines procedures for the determination of flat and elongated particles in coarse aggregate is found in Canadian Standards Association CAN 3-A23.2-M-77 Test A23.13A Flat and Elongated Particles in Coarse Aggregate.

7. Density:

a. **Field Test.** Density may be estimated by hefting a sample of the rock. Experience may assist in the estimation.

b. **Laboratory Tests.** A detailed laboratory test that covers the procedures for determining the density of aggregate is found in Canadian Standards Association CAN3-A23.2-M-77 Test A23.2-10A Density of Aggregate. Density may be described by the following values:

Very Dense	over 3000 kg/m3
Dense	2800 to 3000 kg/m3
Moderately Dense	2600 to 2800 kg/m3
Low Density	2400 to 2600 kg/m3
Very Low Density	less than 2400 kg/m3

8. Grain Size Distribution:

a. **Field Tests.** In the field, gradation may be estimated by the distribution of different sizes in a sample of material. If there is a relatively uniform distribution of sizes the sample is well graded. If there appears to be more coarse aggregate or more fines, the sample is poorly graded.

b. **Laboratory Tests.** A detailed laboratory test that covers a procedure for the determination of the particle size distribution of fine and coarse aggregate using sieves is found in Canadian Standards Association CAN3-A23.2-M-77 Test A23.2-2A Sieve Analysis of Fine and Coarse Aggregate.

c. **Grain Sizes.** The following values may be used to describe grain sizes:

(1) Crystals:

Very coarse	over 25 mm
Coarse	5 to 25 mm
Medium	1 to 5 mm
Fine	to 1 mm
Very fine	indistinguishable

(2) Rock or Mineral Fragments:

Boulder	over 256 mm
Cobble	64 to 256 mm
Pebble	4 to 64 mm

Granule	2 to 4 mm
Sand	0.06 to 2 mm
Silt	0.004 to 0.06 mm
Clay	to .004 mm

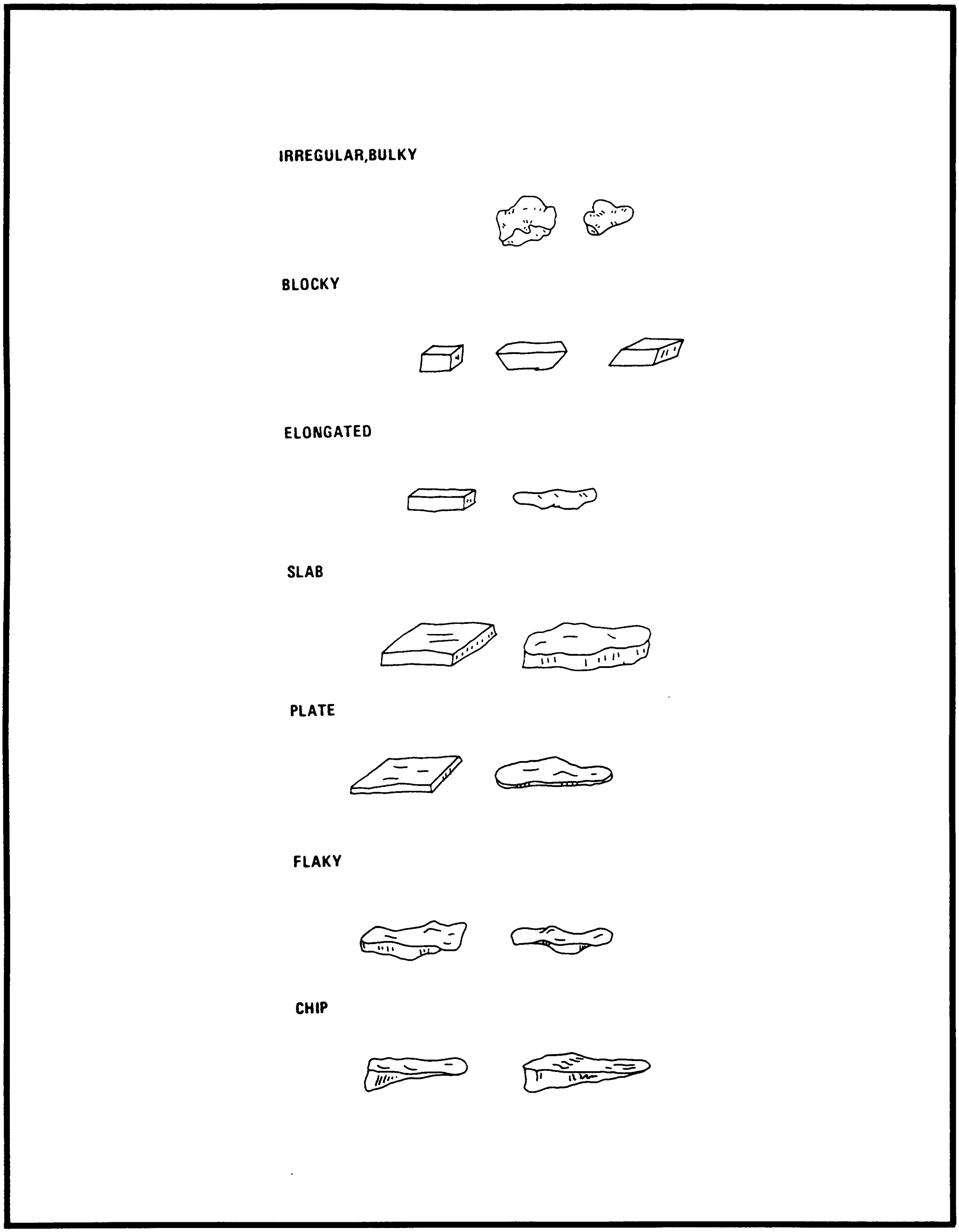


Figure 2A-4 Crushed Rock Shapes

9. **Bedding Thicknesses.** The following values may be used to describe bedding thicknesses:

Very thick	over 3 m
Thick	1 to 3 m
Medium	25 to 100 cm
Thin	50 to 250 mm
Very Thin	10 to 50 mm
Laminated	up to 10 mm

10. **Joint (Fracture) Spacing.** The following values may be used to describe joint spacing:

Very wide	over 3 m
Wide	1 to 3 m
Moderately close	25 to 1 00 cm
Close	50 to 250 mm
Very close	up to 50 mm

ANNEX B, CHAPTER 2
SITE INVESTIGATION REPORT OUTLINE

1 General

a. Stated requirement and imposed limitations

b. Map sheet reference and location of site

c. Broad statement of site suitability

2. Geological Nature of Deposit

a. General (type, appearance, structure of materials, strike, dip)

b. Engineering properties/quality

c. Thickness

d. Quantity available

e. Area extent

f. Topography (terrain, drainage, vegetation, land use)

3. Operational Factors

a. Locations

(1) Quarry/Pit

(2) Construction site(s)

(3) Access routes

(4) Built-up areas

(5) Utilities in area

b. Site Facilities (include sketch)

(1) Working face

(2) Structures and hardstands

(3) Roads

(4) Available space

(5) Available utilities on site

(6) Available plant and equipment on site

c. Groundwater, surface water and drainage

d. Overburden and Slope

(1) Type of overburden (vegetation, soil and rock materials)

(2) Slopes

e. Environmental considerations

f. Tactical considerations

g. Security

4. Miscellaneous

5. Conclusions

a. Evaluation of material and quantity

b. Evaluation of operational requirements and site development

6. Recommendations

7. Enclosures

a. Location map

b. Site sketch and profiles

c. Geologic map and cross-section

d. Boring logs

e. Field and laboratory test results

f. Quantity calculations

g. Photographs

h. Others

CHAPTER 3

PLANNING AND OPERATION OF QUARRIES

SECTION 1

INTRODUCTION

GENERAL

1. Careful planning of the layout and operation of a quarry site is necessary because of the extensive array of equipment and personnel involved. A layout plan establishes the location and arrangement of the quarry and its support facilities while an operations plan specifies the methods and procedures to be used in the development and operation of the complex. These plans should be developed in detail prior to the commitment of resources to the site. In most cases the layout plan and the operations plan will be developed at the same time.

2. Before the commencement of detailed planning, geologic and topographic information must be assembled. This includes plans, profiles and cross-sections. Throughout the planning, consideration should always be given to the task, the site conditions, safety, the economy of resources and the ease of operations.

AIM

3. The aim of this chapter is to discuss planning and operation of a quarry.

SCOPE

4. This chapter describes general quarry terms, quarry layout, the development of the quarry and the quarry organization.

SECTION 2

QUARRY TERMS

QUARRY TYPES

1. The three main types of quarries are hillside, subsurface and terrain quarries.

2. **Hillside Quarries.** Hillside quarries are excavations which occur above the level of the surrounding terrain. These quarries offer good drainage and gravity to aid the flow of materials. They also present potential environmental problems such as noise, dust, flyrock and site restoration as well as possible access problems, if slopes are excessive.

3. **Subsurface Quarries.** Subsurface quarries are excavations which occur below the surrounding terrain. The environmental impact is generally not as great as with hillside quarries. However, drainage is usually poor and materials must be moved against the force of gravity.

4. **Terrain Quarries.** These quarries are usually temporary operations in which the existing terrain is lowered or leveled. This includes a deliberately planned rock cut for a roadway and/or for construction material.

QUARRY NOMENCLATURE

5. The following terms, which are illustrated in Figure 3-2-1, refer to the various parts of a quarry:

   a. The floor is the inside bottom surface that marks the lower limit of excavation. A working floor will be one or more levels above the final floor.

   b. Walls are the nearly vertical surfaces at the lateral limits of the excavation.

   c. The face is the rock surface (usually vertical) from which the rock is excavated.

   d. The crest is the top of the face.

   e. The toe is the bottom of the face.

   f. The bench is the rock behind a face and below a working floor. It appears to be step-like.

   g. Overburden is the waste soil and rock material which overlies the rock to be quarried while spoil is the waste material within a deposit.

METHODS OF DEVELOPMENT

6. Military quarries are usually open-pit operations which involve vertical faces from 2.4 to 12 metres high. Depending on site conditions, production requirements and available resources, quarries may be developed by the single or multiple bench method.

7. **Single Bench Method.** Single bench quarries have only one working floor or operating level. Most military quarries are of the single bench type because they are safer and easier to plan, develop and supervise. They also require less equipment, personnel and training to operate than multiple bench quarries. Unless (or until) such quarries are large enough to accommodate several blasting and loading points, they tend to be

relatively inefficient where high rates of production are needed.

8. **Multiple Bench Method.** Multiple bench quarries have two or more working floors or operating levels arranged in a step-like fashion. Because each level can operate more or less independently, rock is produced more efficiently. Multiple bench quarries require careful planning, complex road networks, closer supervision and more operating personnel and equipment than single bench quarries.

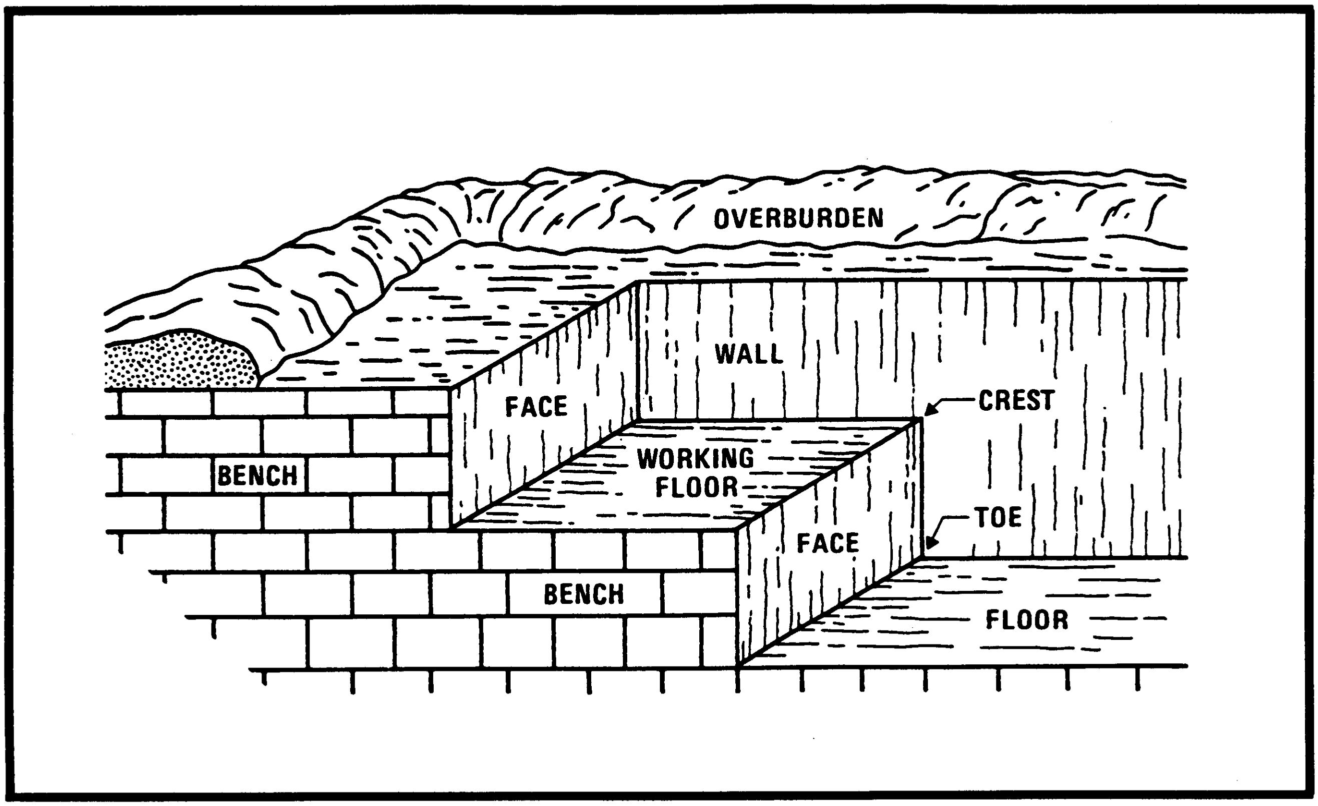


Figure 3-2-1   Quarry Terminology

SECTION 3

QUARRY LAYOUT

GENERAL

1. The quarry layout plan establishes the location, dimensions, and arrangement of the quarry and its supporting roads and facilities. This plan ensures that adequate space is provided for all future activities, that the flow of materials will be as safe and efficient as possible, and that personnel and equipment requirements are recognized and provided for.

DIRECTION OF WORK

2. **General.** The first step in layout planning is to determine the best direction in which to work the quarry. Regardless of the actual dimensions of the final excavation, the working face (or faces) of the quarry should be oriented to minimize the undesirable influences of the rock mass to be excavated.

3. **Massive or Horizontal Rock.** Internal structure bias no impact on the direction of work in unfractured, massive or horizontally layered rocks. Other criteria such as site topography, access or overburden variations may therefore be used to determine the best orientation of the quarry face.

4. **Slightly Inclined Rock.** Where the rock mass contains parallel layers or fractured surfaces which are slightly inclined, the quarry face should be oriented parallel to the strike of the rock so that work may proceed up the dip of the sloping rock surfaces. The bedding or fracture planes can thus be used to help maintain an even, well-drained quarry floor.

5. **Steeply Inclined or Folded Rock.** Where rocks are folded or contain steep inclined layers or fractures, the quarry face should be oriented at right angles to the strike of the rock structure as shown in Figure 3-3-1. This makes it easier to maintain a vertical face and reduces drilling requirements and safety hazards. If the quarry face is oriented parallel to the strike of the rock (with rock layers or fractures inclined toward or away from the face), problems with extended toes (Figure 3-3-2), dangerous overhangs (Figure 3-3-3), rockfalls and rock slides will be encountered along the entire width of the quarry face.

6. **Vertical Rock Layers.** Where rock layers are essentially vertical, the quarry face may be worked either parallel to the strike (to aid in maintaining an even face) or perpendicular to the strike (to aid in maintaining even quarry walls). Blasting is usually more efficient when the face is parallel to the strike.

QUARRY DIMENSIONS

7. **Bench Height.** The greatest influence on the decision as to what bench heights are best suited to the quarry operations are equipment limitations and geologic conditions.

   a. The characteristics of common rock drills are given in Figure 3-3-4. Most quarry operations employ track-mounted drills equipped with sectional drill steels, from 3.0 or 3.7 metres long, which can be coupled as required. Drill holes are usually subdrilled 0.6 to 0.9 metres below the quarry floor to assure complete rock fragmentation between holes during blasting. For convenience, benches are often planned to accommodate some unit number of drill steels (usually 2 to 4). Since drill efficiency decreases about 20 per cent for each additional length of steel used, lower benches are usually preferred when drilling is difficult, as with extremely hard or unfavorably fractured rock. Lower benches are also preferred where rockfall and rockslide hazards exist along the face and where front-end loaders (FELs) are used in loading blastrock after blasting.

b. Where layers of undesirable material occur within a deposit, benches should be planned so that the undesirable and desirable materials may be excavated separately to prevent contamination of the quarry product. Level bedding or fracture surfaces may also be used to define benches. Such surfaces reduce subdrilling requirements and aid in maintaining an even quarry floor.

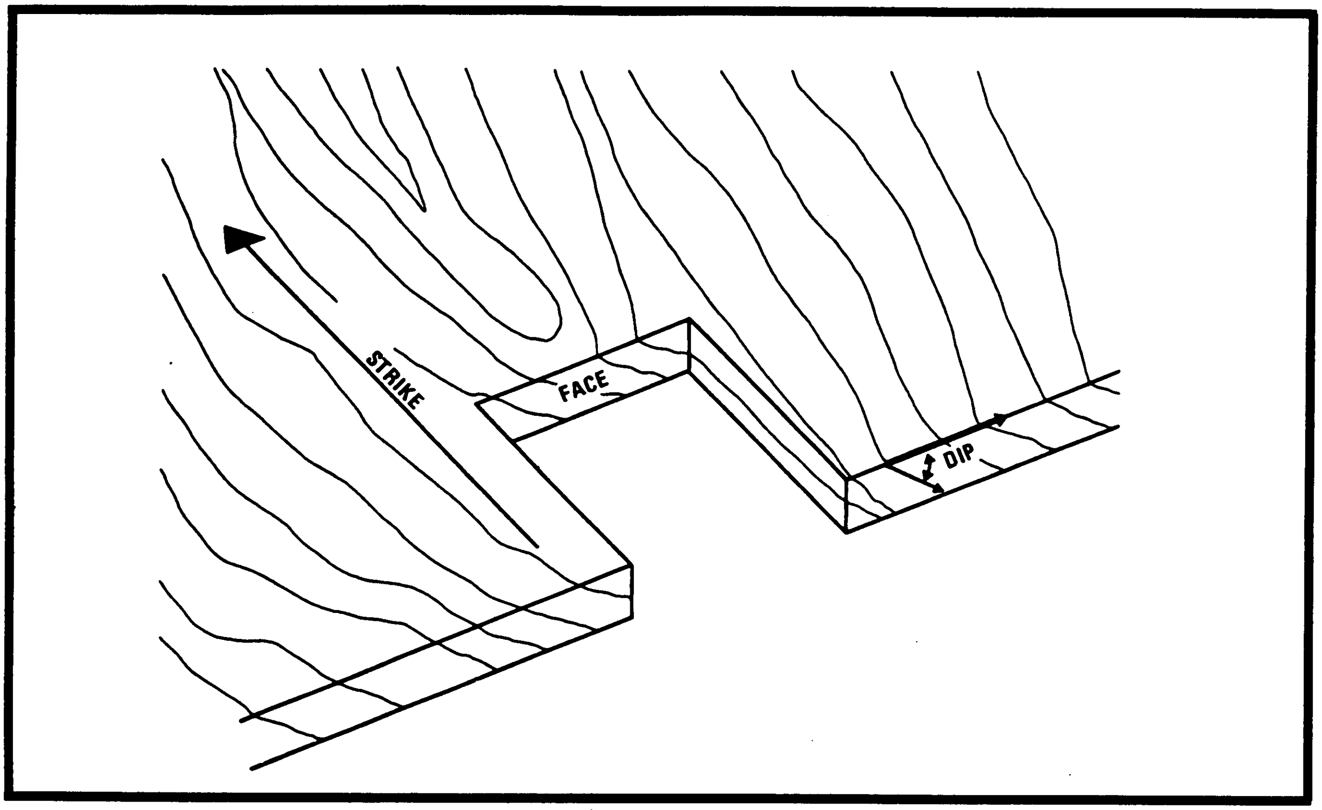


Figure 3-3-1 Quarry Face in Folded or Steep Inclined Layer

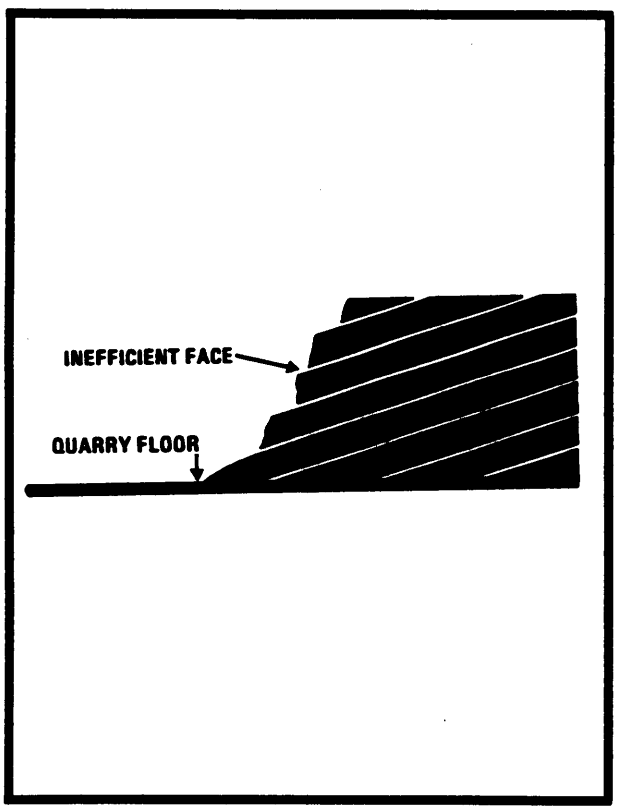


Figure 3-3-2 Extended Toes

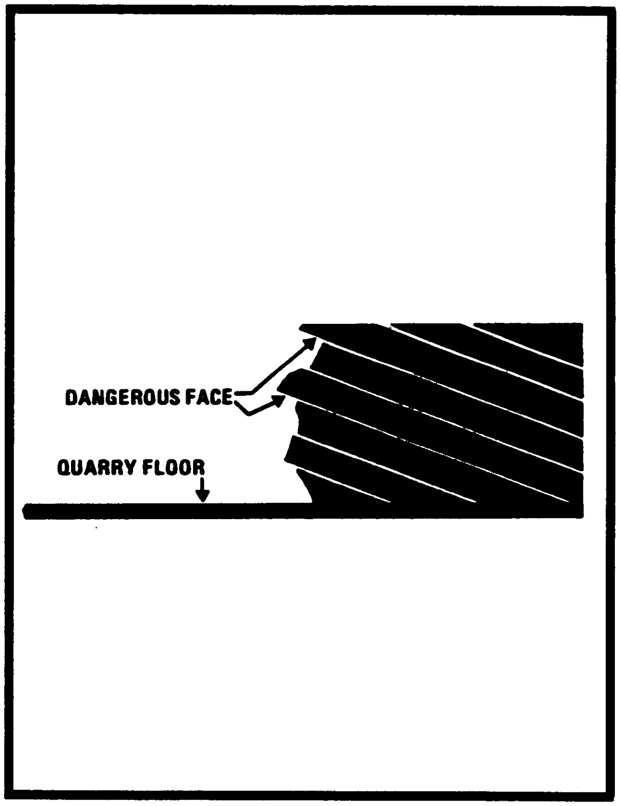


Figure 3-3-3   Dangerous Overhangs

Drill Type	Bit Diameter	Normal Drilling Depth	Maximum Drilling Depth
Hand-held	4.1 to 5.1 cm	1.8 to 2.4 m	3 m
Wagon-mounted	5.1 to 7.6 cm	3 to 6 m	7 m
Track-mounted	7 to 10.2 cm	6 to 12 m	More than 16 m

Figure 3-3-4 Characteristics of Common Rock Drills

8. **Face Width.** As a minimum, quarry faces should be wide enough to meet daily blastrock requirements and not narrower than the turning radius of the rock loading equipment. This radius normally ranges upward from 15 metres. Faces wide enough to provide blastrock for at least several days of operation are preferred since weather conditions or other considerations may interfere with blasting schedules.

9. **Final Dimensions.**

a. The quarry floor is the ultimate bottom of the quarry and is determined by the geology, rock requirements and area restrictions. This ultimate bottom may be achieved in several lifts or working floors in the case of a multiple bench quarry. For example, if it is determined that the rock must be excavated to a depth of 18 metres over a given area in order to obtain the required volume of rock and that the optimum bench height is to be 6 metres, then the quarry floor will be exposed at the third lift. Geologic factors which may limit the depth of a quarry include the depth to the water table and the thickness of usable material. It may be possible to work below the water table in some cases, but well defined and effective plans must be made to control water in the quarry throughout the operation. Area restriction, as a limiting factor, is particularly applicable to subsurface quarries. In planning the layout of a quarry, particularly a subsurface quarry, the minimum length of a uniformly sloping access road is equal to the depth of the quarry divided by the grade limitation of the loaded haul equipment (10 per cent is usually a good figure for trucks). For example, if trucks are to be used to haul from a quarry 18 metres deep, the approximate minimum length of haul road required to leave the quarry will be:

$$\frac{18\text{ m}}{0.10} = 180\text{ m}$$

b. After the level of the quarry floor has been determined, the surface dimensions of the quarry are determined based on the total rock volume required as follows:

$$\text{Total bench area required} = \frac{\text{Total rock volume required}}{\text{Average bench height}}$$

For example, if a bench 10 metres high is to be used and the total volume of rock to be quarried is 1,500,000 cubic metres, then:

$$\frac{1{,}500{,}000\text{ cubic metres}}{10\text{ metres}} = 150{,}000\text{ square metres}$$

of bench surface is required. In determining the surface dimensions of a quarry, consideration should be given to the optimum length and width for minimum overburden removal, the traffic patterns and access road requirements, the boundary limitations, and the proximity of inhabited dwellings or structures subject to blast damage.

OVERBURDEN

10. **General.** Overburden should be disposed of in a place where it will not have to be handled a second time and will be clear of all areas planned for future use. Normally, overburden should be piled to the right and/or left of the longitudinal axis of the quarry. On hillside sites, it should be piled on the downhill side, outside the quarry area. For safety reasons, overburden should never be piled within 16 metres of the quarry rim. In planning overburden disposal, consideration should be given to the relationship of spoil areas to drainage plans as well as the possibility of using the overburden as construction fill.

11. **Grubbing and Clearing.** If the quarry site is wooded, the first operation in preparing the site is to clear all timber and brush. Brush can usually be disposed of by burning (provided it is environmentally acceptable), but larger timber should be moved clear of the site boundaries. Suitable timber should be stockpiled for possible future use in the construction of headwalls and loading ramps. All stumps and large boulders should be excavated and removed from the site. Figure 3-3-5 summarizes the limitations and correct application of engineer equipment for clearing operations. It is sometimes necessary to use explosives to clear the area, especially when the terrain precludes or seriously impedes the operation of heavy equipment. For details on clearing trees and stumps with explosives, refer to B-GW-320-009/FP-002, Engineer Field Manual, Volume 9, Demolitions, Part 2, Engineers and Assault Pioneers.

12. **Stripping.** Stripping overburden is essentially an earthmoving function which may be undertaken using dozers, scrapers, draglines, power shovels, front-end loaders with dump trucks or any combination of these. It may be necessary to use a ripper to loosen the overburden before removing it. (Ripping techniques are discussed in Annex A to this chapter). Frozen material may be loosened with either a ripper or with explosives. Excavation in frozen ground is addressed in detail in Chapter 7.

13. **Timing.** Although overburden removal is one of the first operations to start, it need not be completed before quarrying begins. Once the best approach in establishing the face has been determined, overburden removal should be concentrated in the approach area to allow quarrying to begin with the least delay. Once rock excavation begins, overburden removal operations may be reduced in intensity to keep pace with the day-to-day requirements for rock production.

SER	EQUIPMENT	APPLICATIONS	LIMITATIONS
1	Dozer	Primary equipment for all land clearing. Excellent for removing brush and trees and stumps up to 250 mm in diameter; can remove trees up to 760 mm in diameter. Push, pull or skid material for disposal.	Trees over 250 mm in diameter require special and slower methods of removal by dozer. Manoeuvrability limited in muddy terrain and in dense, heavy growth.
2	Winches, (towing) tractor-mounted	For general light and medium pulling. Uprooting trees and stumps up to 6 10 mm in mounted diameter. Skidding cleared material for disposal. Extricating mired equipment.	Pulling capacity limited by size of tractor. Terrain affects manoeuvrability of tractor. Rigging personnel required.
3	Winches, truck-mounted	Expedient for light pulling of trees up to 150 mm in diameter. Skidding small trees and brush. Extracting mired equipment.	Terrain must be suitable for truck use. Pulling capacity too limited for most operations.
4	Felling equipment	Controlled felling of almost unlimited diameter.	Other units required for uprooting stumps and disposing of felled timber.
5	Chain saw	Sawing timber for salvage. Rapid felling.	Pneumatic saw requires truck-mounted air compressor.
6	Circular or chain saw mounted on tractor	Controlled felling of trees up to 1.3 m in diameter. Sawing timber for salvage. Rapid felling. Excellent for clearing heavy, dense growth in rough and broken terrain.	Gasoline-powered saw too heavy for carrying when doing extensive, rough clearing. Other units required for uprooting stumps and disposing of felled timber. Manoeuvrability limited in muddy and swampy terrain.
7	Ripper	Cutting free roots. Loosening surface boulders. Loosening soil for stripping.	Depth of shank penetration limits use to shallow root. Manoeuvrability limited in muddy or swampy terrain and in dense or heavy growth.
8	Grader	Light clearing of grass, weeds, and small brush and vegetation. Clearing windrowed material. Grading for drainage.	Manoeuvrability limited to terrain free of trees, stumps and boulders. Careful operation required to prevent damaging blade.
9	Scaler	Light clearing of grass, weeds and light under-growth. Hauling and disposing of light cleared material. Grading cleared area for drainage.	Manoeuvrability limited to level terrain free of trees, stumps and boulders. Slow and special techniques required for loading stumps and boulders.

Figure 3-3-5 Applications and Limitations of Engineer Equipment for Land Clearing

HAUL AND ACCESS ROADS

14. **Design.** Roads to the rim of the quarry should follow the shortest and easiest route practicable. Grades should be limited to a maximum of 10 per cent for truck operation, and curves should have sufficient radius to

minimize delay in hauling. As a guide, roads should be designed for safe negotiation at not less than 30 kilometres per hour by a loaded dump truck. Two-way roads to and from quarry areas are usually adequate; however, one-way loop roads are essential within quarries so that the routes of loaded and empty trucks do not cross. A straight ramp, a spiral ramp or switchbacks may be needed to maintain acceptable access from the boundary of the quarry to the working face.

15. **Standard.** Access roads to the vicinity of the quarry and plant should be constructed in the manner described in B-CE-320-012/FT-002, Engineer Field Manual, Volume 12, Horizontal Construction, Part 2, Roads. Usually the access roads, or portions of them, will also be the haul roads from the quarry to the crusher and from the crusher to the construction site(s). Careful consideration should be given to the types and amount of traffic to which the roads will be subjected. For example, the access road to a quarry using a 1.5 cubic metre power shovel must be designed to carry a load in excess of 54 000 kg. Roads should be surfaced with crushed rock and drained to reduce maintenance requirements. To reduce wear and tear on tires, the road surfaces should be kept smooth by constant shaping with a grader and should be kept free from large pieces of quarry-run rock. Water and dust palliatives should be applied to control dust in dry weather.

DRAINAGE

16. Precipitation and seeping ground water must be drained away from the quarry face and other working areas. The working floor of the quarry should slope away from the face to prevent water accumulation in the blasted rock and loading areas. A 3 per cent slope is adequate. In a hillside quarry, water will drain naturally by gravity flow. However, in a subsurface operation, it will be necessary to provide a collection point (sump) where water can be accumulated for pumping. Sumps should be located away from traffic areas or any other area that would interfere with efficient operation.

EQUIPMENT POSITIONING

17. **General.** Equipment should be positioned to ensure efficient operations. This is achieved by placing equipment so that it will be moved as little as possible. It must also be safe from blasting or other activities. The placing of equipment should also take advantage of gravity flow and should minimize the double handling of material. Figure 3-3-6 shows a typical small scale quarry complex.

18. **Air compressors.** Most rock drills are powered by air compressors mounted on trailers, wheels, tracks or skids. The air compressors can be moved around with the drills they support. For deliberate operations of long duration it is more desirable to permanently station the compressors and to connect them in a manifold system, as shown in Figure 3-3-6.

19. **Rock Crushers:**

a. The rock crushing, screening and washing plant should be located close to the quarry, but not so close as to be endangered by quarry blasting. By locating the plant as close to the quarry as possible, maximum use of hauling units can be made. This is important because the raw material from the quarry contains both product and by-product material, while the material hauled from the plant to the construction site contains only product size material. If the crusher can be located close enough to the face, dozers may be able to push blastrock directly to the crusher loading chute; otherwise, both loading and hauling equipment will be needed. Ensure that the plant is not located in the path of future excavation.

b. The actual plant site should be located on stable ground and should be large enough to accommodate the plant and related equipment (conveyors, bins, generators), stockpiles of crushed rock, and loading operations. The terrain should be conducive to heavy equipment operations with only minor earthwork improvements and should be sloped to provide good natural drainage. Proper utilization of a hillside location may permit the use of gravity as an aid in moving material from the face to the plant, from the plant to a storage area or from a storage area to haul units. The site should be accessible to construction operations and, if aggregate is to be washed, close to a source of water.

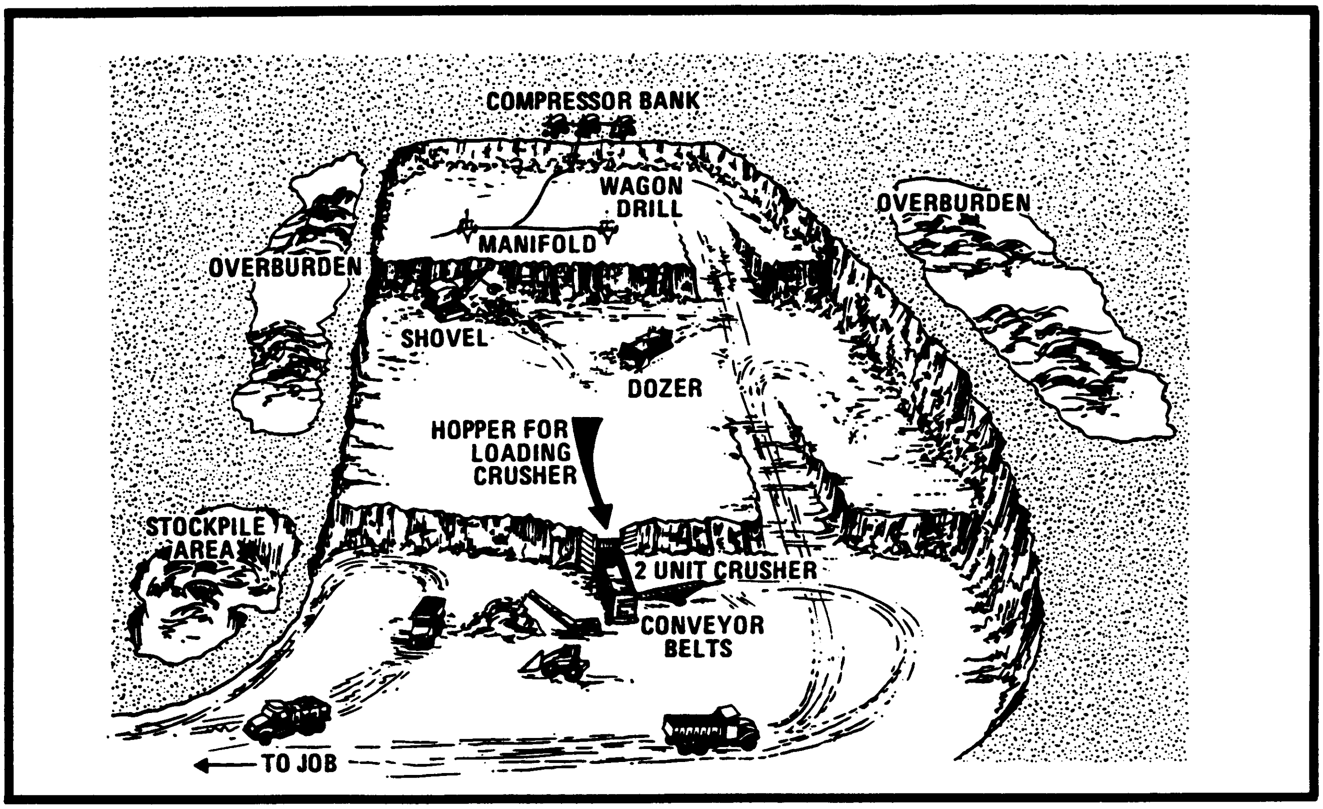


Figure 3-3-6 Layout of a Typical Small-Scale Quarry Complex

20. **Generators.** Most rock processing plants are powered by electricity. If power must be generated on site, the generators should be located under shelter near, but upwind from, the plant.

MATERIALS HANDLING AND STORAGE FACILITIES

21. **General.** Plans for the plant should include adequate material handling devices to expedite the flow of material through the plant and to eliminate double handling of material. Gravity flow-through chutes should be used where possible to eliminate the need for loading and hauling units.

22. **Headwalls and Loading Ramps.** Two levels are normally used for the crushing operation as shown in Figure 3-3-7. Quarry-run rock is dumped directly into the apron feeder or into a loading chute by trucks or dozers from the quarry at the upper level and processed through the plant on the lower level. For operations of short duration, material may be fed into the apron feeder by means of a clamshell, dragline or power shovel. These alternate methods, however, involve double handling of the material and are far less efficient. They also create more safety hazards in the plant area. If a suitable bench is not available, a compacted fill or crushed-rock loading ramp, with a headwall, will have to be constructed. Support for the headwall may be provided by piles. Piles may be driven into the ground or concreted in place. They may be concreted in individually drilled holes or in a continuous footing.

23. **Grizzlies and Scalping Screens.** Grizzlies are very coarse screens for sizing quarry-run rock before it reaches the crushing plant. They consist of a durable, rigid, rectangular frame with steel rails spaced at intervals determined by the crusher opening. If a problem with oversize or undersize material is expected, a pro-screening grizzly (or scalping screen) should be built in the quarry to remove the oversize or undersize rock before the rock is hauled to the plant. If this cannot be done, it may be necessary to construct a scalping screen over the apron feeder of the primary unit of the plant. In this case adequate space must be provided to stockpile the undesirable material until it can be transported to an area for secondary breakage or disposal.

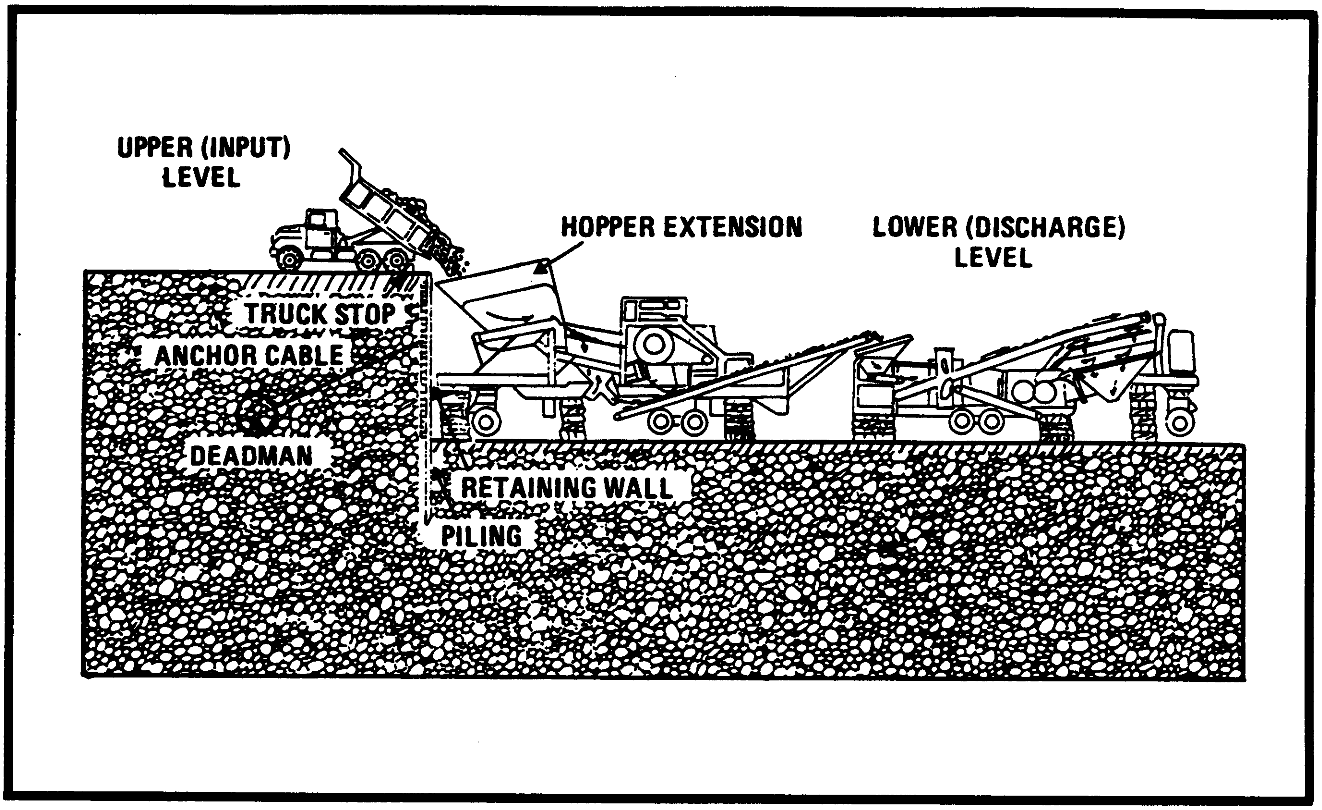


Figure 3-3-7 Crusher Set-up Showing Two-Level Operation

24. **Surge Piles.** Surge piles of material ready for use should be located at each step in the rock processing operation so that all units may operate at full capacity and continue in operation despite interruptions in the normal flow of material. For example, a surge pile of quarry-run material should be convenient to the apron feeder of the primary crusher so that a dozer or front loader can load the crusher when haul units are not on hand. Normally this surge pile should contain enough material to sustain operations for several days should inclement weather, maintenance or quarry blasting interrupt hauling from the quarry. In some cases, surge piles may have to be planned to sustain operations much longer, such as for an entire winter or monsoon season. Often surge piles are planned to allow for late arrival or early release of some elements of the operation, such as blastrock stockpiled for crushing at some future date.

25. **Bins.** When possible, quality product-size material should be stored in elevated or inclined storage bins rather than in open stockpiles. Bins prevent contamination of the material by wind-blown dust and trash and allow complete recovery of the product without double handling. Rock fed into the top of a bin from the crusher may be discharged into hauling units through a trap door in the bottom of the bin. If bins are not available, they may be constructed of wood or metal.

26. **Stockpiles.** If bins are not used, product-size material may be placed on open stockpiles. If more than one product is being produced, each product pile should be separated by distance or headwalls from all others to prevent contamination. Specially screened or washed products should be stored upwind from the plant to

minimize contamination by wind-blown dust. Material from the plant may be placed on the stockpiles by conveyors, dozers, trucks or some combination of these. When planning stockpile locations, adequate space must be allowed for storage. Enough room must be planned on the front side of the piles to load haul units without causing traffic congestion.

OTHER FACILITIES

27. **Water Supply.** If water is required for washing aggregates and there is not a stream or lake nearby, a well may have to be drilled and ponds dug to store the water. For a recirculating water system, one pond is needed for a reservoir and one pond for a settling basin. Water from the reservoir is pumped to the washing unit, used, and then discharged into the settling basin where the dirt, fines and organic material are allowed to settle out. Clean water from the settling basin is then allowed to overflow back into the reservoir. A similar arrangement may be required where stream flow is unreliable and a dam is used to create the needed reservoir. Even where permanent streams or lakes are used as reservoirs, a settling basin should be constructed to protect surface water supplies from contamination.

28. **Typical Layout.** Figure 3-3-8 shows a typical layout for a long duration rock processing plant.

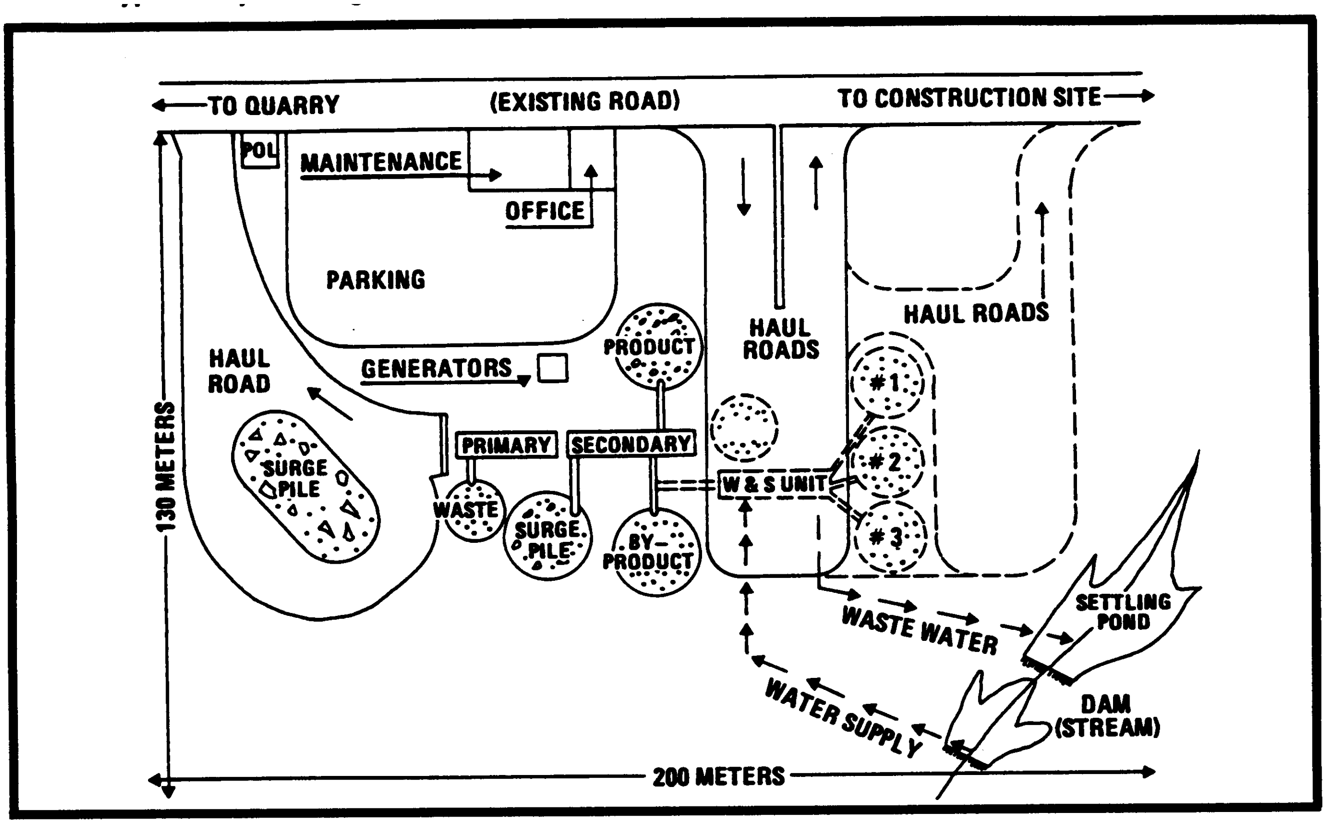


Figure 3-3-8 Typical Layout for a Long Duration Rock Processing Plant

29. **Maintenance Areas.** Maintenance hardstands, work shelters and repair parts storage facilities should be convenient to both the quarry and plant areas and upwind from all major sources of dust. They should be located on the internal road net so that heavy equipment will not have to be taken out onto primary roads for repair. In addition to normal repair and maintenance capabilities, the on-site maintenance facility should also be equipped for heavy-duty welding to repair shovel tracks and dippers, rebuild crusher jaws and rolls, repair truck beds, and for numerous other repair jobs that occur frequently. Provision should also be made for repairing tires, sharpening drill bits and reconditioning drill steels. On large sites, trucks should be used to provide routine maintenance services directly to the operating equipment.

30. **Quarry Office.** A building or shelter should be provided along the access road to the plant where the plant officer can keep records on plant production, maintenance and deliveries.

31. **Explosive Storage Magazines.** Quarry blasting materials should be stored in clean, dry, well-ventilated, reasonably cool, and bullet-proof and fireproof shelters. For convenience and safety, the magazines should be readily accessible to the quarry but a safe distance from each other and from any other installation likely to be endangered by an accidental explosion. Blasting caps should never be stored in the same magazine with other explosives.

32. **Power and Lights.** If a quarry or plant is to be operated during the hours of darkness, provision for a pole-mounted lighting system should be made. Commercial electricity or on-site generating equipment may be used for power. Usually, portable installations are used within the quarry while permanent lights are used in the plant area. All power lines must be strung high enough to clear all traffic.

33. **Miscellaneous.** During site layout planning, consideration should also be made for the requirements for latrines, POL storage, parking, communications and site security.

SUMMARY

34. The establishment of a quarry layout plan is important because it describes how the site will develop for production. It specifically establishes the direction the work will progress and defines the necessary dimensions. It also accounts for drainage and establishes overburden removal, haul and access routes, and equipment, materials handling and storage facilities as well as other miscellaneous facilities.

SECTION 4

QUARRY DEVELOPMENT

GENERAL

1. The development of a site consists of preliminary and continuing work to achieve the desired layout. This section covers the initial stages of development and includes all the steps leading up to the establishment of a bench at the planned height and the completed installation of the crushing and screening plant. The steps include the selection of blasting versus ripping for rock excavation, the preparation of the operations plan, the installation of the crushing and screening plant and the establishment of a working face and floor.

SELECTION OF BLASTING VERSUS RIPPING

2. **General.** Rock may be excavated in quarry operations by either blasting or ripping. The factors that should be considered in selecting the excavation method include the type and availability of equipment, the availability and training requirements of personnel, geological factors, and proximity and tactical restrictions.

3. **Equipment Available.** The availability of the required equipment is a factor in the selection process. Although a large dozer with a ripper attachment is normally used, it is not uncommon in hard rock to use a second dozer that provides additional blade weight on the ripper and forward thrust to the first dozer. This is called tandem ripping. The drilling and blasting equipment required includes compressors and drills. The availability of sufficient quantities of explosives and accessories is necessary for blasting. If the required equipment for both options is available, some other considerations may then influence the selection.

4. **Geological Factors:**

   a. Very often it cannot be conclusively determined whether or not rock can be ripped. On-site trials may be necessary to determine the feasibility of ripping. However, consideration should be given to the physical characteristics of the rock that is to be worked.

   b. The following physical characteristics favour ripping:

      (1) closely spaced fractures, faults and planes of weakness;

      (2) weathering, resulting from temperature and moisture changes;

      (3) brittleness and crystalline nature;

      (4) a high degree of stratification or lamination;

      (5) large grain size;

      (6) the presence of moisture permeated clay and shale; and

      (7) low compressive/shear strength.

   c. Ripping will be difficult and blasting is favoured if the rock formation is:

      (1) massive and homogenous;

(2) non-crystalline and, therefore, not brittle;

(3) without planes of weakness;

(4) fine-grained and has a cementing agent;

(5) of clay origin where moisture may impede ripping because it makes the material plastic.

d. Usually the first ripping pass is the most difficult. Succeeding passes are easier because the material can move into the loosened area created by the previous pass. Therefore, in a ripping trial, the decision to blast should not be based on the poor performance of only the first ripping pass.

e. A refraction seismograph can be used as an aid to determine rippability of materials. It indicates the degree of consolidation, including such factors as rock hardness, stratification, degree of fracturing and amount of decomposition or weathering. This method is based upon the amount of time it takes for seismic waves to travel through different kinds of material. The equipment required to implement this method is not usually available to field units, therefore, the method is not elaborated upon. The equipment would be held by specialist higher formation units.

5. **Personnel.** The number of personnel required for ripping is generally less than the number required for drilling and blasting. Qualified equipment operators are required for ripping while trained compressor, drill and demolition personnel are required for blasting. Demolition safety precautions require a great deal of attention by qualified supervisors and personnel.

6. **Proximity Restrictions.** The proximity of the site to other facilities may restrict blasting operations because of the strength of the blast wave, flyrock, safety or noise. Proximity restrictions generally do not affect ripping operations.

7. **Tactical Restrictions.** Tactical operations may restrict the employment of either method. Noise, flyrock and the blast wave may limit blasting operations to specific hours, if not altogether. Because a dozer is a very valuable piece of equipment in wartime operations, the commander may not provide assurance that it is unconditionally grouped to the quarry commander. The sudden regrouping of a dozer may result in an uncertainty which may favour blasting operations.

8. **Techniques.** A description of the techniques used in drilling and blasting is found in Chapter 4, while ripping techniques are described in Annex A to this chapter.

OPERATIONS PLAN

9. **General.** Once the layout of the quarry site has been determined, a detailed operations plan should be prepared. This plan should specify the methods and procedures to be followed for the entire life span of the quarry. It should take into account the factors of required production, available equipment, site conditions, maintenance requirements, safety requirements, tactical requirements and troop availability and training. A general outline for the operations plan should include the areas of development, rock excavation operations, materials handling, crushing and screening operations, and miscellaneous items.

10. **Development.** This should include:

a. overburden removal (limits, depth, method of removal, location of overburden);

b. construction of access roads, loading ramps and structures as necessary;

c. installation of crushing and screening plant (and related rock processing equipment);

d. installation of compressor manifold systems;

e. development of quarry face and floor including the limits of this development;

f. development of a drainage plan;

g. development of a surge pile and bins/stockpiling plan;

h. development of a utilities plan;

j. administrative site development plan (lights, equipment maintenance site, offices, POL, parking, communications, security, explosives); and

k. allocation of equipment and personnel for site development.

11. **Rock Excavation Operations.** These operations should include:

a. continued overburden removal;

b. drilling and blasting patterns and sequence, and blasting records and procedures or ripping patterns and sequence;

c. equipment and personnel allocation; and

d. equipment maintenance.

12. **Materials Handling.** This should include:

a. loading equipment and accessories,

b. hauling equipment, and

c. maintenance cycle.

13. **Crushing and Screening Operations.** This should include production records and maintenance cycles.

14. **Miscellaneous.** These items include:

a. daily/shift routine,

b. records submission,

c. production meetings,

d. safety and medical plan, and

e. other items.

PLANT INSTALLATION

15. **General.** Work should be started on the installation of the crushing and screening (and washing) plant as soon as possible after the site becomes accessible. Work can then progress simultaneously with the construction of access roads and opening of the quarry.

16. **Site Preparation.** Plant site preparation consists of the following basic steps:

a. **Preliminary Earthwork.** The lower level of the site is initially cut to the proper grade and dimensions. A predetermined portion of the excavated material may be deposited above the planned headwall anchorage for later use in backfilling behind the retaining wall. (See Figure 3-3-7.) Following completion of the earthwork on the lower level, work may begin on the crusher headwall. Where necessary, earthwork may also include the excavation of water storage and settlement ponds.

b. **Hardstands.** Plant equipment should be stationed on stable hardstands which are capable of supporting the weight and vibration of the plant without settlement. Ideally, hardstands should be constructed of reinforced concrete, but this is seldom practical in the theatre of operations. A primary crusher can be used to provide base course material for hardstands. This material should be levelled and compacted to provide adequate support.

17. **Stationing the Plant.** Although crushing and screening plants can be operated from their wheelbase for short periods, it is better on longer and more deliberate jobs to block the plant with the tires clear of the ground. 305 mm by 305 mm timber cribbing or other suitable material may be used for this purpose. Before crushing operations begin, the plant should be levelled from end-to-end and side-to-side. Otherwise, material will be channeled along the low side or end of the plant and increase wear and tear on the equipment.

18. **Hopper Extensions.** If material is to be dumped directly into the apron feeder of the primary crusher unit, extensions must be welded onto the hopper to increase its width to approximately 1.25 times that of the truck beds.

19. **Loading Chute.** A loading chute, as pictured in Figure 3-4-1, is used when a suitable bench greater than 5.5 metres in height is used or when a loading ramp is to be constructed. This chute may also be used with a grizzly at the crusher site to reduce the material fed into the jaw crusher to 75 per cent of the jaw dimensions. For very high headwalls, the use of an inclined chute allows equipment to operate at a greater distance from the edge of the wall, thus reducing the earth pressures against it.
Whenever chutes, bins or hoppers that have control gates are used to handle large rock, they should be kept one-third full so that the impact of failing rock will be absorbed without damage to the structure or equipment.

QUARRY DEVELOPMENT

20. **Profile.** To determine the location of the initial quarry face, a plan and several cross-sections showing the surface configuration and structure of the rock in-place should be drawn across the length and width of the site. Elevations on these drawings should be referenced to a bench mark outside the actual quarry. After profiles of the rock surface have been plotted, the first working level is superimposed at a depth equal to the planned bench height. The intersection of a line from the floor or up the access ramp to the existing grade is the point

where excavation should begin. Initial and subsequent working floors should be selected carefully to ensure that continued development of the site will proceed smoothly. Overburden removal, access construction, traffic patterns and rock excavation plans must be coordinated.

a. **Steeply-sloped Sites.** On steeply-sloped hillside sites, excavation should normally begin at the uppermost working level as shown in Figure 3-4-2. Subsequent, lower working levels may then be established as the upper working level approaches its intended dimensions or as soon as it has been excavated enough to provide sufficient working space for further operations.

b. **Gently-sloping Sites.** Excavation should normally begin at the level of the final working floor when quarries are established on gently-sloping sites. As excavation progresses, higher working floors should be established when the previous benches reach their intended working heights.

c. **Subsurface Sites.** Like steep hillside quarries, subsurface quarries should be excavated from the top down. As each lift has been sufficiently excavated or is near completion subsequent lower levels may begin. Excavation plans should include provisions for access ramps and drainage sumps as shown in Figure 3-4-3.

21. **Cut Design.** Open-pit quarries are normally operated with vertical faces for ease in drilling and blasting the rock. Figure 3-4-2 and 3-4-3 show toe cuts and ramp cuts used to establish the initial, vertical quarry face. In addition to this, full face cuts parallel to the strike of the rock may be needed during the initial development of a site. Chapter 4, Sections 4 and 5, describe the details of blast hole preparation and blast hole design for the patterns of initial quarry development described in this paragraph.

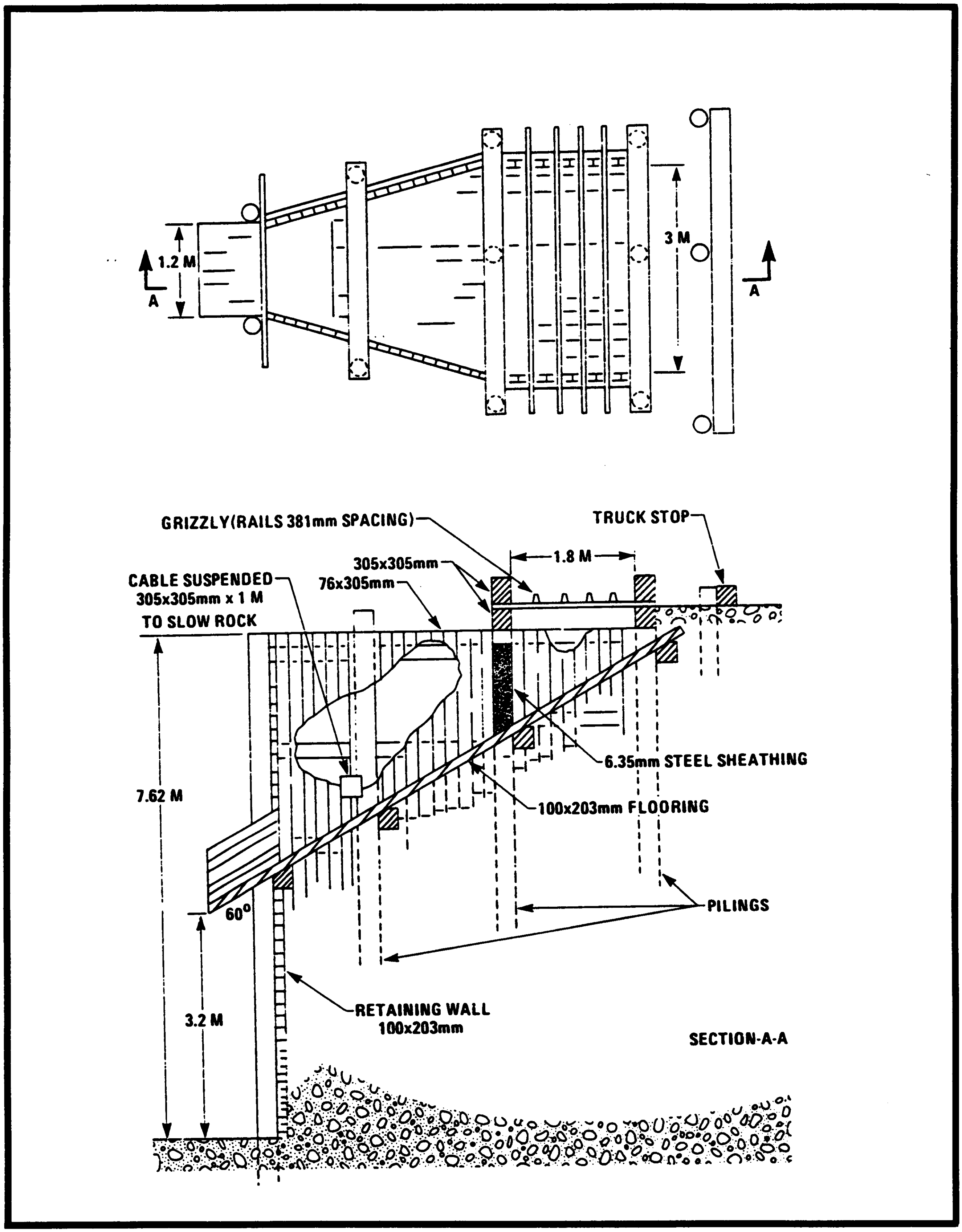


Figure 3-4-1 Loading Chute with Grizzly for Use with a Primary Crusher

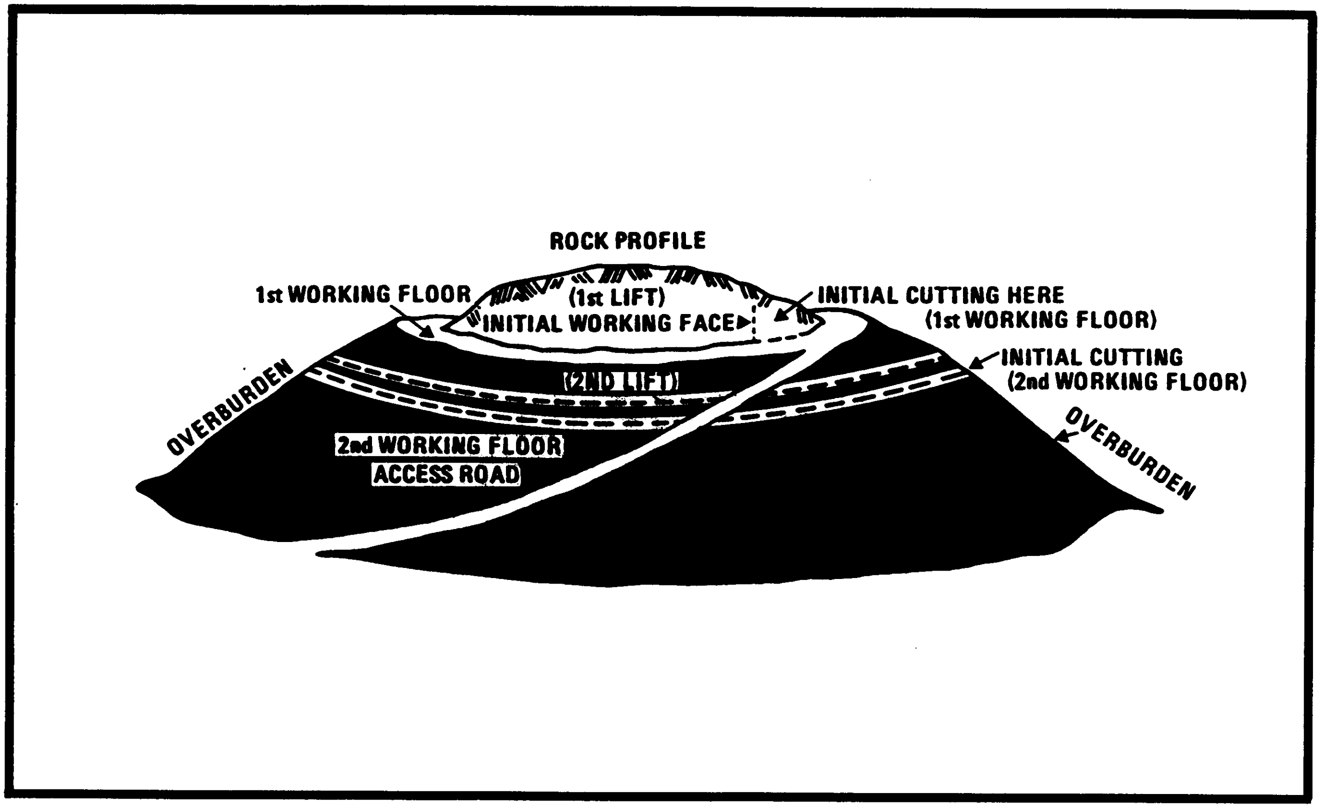


Figure 3-4-2 Opening a Hillside Quarry

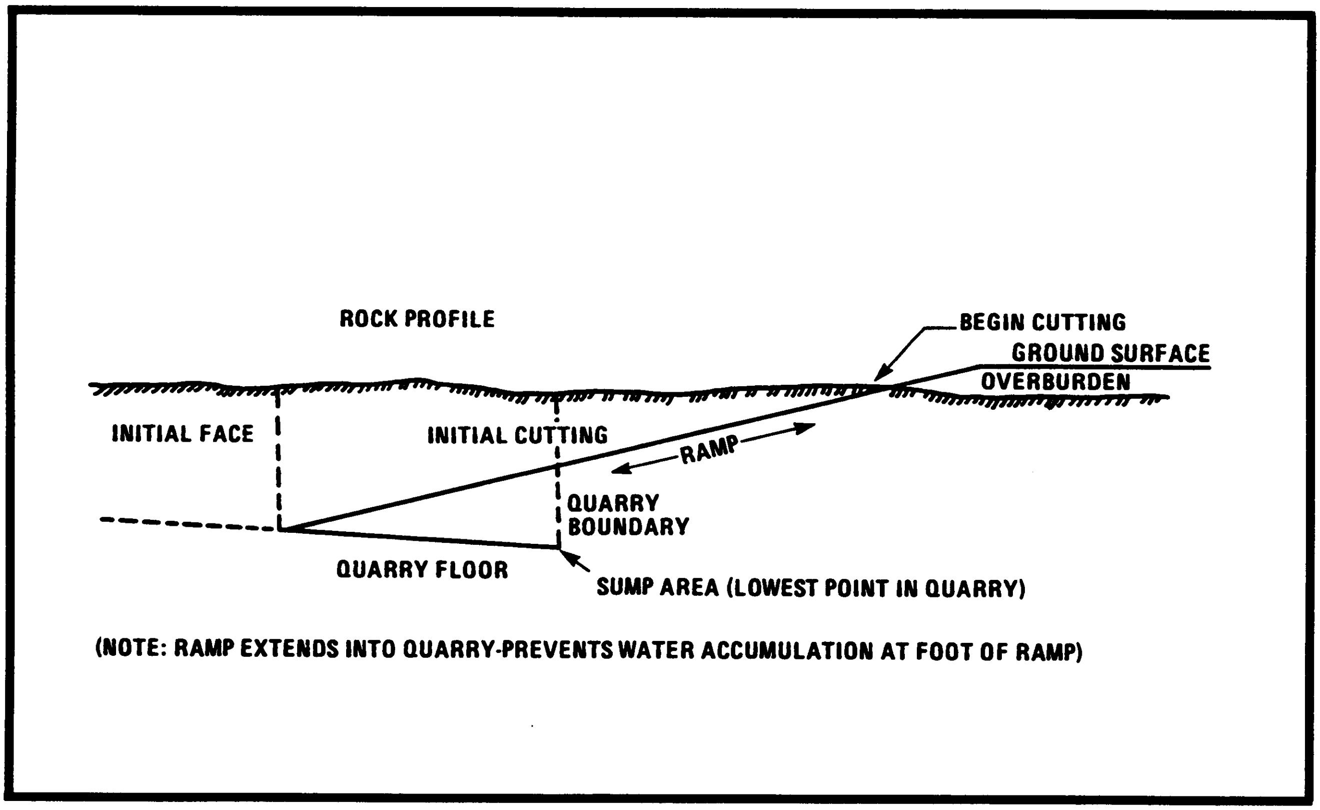


Figure 3-4-3 Opening a Subsurface Quarry

b. **Toe Cuts.** Unless the rock in a hillside or terrain quarry has a vertical face, it will be necessary to remove a toe of rock to begin quarrying. This requires the use of different types of holes, as shown in Figures 3-4-4 and 3-4-5. The method shown in Figure 3-4-4 is preferred because it usually gives better control over rock fragmentation and displacement. However, the method shown in Figure 3-4-5 involves fewer set-ups. All vertical, inclined and lifter holes should be subdrilled from 0.3 to 0.9 metres below the final grade to ensure that the rock between holes will be broken to the desired grade line.

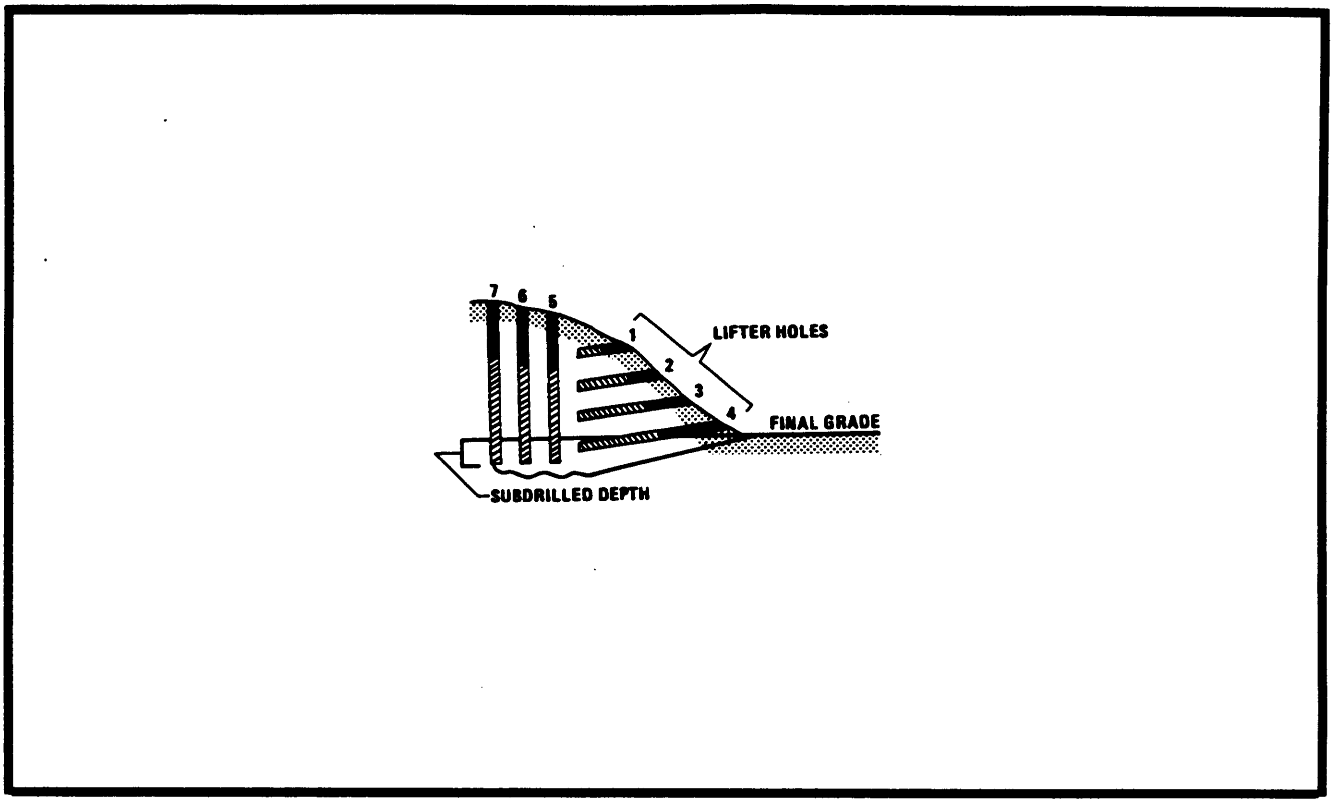


Figure 3-4-4 Toe Removal by Horizontal and Vertical Blastholes.

b. **Ramp Cuts.** Figure 3-4-6 shows a suggested initial blast pattern for excavating a ramp into a subsurface quarry by establishing a vertical face in the first blast. Use of this method allows the easiest possible loading of blasted rock. An alternate method is to establish a vertical face near the low end of the ramp using a V-cut or a pyramid cut (Figures 3-4-7 and 3-4-8). Blasting may then proceed simultaneously up and down the ramp. The blasts at the lower end after the first V-cut or pyramid cut are normally directed into the broken rock produced by previous blasts. Another method to fragment the rock under the planned ramp to the level of the quarry floor is to use a standard, full-depth vertical or steeply inclined blast pattern. A power shovel or dozer may then construct its own ramp into the pit. This allows for continuity in drilling and blasting operations. The resulting ramp can then be easily removed.

c. **Cuts Parallel to Strike:**

(1) **Dip Toward Face.** When it becomes necessary to work a face, satisfactory results may be obtained by drilling inclined holes parallel to the dip and working on the inclined face as shown in Figure 3-4-9.

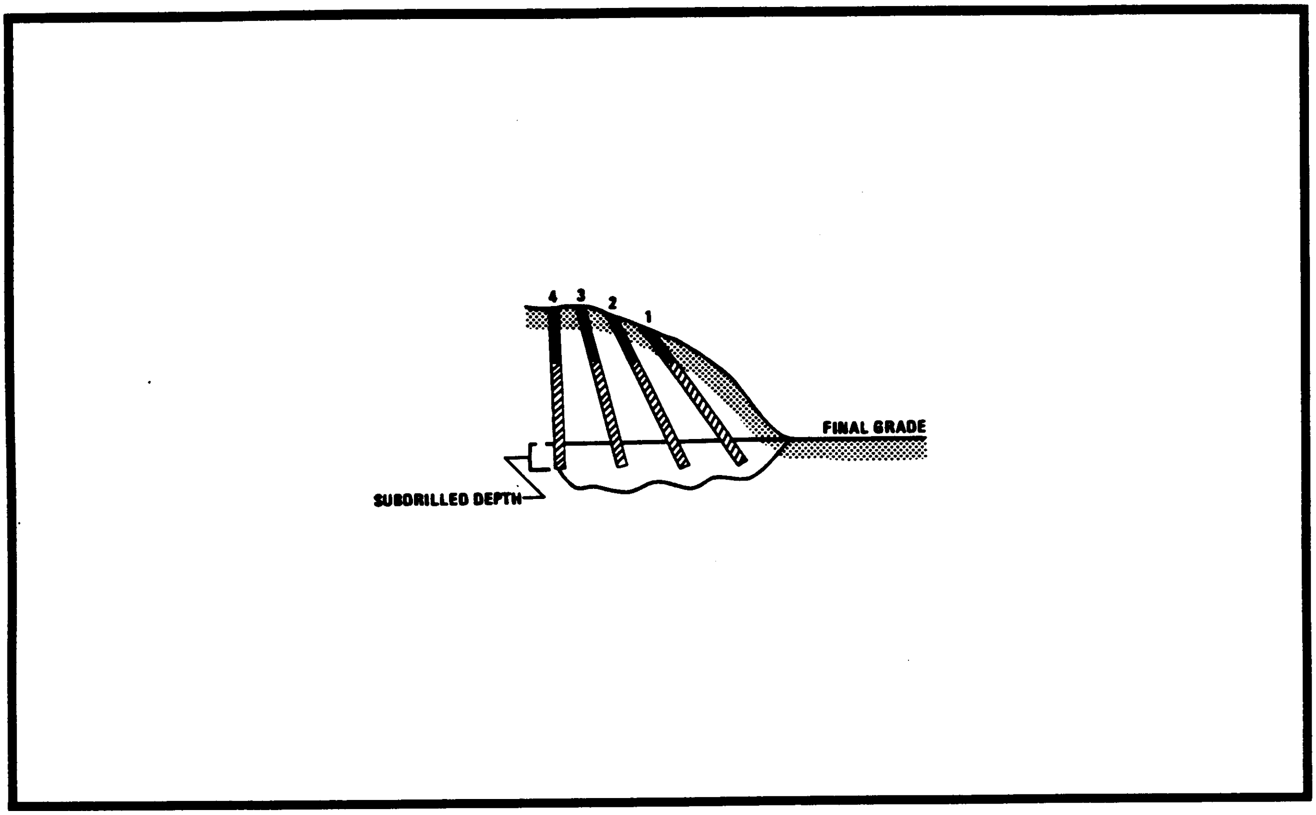


Figure 3-4-5 Establishing a Vertical Face Using Inclined and Vertical Blastholes (Numbers Indicate Sequence of Initiation).

(2) **Dip Away from Face.** It is more desirable to blast with the dip away from the face because rock slide hazards are less severe. In this situation vertical blastholes may be employed as in a normal full face production blast. To eliminate overhang problems, one or more short, lightly-loaded blastholes should be spaced between the last two rows of primary blastholes.

d. **Width of Initial Cuts.** The total width of initial cuts is determined by the working space requirements of loading and hauling equipment. For all cuts, this width is the same as the width desired at the initial face. In the normal method of hauling out blastrock, that is, with a crawler shovel or front-end loader, this width will range upwards from 15 metres.

22. **Charging Initial Cuts.** The holes in initial cuts should be located using the same objective as in normal production blasting, that is to obtain good fragmentation with little displacement. However, in the case of cuts below grade (ramp cuts, V-cuts and pyramid cuts), it may be advantageous to load the drill holes heavily with explosives to remove as much material as possible from the cut with the blast. This practice is limited by the danger to personnel and structures in the area from shock and flyrock produced by the blast.

23. **Backfilling.** All cuts described in paragraphs 21 and 22 are intended to break the rock to a depth of 0.3 to 0.9 metres below the final grade. Backfilling is therefore necessary to bring the surface to a smooth, usable grade at the desired elevation. This is accomplished with rock broken in the blast or any extra fill necessary to complete the job. Backfilling is not required when a suitable working floor can be developed by controlled blasting or by the use of an existing bedding or fracture surface at the level of the quarry floor.

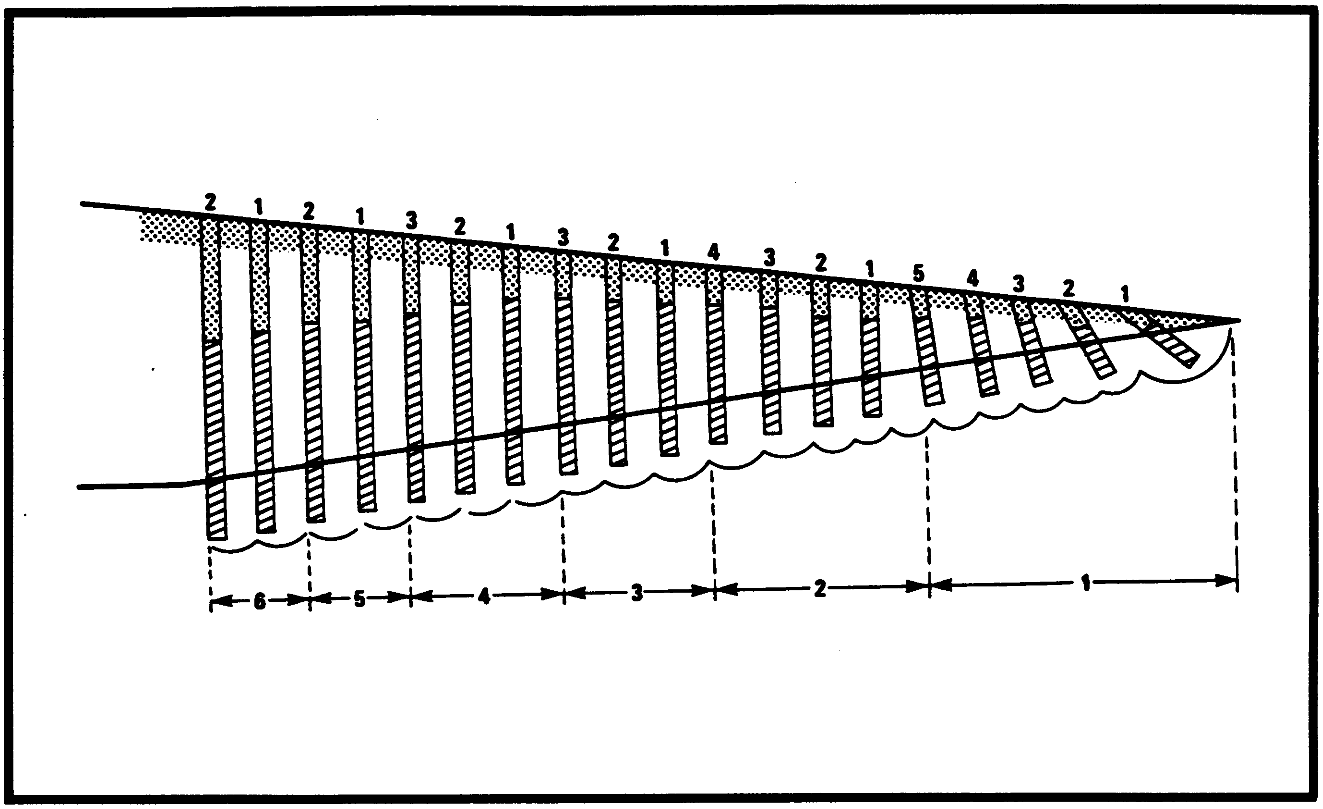


Figure 3-4-6   Drill Patterns to Excavate a Ramp (Numbers indicate sequence of initiation)

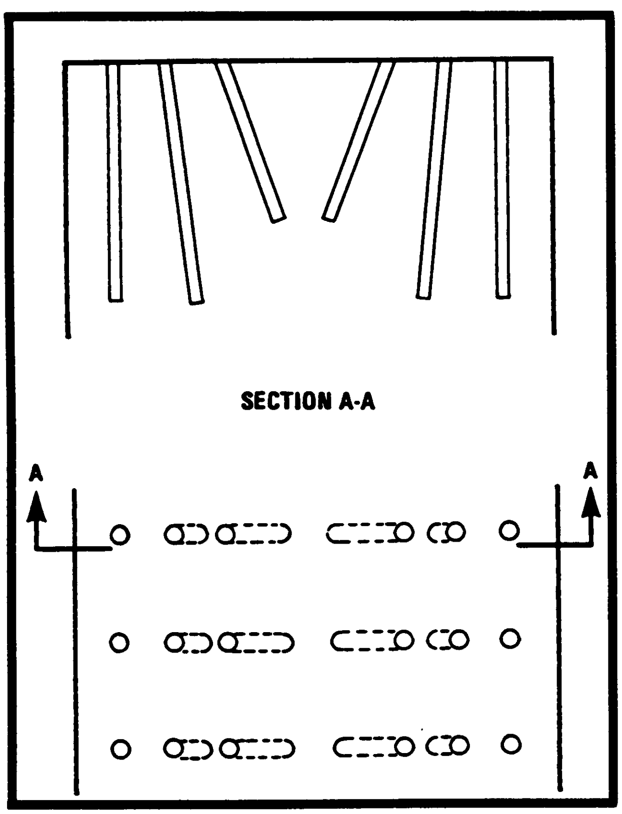


Figure 3-4-7   V-Cut to Open a Subsurface Rock Excavation

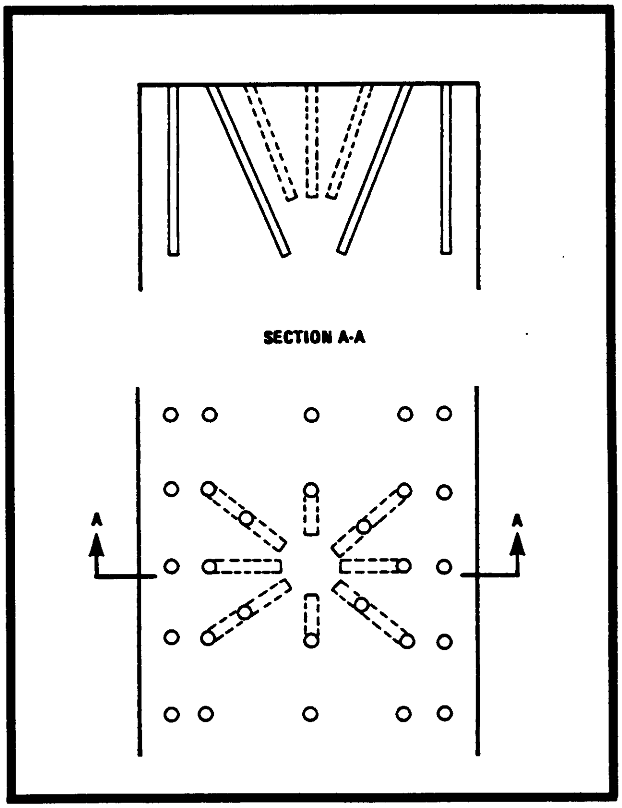


Figure 3-4-8 Pyramid Cut to Open a Subsurface Rock Excavation

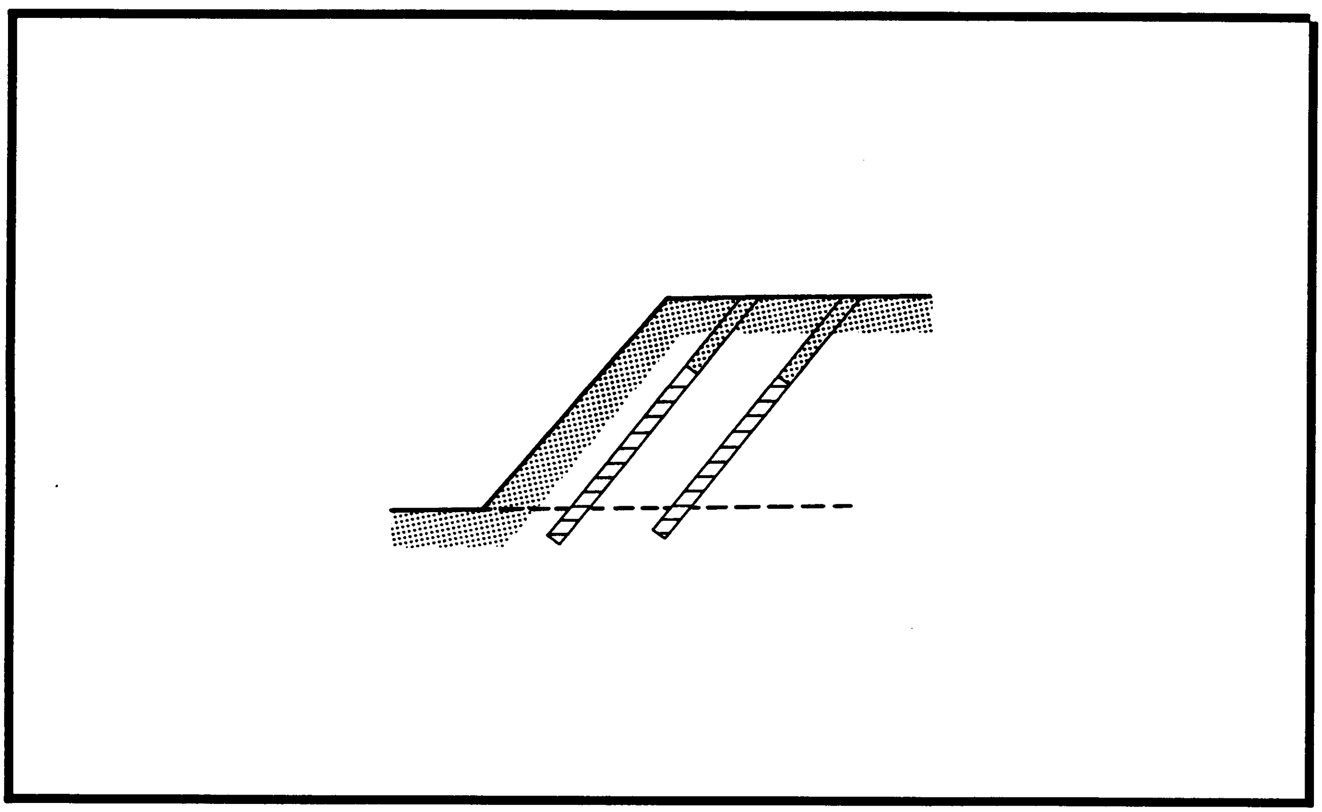


Figure 3-4-9 Inclined Blastholes (Dip Parallel to Face)

SECTION 5

QUARRY ORGANIZATION

GENERAL

1. Quarry operations involve a vast array of personnel and equipment. The amount of these resources, however, is not fixed. The quarry organization is flexible and depends on the size of the operation and/or the amount of equipment and personnel available. This section provides a general description of a quarry operation organization and discusses the records that should be maintained at the site.

QUARRY ORGANIZATION

2. **General.** The fundamental quarry organization consists of the headquarters office, six operation sections and one support section. The operation sections include stripping, quarrying, rock processing, equipment maintenance, road maintenance and delivery sections. Figure 3-5-1 shows the equipment that may be found in these sections. The actual equipment used is based on what is available and what is required by the particular operation.

3. **Quarry Operations HQ.** Quarry operations HQ is responsible for the overall control and administration of site activities. This section includes the quarry site commander, the site second-in-command and site administrative clerks.

4. **Stripping Operations.** This section is responsible for grubbing, clearing, stripping and spoiling all overburden materials. In addition to the equipment operators, this section may have personnel to cut trees or guide equipment.

5. **Quarrying Operations.** This section is responsible for drilling, blasting, loading and hauling rock to the rock processing plant.

6. **Rock Processing Operations.** This section is responsible for crushing, screening, washing, stockpiling and issuing rock products.

7. **Equipment Maintenance Operations.** This section is responsible for the maintenance and repair of all of the plant and equipment on site.

8. **Road Maintenance Operations.** This section is responsible for routine maintenance of quarry roads and traffic areas.

9. **Delivery Operations.** This section is responsible for the delivery of rock products from the processing plant to the construction site(s). Depending on the scale of operations this responsibility may be undertaken by another organization or unit.

10. **Support Sections.** This section is responsible for providing general support not assigned to the other sections. This includes POL, supplies, rations, and storage of equipment, tools and explosives.

QUARRY RECORDS

11. **General.** It is important to maintain accurate records to record the historical evolution of the site, record blasting operations and monitor production.

12. **Development Records.** The development records monitor the evolution of the site. These records include all work done at the site from start to finish. They include sketches, profiles and cross-sections, as well as a record of equipment and personnel used on the site.

13. **Daily Work Log.** The daily work log records the daily progress of operations. It includes a summary of the blasting performed, the production of rock and the delivery of material. it summarizes the equipment and personnel used in the daily operation of the various activities as well as the consumption of water, POL, utilities, etc.

14. **Blasting Log.** The blasting log records all items involved in the blasting operations. It includes the design of the blast, the actual loading records, the effects of the blast and corrective actions.

   a. **Sketch of Face.** A sketch of the face is produced before each blast to record dimensions and the appearance of the face with respect to dip and layers. Photographs may also be included.

   b. **Shot Design.** The shot design should include the calculations and the layout of the explosives.

   c. **Drilling Records.** Drilling records ensure that all holes are loaded. They help to prevent the loading of abandoned holes and they are used for future planning. These records specifically include:

      (1) a plan view showing the locations, depths, diameters and spacing of all holes;

      (2) the location of all abandoned holes; and

      (3) the drillers' log on each hole which contains information concerning the depth and thickness of cracks, clay and mud seams, or soft material encountered while drilling; the time required to drill the hole; hole spacing and burden; drill bit: wear; and whether the hole is wet or dry.

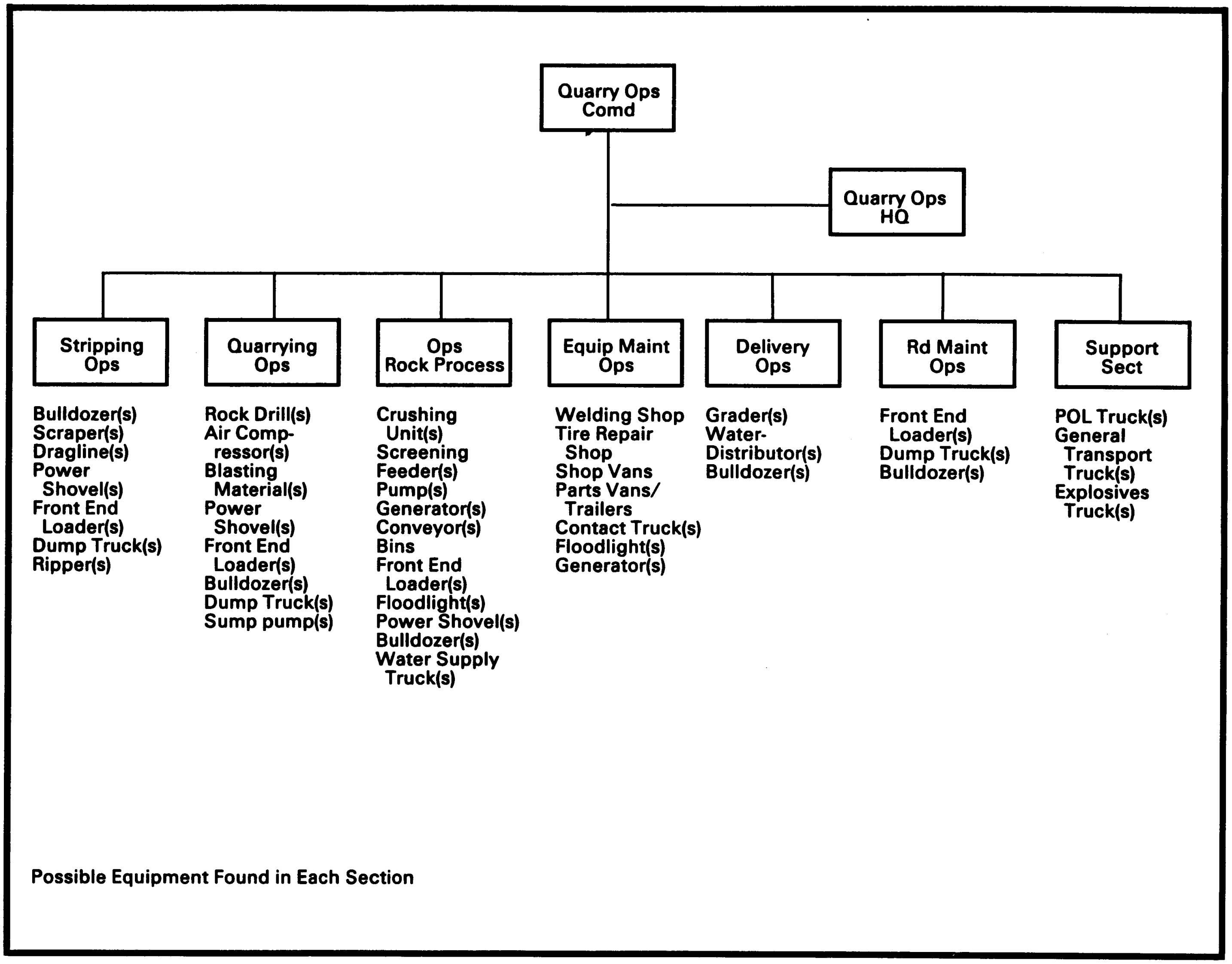


Figure 3-5-1   Organization Chart

d. **Load Records.** These records contain the type and amount of tamping, the amount and type of explosives and accessories used in each hole, the type of circuit, the circuit pattern, the type of detonators and method of initiation. They should also include the amount of time required to prepare each hole. Finally, the load records should be summarized to indicate all explosives and accessories used and the time required to prepare the circuit(s).

e. **Blast Observations.** This log records the time, the results and the success of detonation. It includes any whole misfires or partial misfires. It also indicates a description of the size of the pieces, direction of throw and any effects the blast had on other activities.

f. **Corrective Actions.** This log records the action taken as a result of the blast. It records action taken on misfires and action to adjust techniques and/or amounts of explosives/accessories for future blasts.

15. **Rock Inventory Log.** This log records the production of the quarry. It includes the rock quarried per blast, the running total of rock crushed, the amount of each size stockpiled and the amount of each size delivered.

SECTION 6

SUMMARY

GENERAL

1. Before any activity commences on the selected quarry site, it is important that the operation has been properly planned. The master plan includes the quarry layout, the development of the quarry and the organization that will be used in the operation of the quarry. Well thought out and defined plans in the beginning result in smooth and efficient operations throughout the life of the quarry.

2. Annex B to this chapter presents a generalized flow chart of quarry operations which outlines the sequence of events. The length of each activity arrow is not related to a definite period of time. It simply represents the relative position of one activity to another. The start and end position of each activity is not fixed in its relation to other activities, but simply suggests the time frame in which it should or would naturally occur.

ANNEX A, CHAPTER 3

RIPPING TECHNIQUES

1. **General.** The best ripping technique depends on the job conditions. Experience has outlined several guidelines for ripping.

2. **Number of Teeth to Use.** Start ripping by using the middle tooth of a three tooth ripper. If the material is penetrated easily try the outer two teeth. All three teeth should be used on easy-to-rip material. If the material can be handled with a two tooth ripper, production may be increased using only one tooth because one tooth centers the load on the assembly. There is more slippage and stalling if one tooth of a two tooth assembly becomes stalled temporarily by a hard spot. Using one tooth is also easier on the machine and the operator.

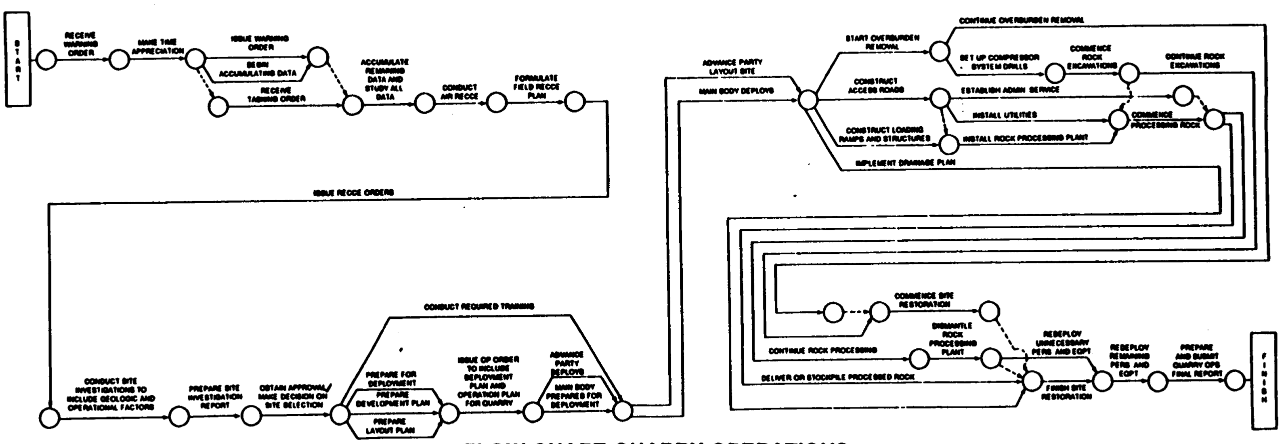
3. **Depth of Teeth.** It is often practical to rip as deep as possible. However, where considerable stratification is encountered, full depth ripping may not be ideal. An attempt should be made at ripping at partial depths to remove the material at its natural layers. It is important to rip to a uniform depth and thus eliminate the hard knobs of rocks which could damage or wear a scraper. A good rule of thumb is to rip no deeper than the depth of ripping on the most difficult part of the cut area.

4. **Pass Spacing.** The crusher acceptance size and hauling/loading method limits ripping spacing requirements. The closer the spacing the smaller the ripped chunks will be. When full penetration can be obtained, pass spacing of one to two metres is satisfactory for many materials. Spacing determines ripping production rates.

5. **Ripping Direction.** Ripping direction may be dictated by quarry development. Where it is not, ripping should be in the same direction in which the scrapers load. If it is found that ripping in the same direction of laminations results in only deep channels, it may be necessary to rip the material across the cut to obtain proper material breakup.

6. **Removing Ripped Material.** Never doze or scrape ripped material without leaving about ten centimetres or ripped material above the unripped formation. The remaining ripped material allows for better traction for subsequent ripping and provides a cushion for the dozer.

7. **Tandem Ripping.** Adding a second dozer to push the first dozer-ripper can extend the range of materials that can be ripped. This is particularly useful when only a small portion of the total rock on a job is too tough for a single dozer-ripper to handle.



FLOW CHART QUARRY OPERATIONS

CHAPTER 4

DRILLING AND BLASTING

SECTION 1

INTRODUCTION

GENERAL

1. **General.** Blasting is the start of the rock production cycle in quarry operations. The type of explosive used in quarry operations is not the same as common military explosives. Therefore the techniques used in quarry blasting are different than the techniques used in some of the more common combat engineer demolition tasks. It is important to use efficient techniques in quarry blasting because of the large quantities of explosives involved.

AIM

2. The aim of this chapter is to discuss drilling and blasting techniques in quarrying operations.

SCOPE

3. This chapter will discuss the following topics:

   a. rock fragmentation principles,

   b. properties and types of explosives,

   c. blast design calculations,

   d. preparation of holes,

   e. methods, and

   f. explosive aids to loosening fill.

BLASTING OBJECTIVES

4. Blasting produces three basic effects which must be controlled. These are fragmentation, displacement and violence. It is desirable in quarry blasting to have fragmentation which results in a narrow range of particle sizes. Too many fines or large slabs are undesirable. The actual limits of the desired sizes vary according to the intended use of the rock and the capabilities of the equipment. The broken rock resulting from a blast, called muck, must be properly loosened and properly displaced for efficient excavation. Too little or too much displacement leads to safety and loading problems. Loose muckpiles from 3.0 to 3.7 metres high are generally preferred for front-end loader operation while more compact muckpiles from 6 to 9 metres high are desirable for power shovels. It is undesirable to overbreak the rock because displacement beyond the intended excavation limits necessitates extra hauling effort. Violence, in the form of noise, airblast and ground vibrations, must also be controlled to protect personnel and surrounding property from damage. A well-designed blast may be defined as one which results in good fragmentation and displacement with a minimum of objectionable violence.

SECTION 2

FRAGMENTATION PRINCIPLES

GENERAL

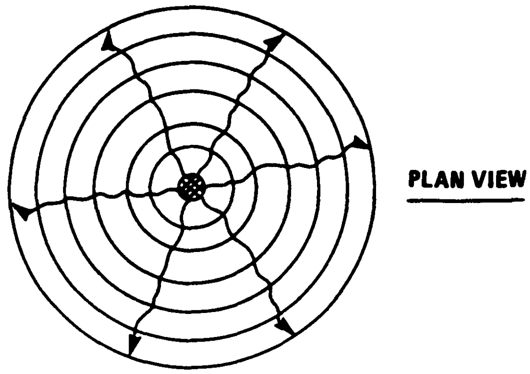
1. **General.** This section describes the mechanics of rock breakage as a result of blasting.

2. When an explosive charge is detonated within a rock mass, it suddenly converts into a bubble of gas which pushes outward against the surrounding rock and creates a shock wave. If enough energy is available, the explosive will overcome the resistance of the rock and will form a crater within the rock structure. In simplified terms, this cratering process may be divided into three stages.

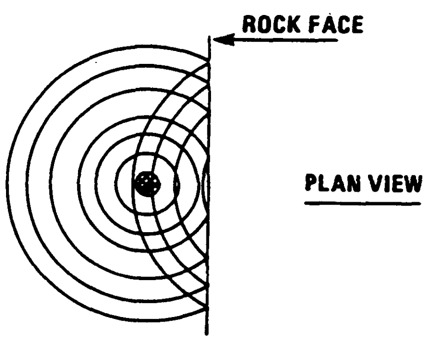
   a. **Stage 1.** On detonation, the explosive produces extremely high pressures within the borehole, often crushing the surrounding rock for a limited distance. The sudden application and subsequent quick release of this pressure produces a compressive shock wave which radiates outward through the rock at 1500 to 6300 metres per second (m/s). This shock wave sets up tangential stresses which produce a set of radial cracks which move out from the region of the hole (Figure 4-2-1 (a)).

   b. **Stage 2.** If the outgoing shock wave of stage 1 reaches a free face or rock boundary, it will reflect back into the rock. This produces a tension wave that counters the effects of the initial shock wave. Since rocks are 10 to 20 times weaker in tension than in compression, primary fractures may develop due to the strength of this reflected wave. Often scabbing or spalling occurs along the free face (Figure 4-2-1 (b)).

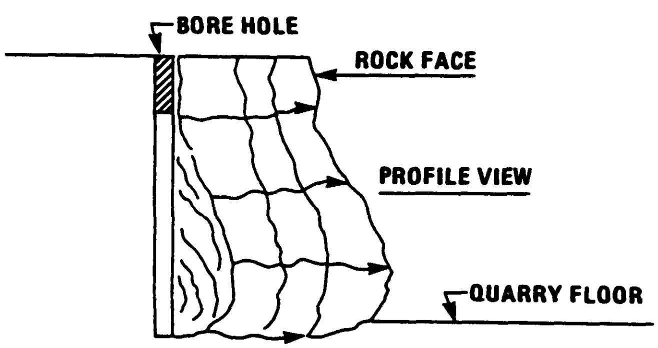
   c. **Stage 3.** The shock wave energy released on detonation conditions the rock by inducing numerous small fractures. Actual cratering is not as quick during this stage. Under the pressure of the expanding explosion gases, the primary radial cracks expand rapidly as rock is pushed away from the borehole toward the nearest free face. When the rock in front of the hole yields and bends outward, tension cracks develop on the bowed rock face and expand back toward the borehole. This allows the compressive stresses in the rock to unload outwardly, similar to a compressed coil spring that is suddenly released. The combination of bending and unloading virtually pulls the rock apart and completes the breaking process (Figure 4-2-1 (c)). Additional fragmentation occurs as the expanding gases work their way through the fractured rock, churning the pieces together and moving them outward.



(A) STAGE 1 SHOWING THE POSITIONS OF THE OUTGOING SHOCK WAVE AND DEVELOPMENT OF RADIAL CRACKS.



(B) STAGE 2 SHOWING THE POSITIONS OF THE OUTGOING AND REFLECTED SHOCK WAVE.



(C) STAGE 3 SHOWING THE EFFECTS OF THE EXPANDING EXPLOSION GASES AND CRATER FORMATION.

Figure 4-2-1 Plan View of the Blasting Process

SECTION 3

PROPERTIES AND TYPES OF EXPLOSIVES

GENERAL

1. **General.** In quarry operations it is desirable to use explosives which are specifically designed for use in these types of operations in lieu of general purpose, more expensive military explosives. This section describes explosives used in quarry operations. An important reference covering the application, use and handling of civilian explosives is the Blasters' Handbook Sixth Edition prepared and published by Canadian Industries Limited, Montreal, Quebec, 1972.

PROPERTIES OF EXPLOSIVES

2. **General.** The properties of explosives which are significant to quarry operations are strength, velocity of detonation, density, physical characteristics, water resistance, freezing resistance, fumes and storage qualities.

3. **Strength.** Strength relates to the amount of energy released by the explosive. It describes the ability of the explosive to do work by the amount of force or power it can develop. The strength of civilian explosives is expressed in terms of an equivalent weight or volume of a straight nitroglycerin dynamite.

4. **Velocity of Detonation.** Velocity of detonation (VOD) is the rate (in m/s) at which the detonation wave is transmitted through the explosive. VOD ranges in explosives from 1500 to 6900 m/s. High velocity explosives release their energy quickly and produce intense shock energy. They have a shattering effect which is well-suited to the fragmentation of strong, brittle rocks of high seismic velocity. Low velocity explosives release their energy more gradually and create less intense shock waves with more sustained gas pressures. Thus they produce a heaving effect which is well suited to blasting highly-fractured rock or soft, weak rocks of low seismic velocity. Slower explosives are also preferred for quarrying coarse material and for cratering. Among explosives in general, density and detonating velocity usually increase together. Thus, dense explosives usually release both more shock energy and gas energy than light explosives.

5. **Density.** Density of explosives may be expressed in two ways. These include grams/cubic centimetre (g/cc) and the cartridge count (or stick count) which is the number of 28.6 mm x 203 mm cartridges found in a 22.7 kg case.

6. **Physical Characteristics.** Physical characteristics refers to the form of the explosive. Form ranges from plastic (gelatins), to granular pellets with no degree of cohesion, to viscous mixtures or slurries.

7. **Water Resistance.** Water resistance is the ability of the explosive to remain effective when contact with water has occurred. Although all civilian explosives deteriorate in water, the speed of deterioration varies. Some explosives deteriorate very rapidly. Others may withstand water long enough to permit detonation after loading while some may allow the loaded wet hole to remain unfired for an appreciable amount of time.

8. **Resistance to Freezing.** Although most explosives will not freeze under ordinary exposure to the lowest temperatures in Canada, some may become stiff and less pliable. This may result in loading difficulties or initiation problems. Therefore, a warm storage area or a warm area to soften the explosive for several hours before use may be required.

9. **Fumes.** Some toxic fumes are produced when explosives are handled or detonated. Some commercial explosives produce fumes during handling which can adversely affect personnel and manufacturers' warning

should be heeded. Ventilation is required to disperse the fumes prior to personnel returning to the site following a detonation. Explosives are classified in terms of the amount of poisonous gases emitted and are expressed as Class 1, 2 and 3. The higher the class number, the greater the amount of poisonous gas emitted.

10. **Storage Qualities.** Explosives are perishable. Some types store better than others. In general, explosives which do not contain ammonium nitrate store the best.

TYPES OF EXPLOSIVES

11. **General.** There is a wide range of explosives that are suitable for quarry operations. These explosives differ tremendously in their properties and are suited for various situations. The most important properties to consider in the selection of explosives for blasting in quarry operations are strength, VOD, density, physical characteristics and water resistance. Annex A to this chapter is a summary of various types of civilian explosives which may be used in quarry operations. It includes both high explosives and blasting agents. High explosives include nitroglycerin and ammonia dynamites as well as gelatins and semi-gelatins. They are initiated by a detonating agent such as a blasting cap or detonating cord. Blasting agents consist largely of ammonium nitrate and have a low sensitivity to shock, friction and impact. They are initiated by specially developed primers.

ACCESSORIES

12. **General.** The array of demolition accessories is extensive. This subsection outlines primers, delays and relays that could be used in quarry operations.

13. **Primers.** Primers are used to initiate blasting agents which are not sensitive enough to be initiated by detonators or detonating cord. Several types of primers are listed in Annex B to this chapter.

14. **Delays.** Delays are blasting caps which have a delay element inserted between the ignition charge and the basic charge. They are available as both electric and non-electric delay detonators. Delays are used for firing charges in rotation or where it is desired to initiate charges with time intervals. Delays are used extensively in quarry blasting methods. These methods are discussed in greater detail in Sections 4 and 6 of this chapter.

a. **Delay Electric Detonators.** There are two types of electric delays, long delay caps and short period caps.

(1) **Long Delay Caps.** There are 21 firing periods from nos. 0 to 20. They are all the same strength but the shell lengths range from 56 mm to 112 mm. The period timings are as follows:

Period	Firing Time (seconds)	Period	Firing Time (seconds)
0	0.2	11	3.9
1	0.5	12	4.4
2	0.8	13	4.9
3	1.1	14	5.4
4	1.4	15	5.9

5	1.7	16	6.6
6	2.0	17	7.3
7	2.3	18	8.1
8	2.7	19	9.0
9	3.1	20	10.0
10	3.5		

(2) **Short Period Caps.** There are 31 firing periods of short period caps. They are all the same strength but the shell lengths range from 32 mm to 64 mm long. The period timings are as follows:

Period	Firing Time (milliseconds)	Period	Firing Time (milliseconds)
0	8	16	800
1	30	17	875
2	50	18	950
3	75	19	1025
4	100	20	1125
5	130	21	1225
6	160	22	1350
7	190	23	1500
8	230	24	1675
9	280	25	1875
10	340	26	2075
11	410	27	2300
12	490	28	2550
13	570	29	2880
14	650	30	3050
15	725		

b. **NONEL Delay Detonators.** NONEL delays are non-electric delays that can be used with any explosive regardless of sensitivity. B-Line Detonating cord, a low initiating strength detonating cord (see Blasters' Handbook), should be used with NONEL delays. These delays are available in both the long and short period series.

(1) **Long NONEL Delays.** There are 19 firing periods from nos. 0 to 1 B. The period timings for these are the same period times as those given for long delay electric cap period nos. 0 to 18.

(2) **Short NONEL Delays.** There are 26 firing periods from nos. 0 to 25. The period timings for nos. 0 to 22 are the same period times as those given for short delay electric cap period nos. 0 to 22. The remaining period timings are as follows:

Period	Firing Time (milliseconds)
23	1675
24	1950
25	2275

15. **Relays.** Detonating relays are inserted in firing circuits to provide split-second firing. Their intent is similar to that of delays. Detonating relays are initiated by detonating cord and are therefore unaffected by stray electrical currents. They are available with firing times of 5, 10 and 15 millisecond (ms) periods as well as ten delay periods from 25 ms to 250 ms at 25 ms intervals. Detonating relays are almost as sensitive to impact as detonators and have limited water resistance.

SECTION 4

BOREHOLE BLAST DESIGN

GENERAL

1. **General.** Blast design involves the location of boreholes relative to the face and each other and defines the parameters of the hole and the charge. This section reviews design considerations, blast design dimensions and actual blast design.

DESIGN CONSIDERATIONS

2. Blast design essentially seeks to control blast effects by adjusting the balance between explosive energy and rock resistance. Before attempting to design a blast one must develop a working knowledge of the influence of rock properties, explosive properties, charge timing and primer location on the actual details of the cratering process.

a. **Rock Properties.** For practical purposes, cratering effects may be evaluated in terms of the density, seismic velocity and structure of the rock being blasted (see Annex C to this chapter).

(1) **Density.** Density refers to the unit weight of a material. In general, dense (heavy) rocks are stronger and more resistant to displacement than light rocks. They thus require relatively more explosive energy (particularly gas energy) for a given blast effect. Rock density is usually given in terms of specific gravity, which describes the relative density of a material as compared to the density of ordinary water:

(a)

EQ4-1

$$G_r = \frac{\text{Rock weight}}{\text{Rock volume}} \times \frac{1}{w} \qquad \text{(Equation 4-1)}$$

Where:

Gr = Specific gravity of the rock
w = Density of water 1.0 g/cm3

Most common rocks have Gr values between 2.4 and 3.1 (Figure 4-4-1).

ROCK TYPE	DENSITY (Gr) g/cc	
	AVERAGE	RANGE
Basalt	2.86	2.8-3.1
Coral	2.3	2.1-2.5
Diabase	2.96	2.6-2.5
Diorite	2.92	2.8-3.0
Dolomite	2.74	2.7-2.9
Felsite	2.66	2.5-2.8
Gabbro	2.96	2.9-3.1
Gneiss	2.74	2.6-2.9

ROCK TYPE	DENSITY (Gr) g/cc	
	AVERAGE	RANGE
Granite	2.65	2.6-2.9
Limestone	2.66	2.4-2.9
Marble	2.73	2.4-2.9
Quartzite	2.69	2.5-2.8
Sandstone	2.54	2.2-2.8
Schist	2.85	2.5-2.9
Shale	2.5	2.4-2.8
Syenite	2.74	2.7-2.9

Figure 4-4-1 Average Rock Densities

(2) Seismic Velocity. Seismic velocity refers to the speed, Vr, at which rocks transmit shock waves. Most common rocks have Vr values between 1500 to 6300 m/s. High velocity rocks are generally harder, stronger and more brittle than low velocity rocks of the same density. They typically require more intense shock energy for good fragmentation. Soft, weak, low velocity rocks tend to be rather resilient. They require less intense shock energy and relatively sustained gas pressures for good fragmentation; excessive energy may cause excessive crushing or powdering around the borehole and violent spalling or scabbing at the free face. In the field, seismic velocity may be roughly estimated by striking a fresh rock sample with a hammer. Weak, low velocity rocks will emit a dull sound and show a crushed or powdered zone where struck. Strong, hard, high velocity rocks resist crushing and powdering and cause the hammer to rebound with a ringing sound. Rock density and seismic velocity usually increase together; dense rocks thus

usually require more gas energy and shock energy than light rocks.

(3) **Structure.** Fractures and bedding planes tend to reflect shock waves, particularly if open cracks or cavities are present. This can lead to reduced fragmentation in front of or between boreholes and, in some cases can lead to overbreak (rock breakage outside the desired limits of excavation). Since rocks tend to break and displace along existing planes of weakness, bedding or fracture surfaces may influence crater shape and blastrock dimensions. Large blocks or slabs may displace without fragmenting unless penetrated by a borehole while smaller, less powerful or more widely-spaced charges may be needed to control displacement when blasting highly-fractured or unconsolidated material. Structural variations within a bench may also influence the selection or distribution of explosives from borehole to borehole in order to balance blast energy for different rock conditions.

b. **Explosive Properties.** Many explosives are assigned strength ratings which relate their energy to that of an equivalent weight or volume of a straight nitroglycerin dynamite. These weight or cartridge strength ratings do not provide a reliable guide to explosive performance because explosives release their energy at different rates. For practical purposes, explosive performance can be more readily evaluated in terms of the size, density and VOD (detonating velocity of the explosive charge). (See Annex A to this chapter).

(1) **Size (effective diameter).** The amount of energy available from a given explosive varies directly with the volume of explosive present. For cylindrical charges, where volume is directly proportional to charge diameter, the amount of explosive available may be evaluated in terms of the effective diameter, De, of the explosive column. De is normally equal to the borehole diameter, Dh for thoroughly tamped or bulk-loaded explosives, or to the cartridge diameter, D, for columns of rigid explosive cartridges. If several small diameter explosive cartridges are bundled together side-by-side within a borehole, the effective diameter of the bundle may be calculated using the following equation:

(a)

$De = D\%N$ (Equation 4-2)

Where

D = Diameter of a single explosive cartridge
N = Number of cartridges in a bundle

The relationship among bundle she, effective explosive diameter and borehole diameter for standard 3.18 cm diameter explosives (like dynamites) can be seen in Figure 4-4-2.

(2) **Density.** Because explosives vary in composition, density is not directly related to explosive performance, but, in general, dense (heavy) explosives release more total energy than light explosives, particularly in the form of larger volumes of gas. Explosive density is usually specified in three ways:

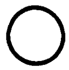
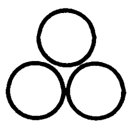
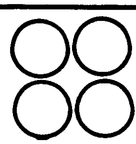
BUNDLE SIZE	EFFECTIVE EXPLOSIVE DIAMETER (D_e)	MINIMUM BOREHOLE RECOMMENDED (D_h)
	3.18 cm	3.81 cm
	4.5 cm	7.0 cm
	5.51 cm	7.62 cm
	6.35 cm	8.26 cm

Figure 4-4-2 Use of Bundle Cartridges of Standard Diameter

(a) by specific gravity, Ge, which is equivalent to density in g/cc;

(b) by stick count, SC, the number of equally dense 3.18 by 20.3 cm cartridges needed to fill a 22.7 kg case; and

(c) by loading density, de, the weight of explosive per unit of explosive per unit length of charge of stated diameter. These measures are interrelated as follows:

EQ4-3

$$G_e = \frac{\text{Weight of explosive}}{\text{Volume of explosive}} \times \frac{1}{w} \qquad \text{(Equation 4-3)}$$

SC = 141/Ge (Equation 4-4)

de = 0.786(De)2(Ge) (w) (Equation 4-5)

(See Annex D to this chapter)

Where

Ge = Specific gravity of the explosive

w = Density of water (1.0 g/cm3)

SC = Stick count

de = Loading density (in units of weight per unit length)

De =Effective explosive diameter

To find the equivalent stick count (SC) when the sticks are either smaller or larger than 3.18 by 20.3 cm use:

SC = 0.08(n) (De)2 (L)

Where

SC = Equivalent number of 3.18 by 20.3 cm sticks needed to fill a 22.7 kg case.

n = Number of odd size sticks in 22.7 kg case, ie, sticks either smaller or larger than 3.1 8 by 20.3 cm

De = Effective explosive diameter of odd size sticks

L = Length of odd size sticks

c. **Charge Timing.** Most rock blasting involves many separate charges or blastholes arranged in a row or series of rows. For cratering to occur, a free face must be provided in front of each hole or row of holes to allow shock wave reflection and rock displacement. In multiple-hole blasting, this free face is provided by delaying the sequence of detonation of blastholes within and/or between rows. (This is elaborated on in Section 6, paragraph 4 of this chapter). Delay intervals must be carefully selected to allow enough time for rock movement to begin. At least 1.5 to 2.5 milliseconds of delay time should be allowed for each 0.3 metres of rock between two independent blastholes or rows of blastholes in normal production blasting. Generally, time-delay intervals of 17 to 50 milliseconds are employed in construction blasting. Longer intervals are often used between holes or rows fired late in a sequence to assure full cratering. Insufficient delay time increases charge confinement and reduces fragmentation and displacement while overly long delays may lead to excessive rock displacement. In layered or fractured rocks, overly long delay intervals may permit rock to shift across adjacent boreholes before they can be detonated. Such cutoffs are a frequent cause of misfires.

d. **Primer Location.** The primer location determines that portion of the ledge which will be stressed and displaced first. As an explosive column detonates away from the primer, shock waves and expanding gases are repeatedly directed into the rock stressed earlier in the blast (Figure 4-4-3). As charge lengths increase, the resulting differences in blast effects become greater.

(1) **Boreholes Perpendicular to Free Face.** In mining, trenching and cratering operations (where boreholes are normally drilled at a right angle to the free rock surface), charges should be primed at the top to direct cratering upward and, thus, provide an outlet for the rock stressed by the explosive column as it detonates downward into the borehole.

(2) **Boreholes Parallel to Free Face.** In open-pit quarrying operations (where essentially vertical boreholes are drilled parallel to a free face), charges should normally be primed at the bottom of the hole to counter the increased rock resistance present in the base of a bench and to help direct the blastrock out onto the quarry floor with little or no high angle flyrock. Top priming tends to produce a waterfall effect with fly rock being left in a high

pile against the quarry face. A combination of top and bottom priming tends to increase stressing in the center of the bench and intensifies fragmentation and displacement.

(3) **Very Long Boreholes.** Very long explosive charges often require several primer locations to balance stresses along the hole and to assure that the entire explosive column has time to detonate before full cratering begins.

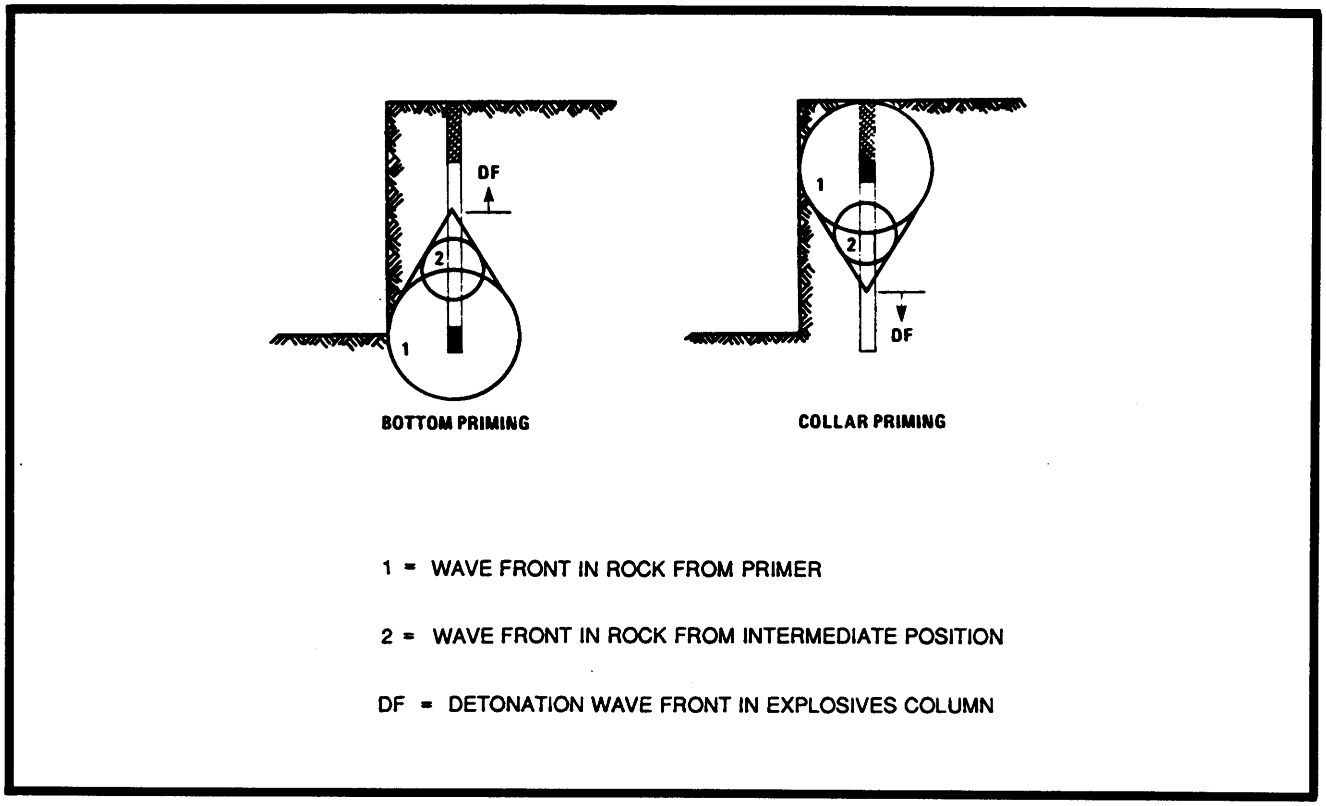


Figure 4-4-3 Compressive Stress Wave-Forms in Massive Uniform Rock

BLAST DESIGN DIMENSIONS

3. Blast design dimensions must be carefully selected to properly balance the distribution of explosive energy within the rock mass. Figures 4-4-4 and 4-4-5 illustrate the use of relationships among the blast design dimension symbols and terms defined below. The blasting patterns shown in Figure 4-4-5 may be used as a first approximation. In multirow blasting (Figure 4-4-5 plans A-E), a row is considered as an array of two or more holes along a line perpendicular to the final rock displacement direction, indicated by the arrow on each plan. In plans F and G (Figure 4-4-5), the one array of holes is considered as a row. The terms b and s are used for convenience in describing the layout of such patterns as plan A, a square grid. They should not be confused with B and S.

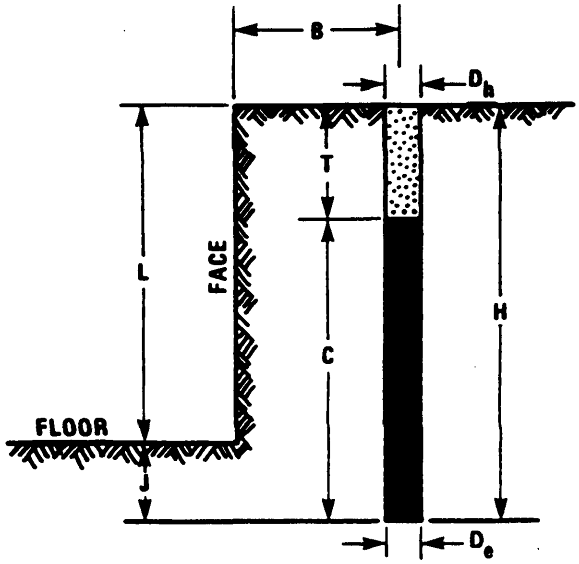
BLAST DESIGN

4. **Standards for Blast Design.** Because blasting is not an exact science, a certain amount of experimentation is needed to obtain optimum results. In this respect, five empirical standards have been developed to guide the design and evaluation of drilling and blasting patterns. All are unitless (dimensionless) ratios which describe the relationships among the various blast design dimensions. For simplicity, they will be dealt with in the context of conventional open-pit blasting situations, but they can be used with equal success in both surface and subsurface operations. The five standard design ratios are shown below as equations solving the unknown design dimensions B, J, T, H and S. Using the guidelines presented in the following discussion,

these ratios may be used to design a series of test blasts. Adjustments can then be made to provide the exact design values for your particular blasting situation. The calculation of each of these design dimensions is discussed in paragraphs 5 to 9:

a. $B = K_b D_e$, K_b = Burden ratio (Equation 4-6)

b. $J = K_j B$, K_j = Subdrilling ratio (Equation 4-7)



Dh = BOREHOLE DIAMETER.

De = EFFECTIVE EXPLOSIVE DIAMETER.

B = BURDEN, THE DISTANCE FROM A CHARGE MEASURED PERPENDICULARLY TO THE NEAREST FREE FACE AND IN THE DIRECTION THAT DISPLACEMENT WILL MOST LIKELY OCCUR AT THE TIME THE CHARGE DETONATES.

J = SUBDRILLING LENGTH, THE DEPTH THE BOREHOLE IS DRILLED BELOW THE ESTABLISHED QUARRY FLOOR.

T = STEMMING (OR COLLAR) LENGTH, THE LENGTH OF BOREHOLE NOT LOADED WITH EXPLOSIVE.

C = CHARGE LENGTH, THE LENGTH OF THE EXPLOSIVE COLUMN.

L = LEDGER (OR BENCH) HEIGHT.

S = SPACING, THE DISTANCE BETWEEN TWO ADJACENT BOREHOLES MEASURED PERPENDICULAR TO THEIR CORRESPONDING BURDEN.

b = DISTANCE BETWEEN TWO ROWS OF BOREHOLES MEASURED PERPENDICULAR TO THE ORIGINAL FACE (SEE FIGURE 4-4-5. PLAN A).

S = SEPARATION BETWEEN ADJACENT HOLES IN A ROW (SEE FIGURE 4-4-5 PLAN A).

Figure 4-4-4 Bench Cross-section View Showing Dh, De, B, J, T, C, L and H

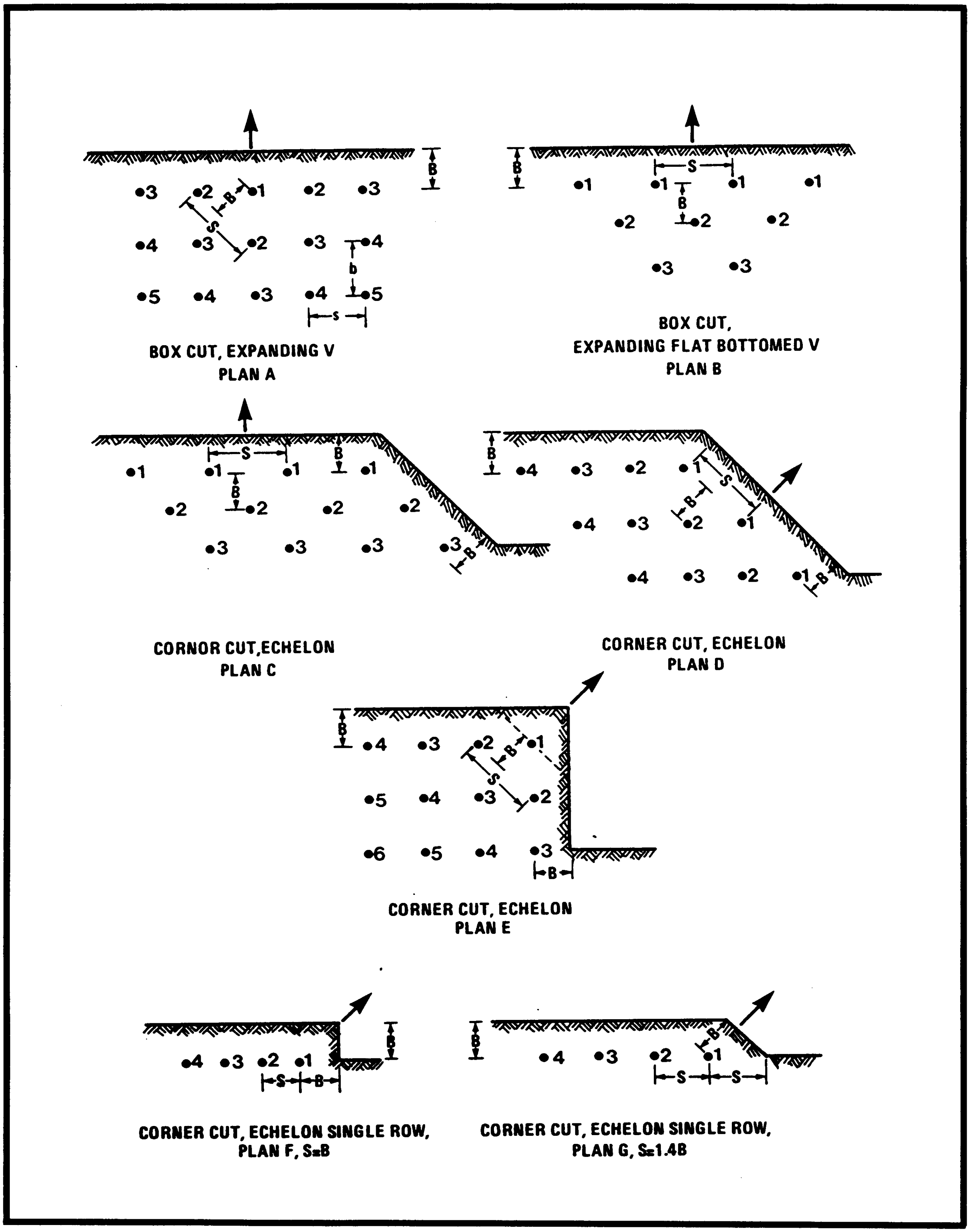


Figure 4-4-5 Generalized Blasting Patterns Showing B, S, b and s (Numbers indicate firing sequence)

c. T = KtB, Kt = Stemming ratio (Equation 4- 8)

d. H = KhB, Kh Hole length ratio (Equation 4-9)

e. S = KsB, Ks Spacing ratio (Equation 4-10)

5. **Calculation of Burden (B).** The rock burden thickness, B, needed to balance the energy of a given explosive charge with diameter De is given by:

B = KbDe (Equation 4-6)

a. **Determination of Kb.** The burden ratio, Kb, normally has a value between 20 and 40, with values near 30 being most common under average field conditions. Smaller values, near 20, are usually appropriate with very strong, dense rocks when using light low-energy explosives while larger values, near 40, are normal where light, weak rocks are blasted using dense, high-energy explosives. As a first approximation, Kb may be selected using Figure 4-4-6. This initial Kb value may then be adjusted following a single-hole test blast. Unconsolidated or highly-fractured rocks often require larger Kb values than indicated by Figure 4-4-6, since they normally offer less resistance than solid rocks of equal density. Relatively low Kb values should be considered where large displacements are desired, for example, in cratering or trenching operations.

EXPLOSIVE DENSITY ROCK DENSITY	**LIGHT** Ge < 1.1 SC > = 130	**AVERAGE** 1.1| = Ge | = 1.4 130 > SC > 100	**DENSE** Ge < 1.4 SC | = 100
LIGHT Gr < 2.6	30	34	38
AVERAGE 2.6 | = Gr | = 2.8	26	30	34
DENSE Gr > 2.8	22	26	30

Figure 4-4-6 Suggested Kb Values for Trial Blast Design

b. **Evaluation of Kb.** Violence, displacement and fragmentation all increase as Kb is decreased. Trial values of Kb may be adjusted based on the following observations:

(1) Kb too small - violent blast with excessive fines and low- angle flyrock; low, scattered muckpile; wide, shallow crater.

(2) Kb too large - high, tight muckpile containing excessive oversize; narrow, deep crater.

c. **Evaluation of De.** When Kb has been adjusted to provide adequate displacement and uniform fragmentation, De may be altered to relatively increase or decrease sizing limits without major change to the remaining blast effects. For a given explosive, smaller values of De provide finer fragmentation while larger De values (and burdens) provide coarser fragmentation.

d. **Designing for a Specific Burden.** Equation 4-6 shows that both Kb and De influence the burden dimension. Since both are functions of the explosive, blasts may be designed for a specific burden by varying either the density, Ge, or diameter, De, of the explosive charge to be employed. Appropriate charge characteristics may be estimated using the following variations of Equation 4-6.

EQ4-6a

$$D_e = \frac{B}{K_b} \qquad \text{(Equation 4-6a)}$$

EQ4-6b

$$K_b = \frac{B}{D_e} \qquad \text{(Equation 4-6b)}$$

e. **Changing Explosives.** Once you have determined the appropriate burden ratio for use with a given rock and explosive, you can estimate the value needed for use with a different explosive by the following:

EQ4-11

$$K_{b2} = K_{b1}\, 3\, \frac{G_{e2}}{G_{e1}} \qquad \text{(Equation 4-11)}$$

6. **Calculation of Subdrilling (J).** Boreholes are normally extended below the established quarry floor to counteract the increased rock resistance at the toe and assure that the entire bench is blasted to the required grade. Equation 4-7 can be used to calculate the length of subdrilling needed:

J = KjB (Equation 4-7)

a. Determination of Kj. Under normal field conditions, the subdrilling ratio, Kj, should have a value of not less than 0.2, with 0.3 being preferred to assure a full face and even quarry floor. Larger values (0.4 to as much as 0.5) may be needed to eliminate humps and toes in the quarry floor when blasting very dense, massive rock. Subdrilling may often be eliminated (that is Kj = 0) where a pronounced parting (bedding or fracture surface) occurs at the established grade line, since the rock will tend to displace along the existing plane of weakness. Kj values near zero may also be used where boreholes are inclined near 45 degrees or have been drilled horizontally. In some cases, a Kj may be needed to prevent the loss of explosion gases where open fractures, cavities or weak rock occur at the base of the bench.

b. **Evaluation of Kj.** Subdrilling controls fragmentation and displacement at the base of a bench where rock resistance is normally greatest. Trial values of Kj may be adjusted according to the following blast observations:

(1) Kj too small - humps in floor in front of borehole; incomplete fragmentation and displacement in the toe.

(2) Kj too larger - large crater in floor extending beyond the original face; excessive fragmentation and displacement in the toe.

7. **Calculation of Stemming (T).** The upper portion (collar) of a borehole is left unloaded to balance blast effects and reduce flyrock. Moist sand, drill cuttings, clay or other stemming material is usually placed in the collar to help confine explosion gases and reduce airblast. The length of stemming (or collar) needed may be calculated using Equation 4-8:

T = KtB (Equation 4-8)

a. **Determination of Kt.** Under average field conditions, the stemming ratio, Kt, should have a value of about 0.7. Values as low as 0.5 may prove suitable in thin-bedded or fractured rocks where bedding or fracture surfaces tend to reflect shock waves away from the collar. In very solid rock, Kt values less than 1.0 may result in cratering with backbreak and possible violence, especially if boreholes are primed at the top.

b. **Evaluation of Kt.** Stemming controls the distribution of blast energy at the top of a bench where rock resistance is normally low and where, usually, two free faces are present. Trial blasts can be expected to produce the following results where incorrect Kt values are used:

(1) Kt too small - ejection of stemming and venting of explosion gases; violent airblast; cratering and backbreak at the collar; oversize on top of the muckpile; high-angle flyrock.

(2) Kt too large - overhanging face or incomplete fragmentation in the collar region; oversize on top of the muckpile.

8. **Calculation of Hole Length (H).** The total length needed for a vertical borehole is given by Equation 4-12:

H = L + J (Equation 4-12)

a. Determination of Kh. For safety, the hole length ratio, Kh, should be determined using Equation 4-9a to assure that your explosive charge is properly balanced and primed before any test blast is ordered.

EQ4-9a

$$K_h = \frac{H}{B} \qquad \textbf{(Equation 4-9a)}$$

b. **Evaluation of Kh.** Kh values help describe the distribution and balance of blast effects along the length of an explosive charge. Usually production blasting involves Kh values between 1.5 and 4.0. Values smaller than about 1.5 usually produce a violent blast with cratering, backbreak, high-angle flyrock and severe airblast due to the relative shallowness of the bench as compared to the rock resistance at the toe, where most of the explosive charge lies confined within the subdrilled portion of the borehole. When blasting with a single primer location at Kh values larger than about 4.0, rock displacement may begin near the primer before the entire explosive column has had time to detonate. Explosion gases venting prematurely through this initial crater may leave excessive and oversize toes or overhangs, and undetonated explosive. Since bench heights are normally pre-determined, excessively low Kh value may be corrected by changing to an explosive of smaller density and/or diameter. The blast may then be redesigned for a smaller burden. Alternately, the bench may be blasted using inclined or horizontal holes. These techniques permit longer holes to be used without altering the burden dimension. Blasts involving excessive Kh values may be fired successfully provided multiple primer locations are provided within the boreholes. Usually a combination of top and bottom priming is used, but mid-column primers may be needed in addition if Kh is much greater than 4.0.

9. **Calculation of Spacing (S).** Once you have verified or refined your values for Kb, Kj, Kt and Kh, by a series of single-hole test blasts, you can proceed to calculate the spacing needed between holes in a multihole blast using Equation 4-10:

$S = KsB$ (Equation 4-10)

a. **Determination of Ks.** Ks values of 1.0 to 2.0 are usually used in normal production blasting. The basic principles for determining Ks may be summarized as follows:

(1) For independently-fired charges and single-row blasts where adjacent charges are detonated in sequence with a time-delay interval long enough to permit each charge to complete its blasting action, Ks should have a value near 1.0 or 1.4, depending on the desired crater form (see Figure 4-4-5 Plans F and G, and Figure 4-4-8).

(2) For simultaneous initiation of charges in the same row (see Figure 4-4-5 Plans B and D, and Figure 4-4-9), Ks should be about 2.0. In practice, lower values of Ks are generally needed when Kh is less than about 4.0 to balance blast effects between holes and compensate for the relatively shorter explosive columns involved (see Figure 4-4-7).

If Kh =	1.0	1.5	2.0	2.5	3.0	3.5	4.0 (+)
Try Ks =	1.4	1.5	1.6	1.7	1.8	1.9	2.0

Figure 4-4-7 Suggested Ks Values for the Design of Trial Blast Involving Simultaneous Detonation of Charges in the Same Row

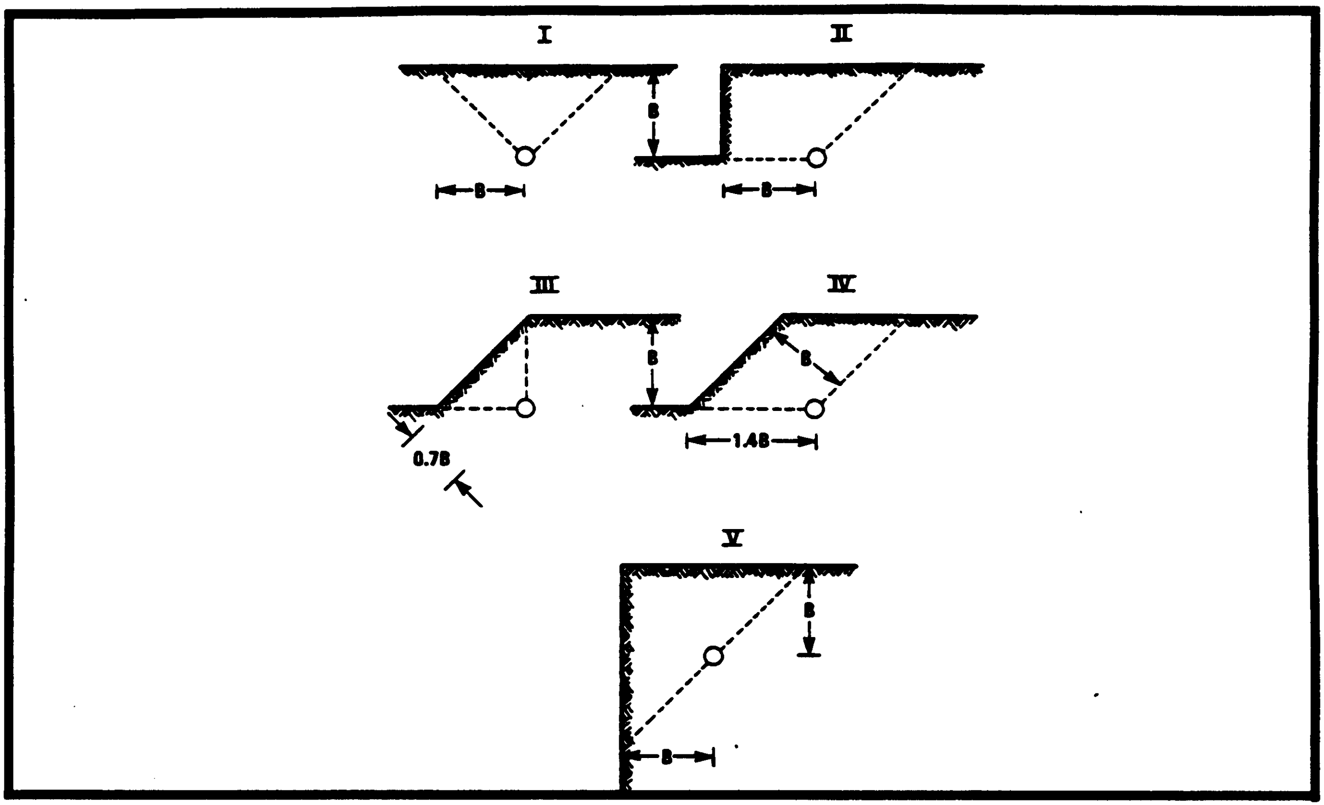


Figure 4-4-8 Basic crater forms in the plane of charge diameter for independently-fired charges.

(3) For sequence timing in the same row and simultaneous initiation between charges in adjacent rows (Figure 4-4-5, Plan A), the entire blast should be laid out in a square grid to balance stresses throughout. When so designed, the true burden, B, and true spacing, S, between holes will lie at about a 45 degree angle to the original face. For convenience, the patterns should be laid out using the terms b and s where:

b = 1.4(B) (Equation 4-13)

s = Ksb (Equation 4-10a)

In such square patterns, Ks normally has a value of 1.0 so that s = b. Larger values of Ks, up to about 1.2, may be used in some cases to promote rock movement forward, away from the face. Likewise, Ks values slightly less than 1.0 may be used to promote rock movement along or parallel to the original face.

b. **Evaluation of Ks.** Ks controls blast effects between boreholes. Incorrect Ks values produce the following:

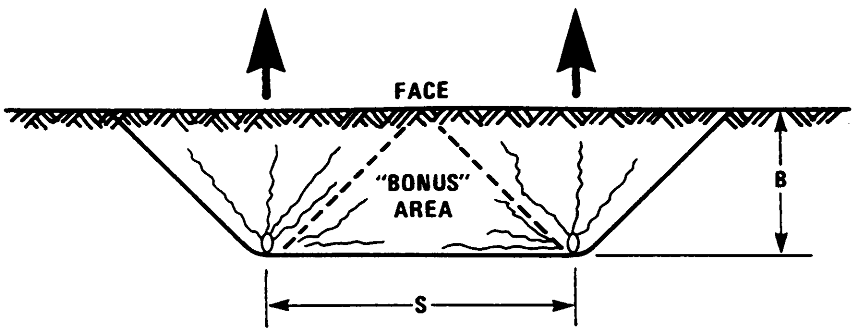


Figure 4-4-9 Basic crater form in the plane of charge diameters for simultaneously-fired charges

(1) Ks too small - shearing action between holes causes burden to displace before complete fragmentation has had time to occur; large slabs and boulders present on outside of muckpile; backbreak between holes leaves irregular face.

(2) Ks too large - incomplete fragmentation between holes leaves irregular face, humps in the quarry floor and oversize in the muckpile within the bonus area. (See Figure 4-4-9)

10. **Calculation of Explosive Weight (E).** The total weight of explosive, E, required to load a borehole may be calculated by multiplying the loading density, de, by the total length of the charge, C, as follows:

de = 0.786(De)2(Ge)(w) Equation 4-5)

C = (H-T) for a single borehole (Equation 4-14)

E = de(C) for a single borehole (Equation 4-15)

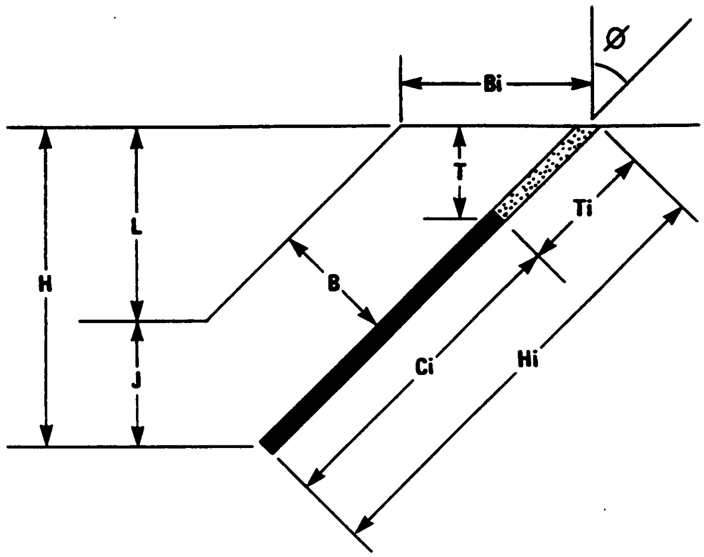
11. **Use of Inclined Boreholes.** Boreholes inclined at angles of 10 degrees to 45 degrees to the vertical offer many advantages over the usual vertical holes (see Figure 4-4-10). Such holes may be designed using the same methods and considerations described above except that the layout must consider the inclined length of the borehole (Hi), stemming (Ti), and explosive charge (Ci) and the apparent surface length of the burden (Bi) (see Figure 4-4-11). Benefits tend to increase progressively as holes approach 45 degree inclinations.

Advantages	
!	Boreholes can be aligned parallel to structural features in the rock or inclined rock surfaces.
!	Improved stress balance in the toe and collar regions results in better fragmentation, less backbreak and ground vibration, elimination of toe problems and improved production per unit weight of explosive.
!	Less subdrilling is needed and basing produces less damage to the rock below the established grade line.
!	Smaller charge diameters or larger burdens and spacings can be used.
!	Operations are safer for men and equipment along the face.
Disadvantages	
!	Inclined boreholes are difficult to lay out on irregular ground.
!	Holes inclined more than about 20 to the vertical are hard to align and may cause excessive drill wear.
!	Inclined boreholes are difficult to load and stem due to sidewall friction unless pneumatic loading equipment is used.

Figure 4-4-10 Advantages and Disadvantages of Inclined Boreholes

SUMMARY

12. **General.** Blast design is a function of many variables. Inevitably, design plans change on site as blast results are observed. This is acceptable because field conditions are seldom ideal. The method of design in this section recognizes that adjustments will likely be made. There are two less complicated methods of blast design based on trial shots that can be found in US Army publication TM 5-332 pages 37 to 39. These methods are very broad and involve a great deal of time and effort in trial and error sequences to determine the blast design for the site.



ANGLE (Ø)	COSINE
10°	0.985
15°	0.966
20°	0.940
25°	0.907
30°	0.866
35°	0.820
40°	0.767
45°	0.707

$$B_i = B/\cos \phi \quad (5\text{-}17)$$
$$T_i = T/\cos \phi \quad (5\text{-}18)$$
$$C_i = C/\cos \phi \quad (5\text{-}19)$$
$$H_i = H/\cos \phi \quad (5\text{-}20)$$

Figure 4-4-11 Design Dimensions for Inclined Boreholes

SECTION 5

PREPARATION OF HOLES

GENERAL

1. **General.** The preparation of holes for blasting is an important step in blasting operations. A poorly prepared hole may create a partial misfire which causes safety problems as well as delays in production. This section outlines the considerations required to drill, clean and load holes.

DRILLING

2. **General.** Boreholes for quarry operations may be vertical or inclined. Whenever possible vertical holes are used because they are easier and quicker to drill. Where a distinct seam or separation does not occur at the quarry floor, subdrilling should be done. Subdrilling, or drilling below the floor level, prevents the occurrence of toes at the face bottom. To keep the quarry floor level, all vertical holes should be drilled to the same elevation while inclined holes should be started at the same level and drilled at the same angle. The basic rubs of drilling are to start the hole straight and keep the drill bit cutting, through the application of the proper amount of pressure.

CLEANING

3. **General.** As the depth of the hole increases, it is imperative that the dust and chips be cleaned out to permit the bit to cut more effectively. Failure to do this results in a decrease in the rate of drilling as well as an increase in the probability of sticking or binding the drill steel. The grit or cuttings in an uncleaned hole use valuable space intended for explosives as well as making loading difficult. Cleaning provides a check for obstructions which may damage fuses, detonating cord or rip bagged explosives. Holes can be cleaned by the use of compressed air or water. Once cleaned, the hole should be plugged with wooden or paper plugs to keep rain, dirt and small rocks from falling into the hole.

LOADING

4. **General.** Because many civilian explosives may be detonated by impact or friction, the loading of boreholes should be the responsibility of properly trained personnel. Extraneous electricity, such as from a thunderstorm several miles away, may cause electrical firing devices to initiate. Improper tamping or placing of primers, delays, etc, may result in partial misfires or premature firing. There are various methods to load explosives which include loading cartridges, blasting agents and slurries by hand, pneumatically or in bulk. These methods are clearly described in the CIL Blasters' Handbook. A discussion of stemming boreholes and loading in wet boreholes is included in Chapter 11 of the handbook. The reader is strongly advised to consult this reference before loading boreholes.

SECTION 6

BLASTING METHODS

GENERAL

1. **General.** The selection of drilling patterns and initiation is as important as the selection of borehole and charge parameters. Drilling patterns and initiation should be designed to complement charges and mucking operations to improve total quarry efficiency. This section outlines drilling and blasting patterns for single and multiple rows, as well as patterns for dealing with rock cracks. It also outlines sinking cut blasts (establishing a quarry face) and pre-shearing techniques.

DRILLING AND BLASTING PATTERNS

2. **Planning Guidelines.** Blasting patterns are usually selected based on the desired direction(s) of rock displacement, final cut configuration, rock structure, and the amount of explosive allowed per delay interval (to control noise, airblast and ground shock). The basic patterns shown in Figure 4-4-5 may be used as a first approximation for the layout of production blast arrays. Individual patterns may be combined or modified in various ways to meet local needs. For example, individual burdens, spacings and charges may be adjusted to meet variations in rock resistance or structure. Independently-fired or delayed boreholes may be added to rows or patterns to square corners, direct displacement or improve fragmentation in difficult areas. Using the guidelines presented in Section 4 of this chapter, one can even lay out patterns involving combinations of vertical, inclined and/or horizontal boreholes. Whatever the situation, the blast dimensions, charge distribution and delay sequence should be planned so that each charge has adequate energy to fragment and displace its respective burden and adequate relief to develop its full cratering capacity.

3. Single-row patterns (Figure 4-6-1) are usually used for shallow cuts and for blasting high benches where blast violence and muckpile height restrictions limit operations.

   a. **Simultaneous Initiation.** This pattern (Figure 4-6-1 (a)) allows relatively wide spacings between charges and affords maximum breakage per borehole with relatively large forward displacement. Due to the large charge spacings and possibility of shearing between charges, its use may result in problems with oversize, humps and bootlegs between holes. On large arrays the number of charges per delay may create excessive noise, airblast and ground vibration.

   b. **Delayed Initiation.** This pattern (Figure 4-6-1(b)) requires more holes per width of face, but it provides a better distribution of blast energy and more control over displacement and violence than the simultaneous pattern. Fragmentation is generally improved due to the twisting motion imparted to the rock and collision of fragments as holes detonate in sequence. Since each hole will tend to displace rock toward the crater formed by the preceding charge, displacement may be controlled by arranging the detonation sequence from the center out, from left to right or from right to left according to your needs.

4. Multiple-row patterns (Figure 4-6-2) are used in most production rock blasting, generally with benches up to about 12 metres in height. Burden and spacing relationships are usually determined in accordance with the guidelines presented in Section 4 of this chapter except that in very deep patterns (generally involving more than 4 rows), the distance between rows (B or b) may need to be reduced by up to 30 per cent to compensate for accumulations of blastrock against the face.

   a. **Staggered and Rectangular Patterns.** These patterns are used for the simultaneous initiation of holes within a row and with delays between rows. Both patterns direct cratering effects forward from the face at right angles to the rows. If more than one face is present, rows may be laid out to direct rock movement either out into the quarry or laterally along the cut (see Figure 4-4-5, plans C and D). The staggered pattern employs offset rows to improve charge distribution and fragmentation in the bonus area. Rectangular arrays are commonly used in construction blasting other than quarrying. They are particularly useful for through cuts where square corner-cuts and even sidewalls are desired.

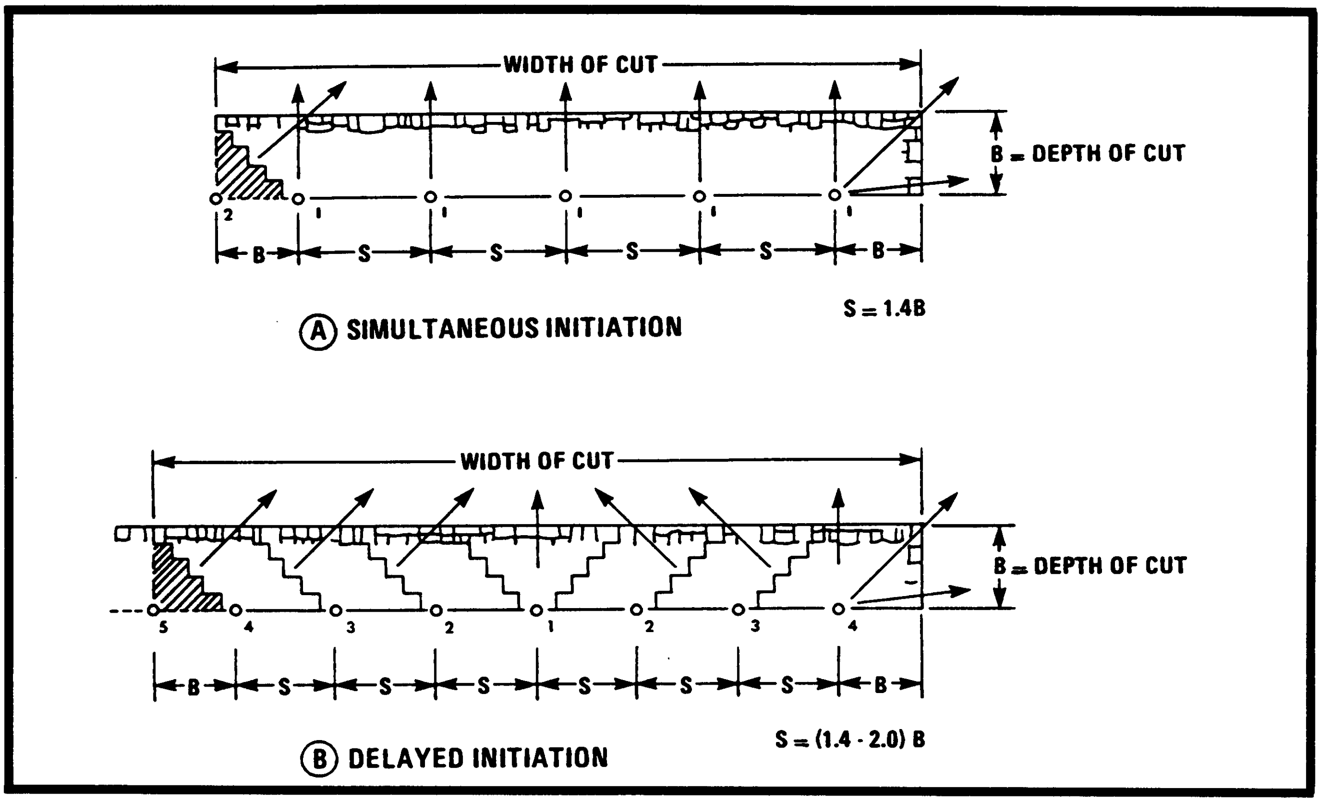


Figure 4-6-1 Single-row Blasting Patterns

b. **Square Patterns.** These patterns are most widely used for quarrying rock aggregates. Like single-row delay patterns, they afford good control over rock displacement and generally improved fragmentation with a minimum of violence They also facilitate the maintenance of square corners, should this be desired. Layout requires close supervision to assure that charges are primed and fired at the proper delay interval.

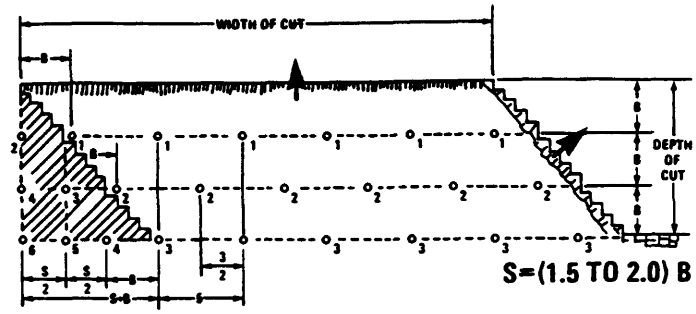
5. **Effects of Structure on Patterns.** Major cracks, cavities and weak rock zones can reflect shock waves and permit rock movement much like a free face. Where such features are present within a cut, blasting patterns often require modification to assure a balanced distribution of blast energy.

a. Vertical or near vertical cracks or weak zones can be treated much like the corner of a bench. Initial boreholes may be laid out a burden distance from the crack and the remainder of the pattern can then be bore on these holes (Figure 4-6-3). Where practical, patterns should be laid out parallel to such features to increase the rock yield per borehole.

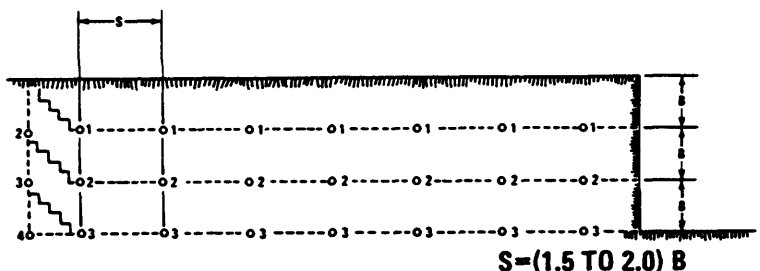
b. **Inclined Cracks.** When cracks, fissures or weak rock zones are inclined so much that vertical boreholes leave excessive burdens near the bottom, you may have to resort to inclined holes to remove the material below the crack (Figure 4-6-4). A similar technique may be used to blast inclined faces for effective toe removal. Notice that the rock above the crack is removed first.

This method is only needed where it is not possible to drill through the crack and deck load around it. Usually patterns should be laid out at right angles to such inclined features to avoid toe or overhang problems along the face.

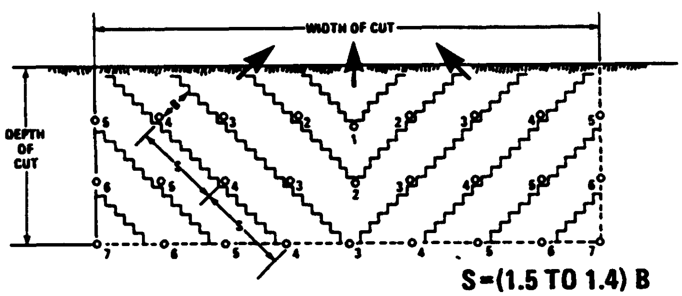
c. Horizontal cracks or weak zones may usually be blasted using a normal pattern except that inert stemming material may be used to bridge the weak zone. If the zone is of such a size that it cannot be drilled through, the rock may be removed in two lifts using vertical or horizontal holes. Explosive diameters, burdens and spacing, may require adjustments to compensate for decreased hole lengths.



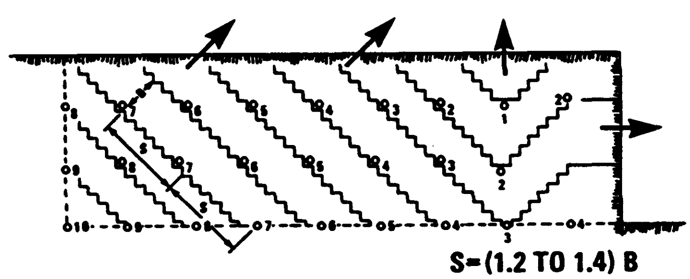
(A) STAGGERED PATTERN FOR DELAY BETWEEN ROWS, SIMULTANEOUS WITHIN ROWS



(B) RECTANGULAR PATTERN.



(C) DELAYS WITHIN ROWS-THROWN TO CENTER.



(D) DELAYS WITHIN ROWS-THROWN TO SIDE.

Figure 4-6-2 Multiple-row Blasting Patterns

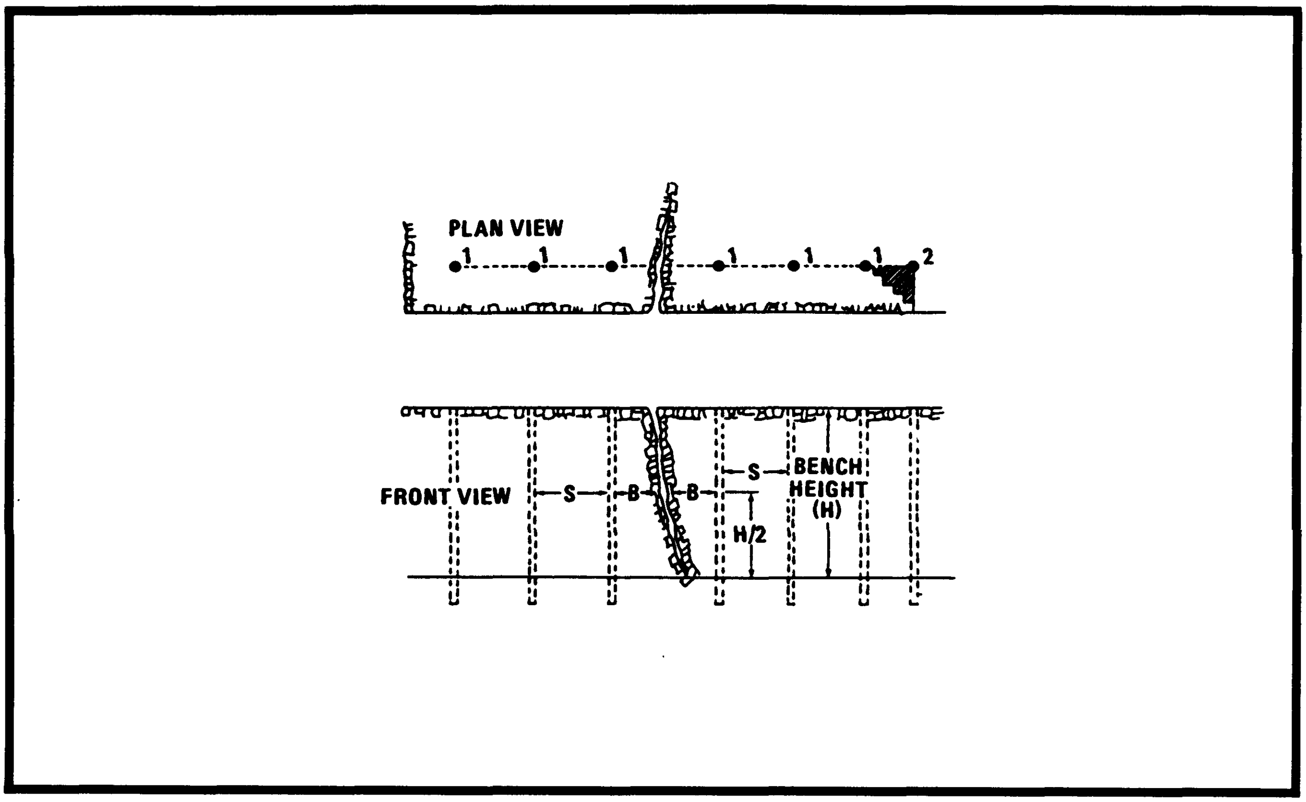


Figure 4-6-3   Blasting Pattern Along a Vertical OU4F;92517500118G Crack.

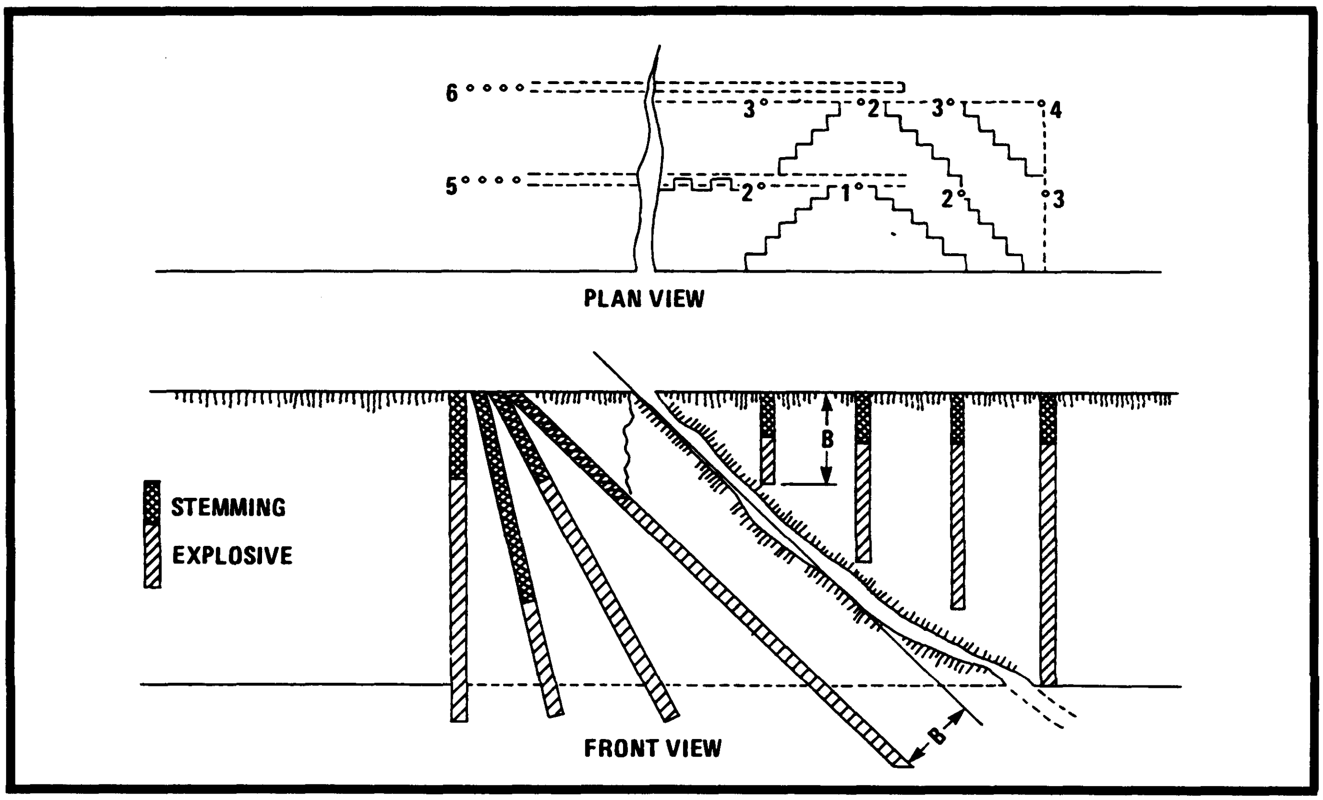


Figure 4-6-4   Blasting Pattern Along an Inclined Crack

SINKING CUT BLASTS

6. **General.** Sinking cuts are blasted to open a free face so that subsequent blasts can begin breaking it. It is similar to blasting for a building foundation where faces are created. Figure 4-6-5 shows a drilling pattern for a sinking cut blast. Initiation is best done with split second short period caps. The centre holes should be primed with no. 0 periods with the surrounding holes progressively using higher number delays (See Section 3, paragraphs 12 to 15 of this chapter). This results in the center shots blasting the cut while the surrounding holes progressively break into this free face. Charges in the early firing holes should be concentrated as low as possible. In later firing holes the charges should be placed within 1 to 2 metres of the collars for proper fragmentation. Firing intervals are usually 25 ms. Sinking cuts can be blasted from 4.5 to 6 metres in a single lift.

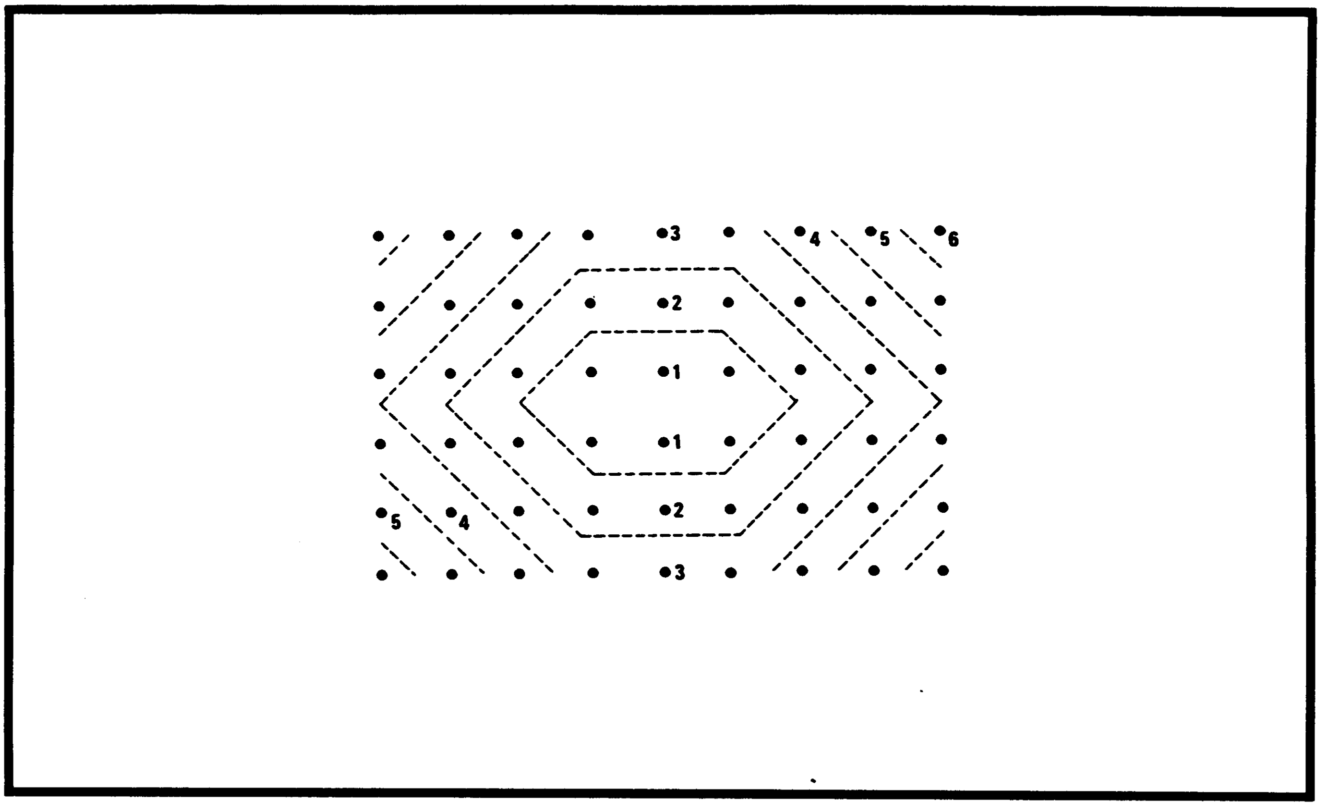


Figure 4-6-5 Drilling Pattern for a Sinking Cut f(numbers indicate sequence of initiation).

PRE-SHEARING

7. **General.** Pre-shearing is a blasting technique used to create a smooth, vertical wall with minimum or no overbreak. It essentially involves a perimeter line around the excavation of closely spaced holes that are lightly loaded and detonated with the primary blast. This creates a zone of weakness which reflects the primary blast and prevents overbreak.

8. **Drilling and Loading Pattern.** Pre-shear holes are usually 64 mm in diameter and 305 to 610 mm in spacing. Good hole alignment is necessary for good pro-shearing results. Pre-shear holes are seldom more than 9 metres deep. If holes are less than 450 mm apart, every second hole may be loaded while every hole is loaded when the spacing is 610 mm. Under normal rock conditions the load per metre of hole is from 0.22 kg to 0.37 kg. The best explosive to use for pre-shearing is Xactex or Shearex (see Annex A to this chapter) initiated with a forcite primer or detonating cord.

9. **Firing.** Pre-shear holes must be fired at the same time for shearing action to result from hole to hole.

Pre-shearing should also be fired with the primary blast in quarrying. This reduces the drilling and blasting cycle and eliminates difficulties in drilling after pre-shearing due to ground movement. The circuit should be arranged with delays or relays to produce the following sequence:

a. all pre-shear holes fired instantaneously;

b. holes in primary blast fired; and

c. subsequent series holes fired to open the face while retreating towards the pre-shearing.

The row of holes immediately in front of the pre-shear face should be primed at the top and at the bottom to guard against the possibility of ground movement cut-offs.

10. **Precautions in Pre-shearing.**

a. The row of holes in front of the pre-shearing face should be the same diameter as the pre-shear holes and be no closer than 1 metre from the free face. This will contribute towards a smooth pre-shear wall.

b. The row of holes in front of the pre-shearing face should have a delay with one consecutive delay period omitted in order to have minimum relief of burden. There should never be two rows of holes on the same delay period in front of any pre-shearing holes.

SECTION 7

EXPLOSIVE AIDS TO LOOSENING FILL

GENERAL

1. **General.** There may be a requirement to loosen fill before a shovel, loader or scraper can pick up the material. A ripper is the ideal solution to this problem, however, one may not be available. Explosives may be used as a means of loosening the fill for mechanical excavation.

2. **Method.** There is no simple formula to determine the amount and position of explosives because of variables which include the type of explosive and the type of material. Therefore the best means to determine the quantity of explosives required to sufficiently loosen the fill is by test blasts on site. The procedure on use of explosives as a digging aid for field defences, found in B-CE-320-002/PT-001, Engineer Field Manual, Volume 2, Engineer and Assault Pioneer Field Pocket Book and B-GL-320-007/PT-001, Engineer Field Manual, Volume 7, Field Defence and Obstacles, may be used as a guideline for loosening material with explosives for mechanical excavation.

SECTION 8

SUMMARY

GENERAL

1. **General.** Drilling and basting constitute a major phase in most quarry operations and can employ a great deal of the personnel. Because of the number of personnel involved, and the vast amount of explosives used in quarry operations, care and respect should prevail during blasting. Generally, civilian explosives are better suited for quarry operations than general purpose military explosives. Proper handling of explosives and efficient employment and layout in drilling and blasting can result in significant yields of fragmented rock for further processing in the quarry operation cycle.

ANNEX A, CHAPTER 4
TYPES AND PROPERTIES OF CIVILIAN EXPLOSIVES OF USE IN QUARRY OPS

SER	EXPLO-SIVE	STRENGTH	VELOCITY OF DETONA-TION	DENSITY	PHYSICAL CHARACTERISTIC	WATER RE-SISTANCE	FUMES	STORAGE QUALITY	REMARKS
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
1	CIL Ditching Dynamite	50%	5330 m/s (high)	110 cartridges	Very cohesive in cartridges	Excellent	Class 3	Excellent	Not used in boreholes, expensive, sensitive to shock, flammable
2	Dynamex	40, 50, 60, 70%	3600 to 2700 m/s	140-144 cartridges	Cohesive, granular in cartriges	Good if unbroken	Class 2		Very effective for quarry ops, economical
3	Ammonia Dynamite	20% to 60%	2100 to 2700 m/s	150-163	Fairly cohesive, granular in cartridges	Satisfactory if unbroken and fired after reloading	Class 2 (60% class 3)		Good for quarries where breaking conditions not difficult, minimum
4	Belite-A	60%	2700 m/s	158	Fairly cohesive, granular in cartridges	Reasonable if unbroken			Useful if breaking conditions not difficult
5	Polar Stumping Powder	20%	1800 m/s (low)	137	Granular in cartridges	Low	Class 3		Effective for stump blasting or for frozen soil or gravel
6	Blastol	60%	3400 m/s (medium)	158 cartridges	Fairly cohesive, granular in cartridges	Sufficient if unbroken	Class 3		General surface work

SER	EXPLO-SIVE	STRENGTH	VELOCITY OF DETONA-TION	DENSITY	PHYSICAL CHARACTERISTIC	WATER RE-SISTANCE	FUMES	STORAGE QUALITY	REMARKS
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
7	Giant Gelatin	20% to 90%	4300 to 7000 m/s	104 to 135	Dense, cohesive, very plastic	Excellent	20-60% Class 1 75% Class 2 80-90% Class 3	Excellent	Expensive
8	Forcite	30% to 90%	4200 to 6900 m/s	115 to 139	High density plastic	Good up to 2-3 days	Class 1	Very good in good atmosphere	Widely used, cost moderate
9	Geogel	60%	6100 m/s		Rigid, spirally would glued shells very plastic	Excellent	Class 2		Shells 5.7 cm x 2.21 kg and 5.7 cm x 1.1. kg
10	Submagel	40% to 95%	High	122 to 129	Dense, cohesive plastic	Good for several days in water	Class 1 (40-60) Class 3 (75-95)		Very effective for underwater blasting
11	Power Frac 75	75%	4900 m/s	1.34 g/cc	Cartridges	Excellent	Class 3		
12	Dygel	75%	4600 m/s	145	Cohesive in cartridges	Sufficient if fired after loading	Class 1		Used in long hole blasting operations
13	Cilgel B	70%	3700 m/s	145	Cohesive in cartridges	Sufficient if fired after loading	Class 1		Good replacement for Amex II or AN/FO in wet holes
14	Cilgel C	70%	3700 m/s	160	Cohesive in cartridges	Sufficient if fired after loading	Class 1		

SER	EXPLOSIVE	STRENGTH	VELOCITY OF DETONATION	DENSITY	PHYSICAL CHARACTERISTIC	WATER RESISTANCE	FUMES	STORAGE QUALITY	REMARKS
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
15	Xactex		2600 m/s		Rigid tubes 610 mm x 16 mm	Sufficient if fired after loading		Requires good storage	Used to control overbreak and in pre-shearing
16	Shearex		2900 m/s	138	Rigid tubes 406 mm x 22 mm	Sufficient if fired after loading	Class 1	Requires good conditions	Used in perimeter blasting and pre-shearing
17	Nitrone T1, T3	Equal to 50 and 60% gelatin	3400 to 4300 m/s	1.3 to 1.5 g/cc	127 mm cans from 229 to 610 mm long	Unlimited in undamaged can		Excellent	Requires a primer, excellent for quarry ops
18	Nitrox	Equal to 80-90% gelatin	4800 to 5600 m/s	1.7 g/cc	Same as 17	Same as 17		Excellent	Stronger and denser than Nitrone (17)
19	Amite or Amite II	Equal to 50% gelatin	3500 m/s	1.1 g/cc	100 to 229 mm dia paper and steel cans	Sufficient in unbroken paper if fired, excellent in cans			Used in large dia holes and substitutes for Nitrone T3
20	Nitropel		5000 m/s	0.94 g/cc	Free running agent in 5.7 cm bags	Unlimited			Used to increase density of borehold around Nitrone Nitrox or Amite cans (17-19)
21	Amex		3300 m/s	0.8 g/cc	Free flowing AN/FO prills and oil in 22.7 kg bags	None			Suitable for variety of blasting operations

SER	EXPLOSIVE	STRENGTH	VELOCITY OF DETONATION	DENSITY	PHYSICAL CHARACTERISTIC	WATER RESISTANCE	FUMES	STORAGE QUALITY	REMARKS
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)
22	Lomex		2500 m/s	0.9 g/cc	AN/FO smaller to Amex II	None			Lower energy than Amex II (21) and used where there are problems with ground control
23	Hydromex and Hydromex T-3	Same as high strength gelatin (7)	5600 m/s	1.55 g/cc	AN, TNT, water in bags w/dia 13 to 203 mm or bulk loading				Good gor hard breaking ground
24	Hydromex T-9	Same as Hydromex (23)	5800 m/s	1.55 g/cc	More TNT than Hydromex (23)				Improved shattering effect than Hydromex (23)
25	Hydromex M-2, M-4, M-8	27, 57, 100% more energy than Hydromex (23)	4900 m/s	1.55 g/cc	AN, TNT, water and powdered metals				Better performance than Hydromex (23)
26	Hydroflo, Hydroflo 5, 10 and 15		4900-5600 m/s	1.45 g/cc	203 mm x 22.7 kg bags, fluid slurry	Good			Good for medium to large diameter holes
27	Nitrex 2, 3, 4, 5, 6, 8		4000 m/s	1.25 - 1.36 g/cc	NCN slurries in bag or bulk	Good			Good for medium to large diameter holes
28	Powermax	Equal to Forcite 75% (8)	3800-4600 m/s	1.25 g/cc	Metallize cap sensitive Slurry in tubing or bulk	Excellent	Class 1	Excellent	

NOTE

Serial 1 Straight nitroglycerin dynamite.

Serials 2 – 6 Ammonia Dynamites - use ammonium nitrate for a portion of the liquid nitroglycerin. They are less sensitive to shock and friction and less resistant to water.

Serials 7 – 11 Gelatin Dynamites - have a gel base that varies from thick liquid to a rubber-like substance. They are insoluable in water and are plastic in nature.

Serials 12 – 16 Semi-gelatin Dynamites - are economical and useful when storage, exposure and use are not severe.

Serials 17 – 19 Packaged grade blasting agents are largely ammonium nitrate. They are relatively safe in handling and have a low sensitivity to shock, friction and impact.

Serials 20 – 22 Free Running Blasting Agents.

Serials 23 – 28 Blasting slurries have a gel-like consistency. They combine high bulk strength, high density and VOD with low sensitivity to shock, friction and impact.

ANNEX B, CHAPTER 4
PRIMERS

SER	PRIMER	EXPLOSIVE	FORM OF PRIMER	COMPOSITION	PRIMER INITIATED BY	REMARKS
(a)	(b)	(c)	(d)	(e)	(f)	(g)
1	Nitrone Primer	Nitrone, Amite and blasting agents packed in rigid containers	In cans of sizes: 100 mm x 610 mm 126 mm x 610 mm 178 mm x 610 mm	Ammonium nitrate	detonator or detonating cord	VOD - 4000 m/s Density - 1.2 g/cc
2	Pento-Mex Primer	Slurry or AN/FO mixtures	In cans 0.16 or 0.32 kg and 51 to 127 mm dia and 51 to 127 mm length	TNT and PETN mixture	detonating cord or detonators	VOD 8000 m/s Density 1.6 g/cc completely waterproof, long storage life
3	Procore Primer	Slurry or AN/FO mixture	Same as Pento-Mex (2)	TNT cast around a Pentolite core	detonating cord	Same as Pento-Mex (2)
4	Primte Primer	Amex II	Cartridges of size: 22 x 101 mm 25 x 101 mm	High strength semi-gelatin	detonating cord	
5	Nitrone S-1 Primer	Same as Nitrone Primer (1)	In 0.45 kg cans	Ammonium nitrate	electric detonator or detonator cord	Density 1.2 g/cc VOD 4000 m/s

ANNEX C, CHAPTER 4
GENERALIZED PROPERTIES OF SELECTED ROCKS

GENERALIZED PROPERTIES OF SELECTED ROCKS					
ROCK TYPE	DENSITY (Gr) gm/cc		TYPICAL SEISMIC VELOCITY (Vr)*	SOLID WEIGHT	
	AVERAGE	RANGE		pcf	T/CY
Basalt	2.86	2.8-3.1	High	178	2.41
Coral	2.3	2.1-2.5	V. Low	143	1.93
Diabase	2.96	2.6-3.1	High	182	2.46
Diorite	2.92	2.8-3.0	High	182	2.46
Dolomite	2.74	2.7-2.9	Medium	171	2.31
Falsite	2.66	2.5-2.8	Medium	166	2.24
Gabbro	2.96	2.9-3.1	High	185	2.49
Gneiss	2.74	2.6-2.9	Medium-High	171	2.31
Granite	2.65	2.6-2.9	Medium-High	165	2.23
Limestone	2.66	2.4-2.9	Medium	166	2.24
Marble	2.63	2.4-2.9	Medium	164	2.22
Sandstone	2.54	2.2-2.8	Low-Medium	159	2.14
Shale	2.5	2.4-2.8	Low	156	2.11
Schist	2.85	2.5-2.9	Medium	178	2.40
Syenite	2.74	2.7-2.9	Medium-High	171	2.31
Quartzite	2.69	2.5-2.8	High	168	2.27

* Seismic velocity (Vr) of rock generally varies with density. In general, the range considered for high, medium or low are as follows:

HIGH - More than 5580 m/s

MEDIUM - 3600 m/s to 5580 m/s

LOW - Less than 3600 m/s

LOADING DENSITY
ANNEX D, CHAPTER 4

Effective Explosive Diameter (inches)	Loading density, de, in pounds per foot of column for given densities, Ge.												
	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90
1.00	0.24	0.27	0.31	0.34	0.37	0.41	0.44	0.48	0.51	0.54	0.58	0.61	0.65
1.25	0.37	0.43	0.48	0.53	0.58	0.64	0.69	0.74	0.80	0.85	0.90	0.96	1.01
1.50	0.53	0.61	0.69	0.84	0.84	0.92	1.00	1.07	1.15	1.23	1.30	1.38	1.46
1.75	0.73	0.83	0.94	1.14	1.14	1.15	1.36	1.46	1.56	1.67	1.77	1.88	1.98
2.00	0.95	1.09	1.23	1.50	1.63	1.63	1.77	1.91	2.04	2.18	2.32	2.45	2.59
2.25	1.20	1.38	1.55	1.72	1.88	2.06	2.24	2.41	2.59	2.76	2.93	3.10	3.28
2.50	1.48	1.70	1.92	2.13	2.33	2.54	2.77	2.98	3.19	3.40	3.62	3.83	4.04
2.75	1.79	2.06	2.32	2.57	2.81	3.07	3.35	3.60	3.86	4.12	4.38	4.63	4.89
3.00	2.04	2.45	2.76	3.06	3.36	3.67	3.98	4.29	4.60	4.90	5.21	5.52	5.82
3.25	2.50	2.88	3.24	3.60	3.93	4.29	4.68	5.03	5.39	5.75	6.11	6.47	6.83
3.50	2.91	3.32	3.75	4.17	4.58	5.00	5.42	5.84	6.26	6.67	7.09	7.51	7.92
3.75	3.35	3.83	4.31	4.79	5.26	5.74	6.22	6.70	7.18	7.66	8.14	8.62	9.10
4.00	3.73	4.36	4.90	5.45	5.86	6.40	7.08	7.63	8.17	8.72	9.26	9.81	10.35
4.50	4.82	5.52	6.21	6.89	7.56	8.25	8.96	9.65	10.34	11.03	11.72	12.41	13.10
5.00	5.96	6.81	7.66	8.51	9.59	10.21	11.07	11.92	12.77	13.62	14.47	15.32	16.17
5.50	7.17	8.24	9.27	10.30	11.28	12.30	13.39	14.42	15.45	16.48	17.51	18.54	19.57
6.00	8.58	9.81	11.03	12.26	13.49	14.71	15.93	17.16	18.39	19.61	20.84	22.06	23.29
7.00	11.68	13.35	15.02	16.68	18.35	20.02	21.69	23.36	25.03	26.69	28.36	30.03	31.70
8.00	15.26	17.43	19.61	21.79	23.97	26.15	28.33	30.51	32.69	34.87	37.04	39.22	41.40
9.00	19.30	22.06	24.82	27.58	30.35	33.09	35.85	38.61	41.37	44.13	46.88	49.64	52.40
10.00	23.84	27.24	30.64	34.05	37.46	40.86	44.26	47.67	51.07	54.58	57.88	61.29	64.69

CHAPTER 5

PLANNING AND OPERATION OF PITS

SECTION 1

INTRODUCTION

GENERAL

1. Pits are often a good source of material for construction projects. They are more economical and generally simpler to operate than quarries since no drilling, blasting or crushing is required. Pits generally require less equipment and fewer phases of operations than quarries.

AIM

2. The aim of this chapter is to discuss the planning and operation of pits.

SCOPE

3. This chapter describes the types of pits, the layout of a pit, the development of pits and a pit organization.

SECTION 2

TYPES OF PITS

GENERAL

1. There are thee types of pits. These include borrow pits, sand and gravel pits and miscellaneous pits. They can be surface or subsurface pits.

BORROW PITS

2. Borrow pits are the source of select soil other than sand and gravel for use in embankments, fills and subgrades. The pit is normally worked dry with earthmoving equipment and should be drained to eliminate standing water. Borrow pits used to furnish material for construction should be located near roads. Sufficient space between the haul road and the borrow pit must be left to avoid traffic hazards.

SAND AND GRAVEL PITS

3. **General.** There are two kinds of sand and gravel pits.

4. **Bank or Hill.** A bank or hill gravel pit yields a clayey gravel, which is very desirable for surfacing because of its binding qualities. It is also a,source for base courses and fills. Bank gravel pits are worked dry with earthmoving equipment.

5. **Alluvial.** The alluvial gravel pit derives its name from the origin of the deposit as the material has been stream-deposited. The gravel obtained from alluvial pits is usually clean and free of clay and humus, and is therefore particularly desirable for concrete and asphalt work. This type of pit may be worked either wet or dry, depending upon water level conditions. Earthmoving equipment is used to work such pits.

MISCELLANEOUS PITS

6. Miscellaneous pits contain mixed tailings, slag, cinders or the like, for use as surfacing and aggregates. They are worked dry with earthmoving equipment.

SECTION 3

PIT LAYOUT

GENERAL

1. The pit layout plan establishes the location and arrangement of a pit. This plan ensures that adequate space is provided for all future activities, that the flow of materials will be as safe and efficient as possible, and that personnel and equipment requirements are recognized and provided for.

PIT DIMENSIONS

2. The dimensions of the pit are based on bedrock restrictions or rock wall restrictions, the available area of the site, the quantity of material required and the equipment available. Once these factors have been evaluated, the limits of the pit should be established.

OVERBURDEN REMOVAL AND HAUL AND ACCESS ROADS

3. Overburden removal principles for pit operations are the same as those for quarry operation found in Chapter 3. The design and standards for haul and access roads for pit operation is similar to those for quarry operation found in Chapter 3.

DRAINAGE

4. Adequate drainage is an essential part of all pits except alluvial pits. The type of drainage required will depend entirely upon the location of the site and the amount of water to be eliminated. Hillside locations are comparatively easy to drain by making an interceptor ditch along the uphill side with a scraper or dozer or by plowing a single furrow with a breaking plow. When the floor of a site is below ground level, disposal of both surface and seepage water must be undertaken. If open ditches cannot be dug to take advantage of gravity flow, all water must be directed to a sump hole and then removed by a pump. In pits, mud and water make operation of tracked and wheeled equipment difficult or even impossible. A slight slope on the pit floor must be maintained at all times to permit water to drain away from the working face of the pit.

MISCELLANEOUS FACILITIES

5. **Maintenance Areas.** Maintenance hardstands, work shelters and repair parts storage facilities should be convenient to the pit. (See Chapter 3, Section 3, paragraphs 27 to 33.)

6. **Pit Office.** A building or shelter should be provided along the access road to the pit where the pit officer can keep records of production and maintenance.

7. **Lighting.** If the pit is to be operated during the hours of darkness, provision for a pole-mounted lighting system should be made. Commercial electricity or on-site generating equipment may be used for power. All power lines must be strung high enough to clear all traffic.

8. **Miscellaneous.** During site layout planning, consideration should be given to requirements for latrines, POL storage, parking, communications and site security.

SECTION 4

PIT DEVELOPMENT

GENERAL

1. The development of a pit site consists of preliminary and continuing work to achieve the desired layout. This section covers the initial stages of development and the operation of a pit.

OPERATIONS PLAN

2. **General.** After the layout of the pit site has been determined, a detailed operations plan should be prepared. This plan should specify the methods and procedures to be followed for the entire life of the pit. It should take into account the required production, equipment availability, site conditions, maintenance requirements, safety requirements, tactical requirements, and troop availability and training. A general outline for the operations plan should include the areas of development, excavation operations, material handling and miscellaneous items.

3. **Development.** Development should include:

   a. overburden removal (limits, depth, method of removal, location of overburden),

   b. construction of access roads, loading ramps and structures as necessary,

   c. development of pit face and direction of excavation,

   d. drainage plan,

   e. allocation of equipment and personnel for site development, and

   f. administration site development plan (utilities, lights, office, POL, parking, equipment maintenance site, communications, security).

4. **Excavation Operations.** These should include:

   a. method of excavation,

   b. continued overburden removal,

   c. truck routes,

   d. equipment and personnel allocation, and

   e. equipment maintenance.

5. **Materials Handling.** This should include:

   a. hauling equipment and accessories as well as personnel, and

   b. the maintenance cycle.

6. **Miscellaneous Items.** These items include:

   a. daily/shift routine,

   b. records submission,

   c. production meetings,

   d. safety and medical plan, and

   e. other.

PIT DEVELOPMENT

7. **General.** The development of a pit is highly influenced by the type of equipment available. The remainder of this section describes the fundamentals of, and the various methods used, in pit development.

8. **Fundamentals.** The fundamental requirements of pit development are:

   a. **Zoning.** Pits should be divided into zones to permit efficient operation and use of equipment. While one zone is being worked, stripping operations should be in process in another zone, with clearing and grubbing operations being conducted in a third zone.

   b. **Routes.** The routes within the area of operation should always be one way routes. This eliminates the crisscross of loaded and unloaded trucks thus making the hauling process safer and minimizing confusion. This system allows for sufficient waiting room for empty trucks as well.

9. **Excavating with Scrapers.**

   a. **Use of Scrapers.** Tractor-drawn and motorized scrapers are the most efficient items of equipment available to military units for removing large quantities of pit material in a minimum length of time. The maximum efficient one-way haul for crawler, tractor-drawn scrapers, is about 450 metres. In order to obtain a worthwhile load the tractor-drawn scraper needs the help of an additional pusher dozer. Motorized scrapers haul efficiently over good roads up to 1500 metres one way, and may haul as far as 8 to 10 km if necessary. Scrapers are loaded downhill to obtain maximum loads and to facilitate loading. The digging is started on the upgrade just before the crest. The power requirement for the first few yards is small as resistance increases with the load., The machine is rounded into the downgrade for the bulk of the load. This keeps the crest cut down without sacrificing much of the advantage of the slope (see Figure 5-4-1). Material is removed from the floor of the pit in successive thin layers over the entire width of the zone. During excavation, scrapers should be carefully spotted to maintain an even downgrade and to prevent cutting holes below the general level of the floor. If the pit is longer than 30 metres in the direction of loading, the scrapers should be staggered along the length of the cut as well as across the width of the zone. Figure 5-4-2 depicts the layout and development of a scraper pit with lines A-A and B-B showing the limits of the pit. Lines A-A and B-B down the middle of the area divide it into three zones, for concurrent excavating, stripping and clearing. Zone 1 is being excavated, Zone 2 is being stripped and Zone 3 is bring cleared. Three tractor-drawn scrapers in staggered formation, load downhill in Zone 1, while a dozer strips downhill in Zone 2.

b. **Use of Ripper.** In consolidated gravels or soft rock, when scrapers assisted by pusher tractors will not pick up a heaping load in 45 metres, a ripper should be used to loosen the material, thereby increasing the loading efficiency. One method is to attach a ripper to the pusher tractors thus loosening up material for the next pass by the scrapers. This method reduces the quantity of equipment required. A 110-to-140-drawbar-horsepower tractor towing a heavy ripper can loosen 460 to 920 cubic metres per hour. Rippers are operated downhill and an entire zone is ripped at one time while the scrapers are hauling from another zone. While the use of the ripper to loosen the material is generally the most economical method, blasting may be used in the absence of a ripper. Chapter 3, Section 4, paragraphs 2 to 8 discuss selection criteria for blasting versus ripping, while Chapter 3, Annex A, describes ripping techniques.

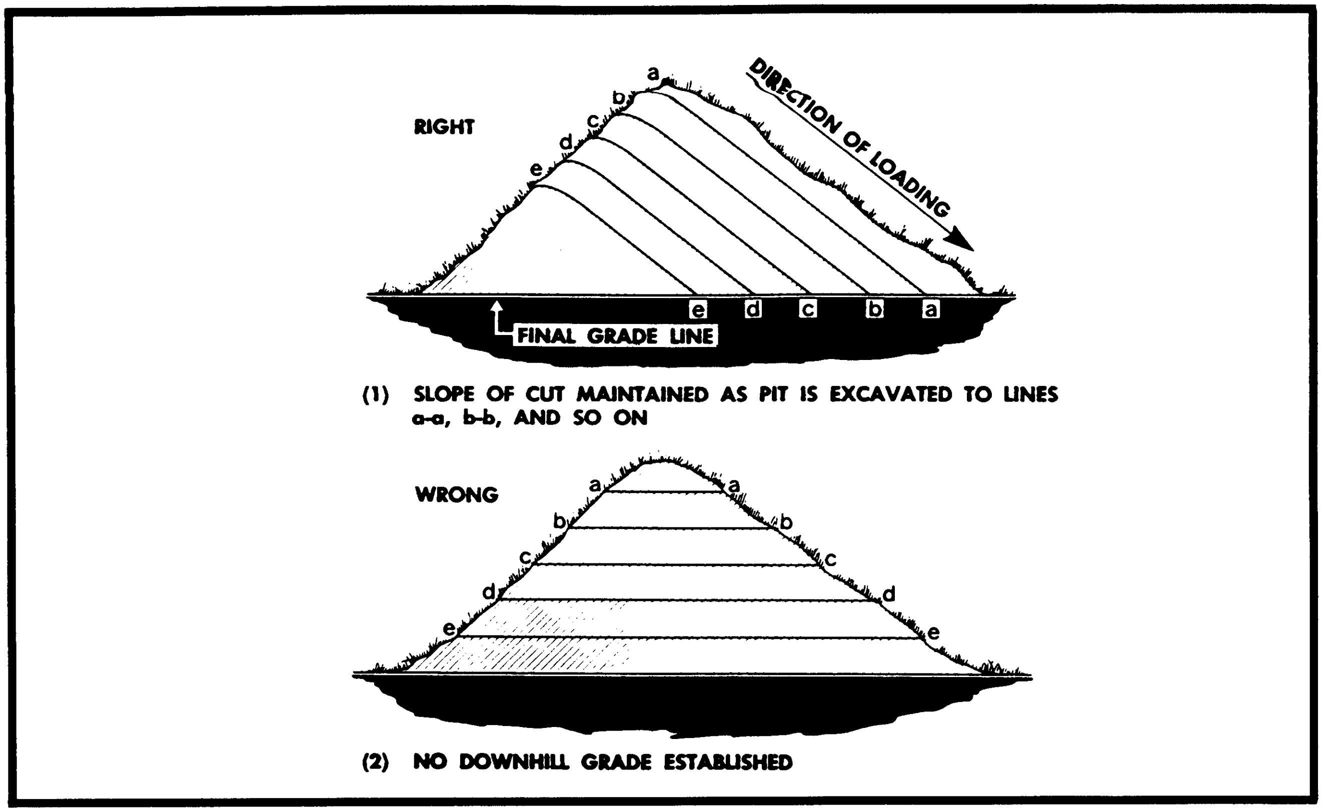


Figure 5-4-1 Right and Wrong Methods of Loading Scrapers

10. **Excavating with Power Shovel and Loading Trucks.**

a. **Operating Principles.** The shovel and truck combination is primarily used in pits consisting of above water gravel deposits, because as a rule, required quantities are less, and hauling distances are greater than for earth borrow pits. The power shovel is particularly adapted to hillside deposit removal. Power shovels may also be profitably adapted to horizontal deposits provided a working face of the proper height is maintained when faces are excessive in height, (over two-thirds boom height) a dozer should be used to feed the shovel from above to prevent a dangerous overhang, or a multiple-face operation should be used.

b. **Terrain Slope Deposits.** Deposits are excavated by power shovels on benches in successive cuts parallel to the contour lines (Figure 5-4-3). First, a road is cut and levelled with a dozer along the toe of the slope of a hill. Starting from this road, the shovel is used to cut into the bank until the shovel is off the road. The shovel is then still in position to reach trucks parked on the road. The first cut is completed, and a second cut made while the trucks use the first cut as a road. When the shovel has advanced into the hill to a point at which the maximum working face height is reached, a second road is dozed above the cut and a new bench started. The stability of the cut slope should be carefully considered. When the second face reaches a maximum height, a third bench is started or the shovel is moved back to the first bench and that face advanced. When more than one shovel is used, several benches may be operated simultaneously. If the benches are of sufficient length and width, two or more shovels may be operated on the same bench. The floor of the benches should always be kept sloping slightly upward toward the face to provide drainage.

c. **Horizontal Deposits.** In level country it is sometimes necessary to use power shovels to excavate material from deposits below the surrounding ground level. This type of pit is particularly adaptable to gravel deposits when drainage is not a problem. When deposits are sufficiently large, pits are best developed by the circular bench method (Figure 5-4-4). One method is to excavate an initial trench of the desired depth with a dozer and/or scraper. Another

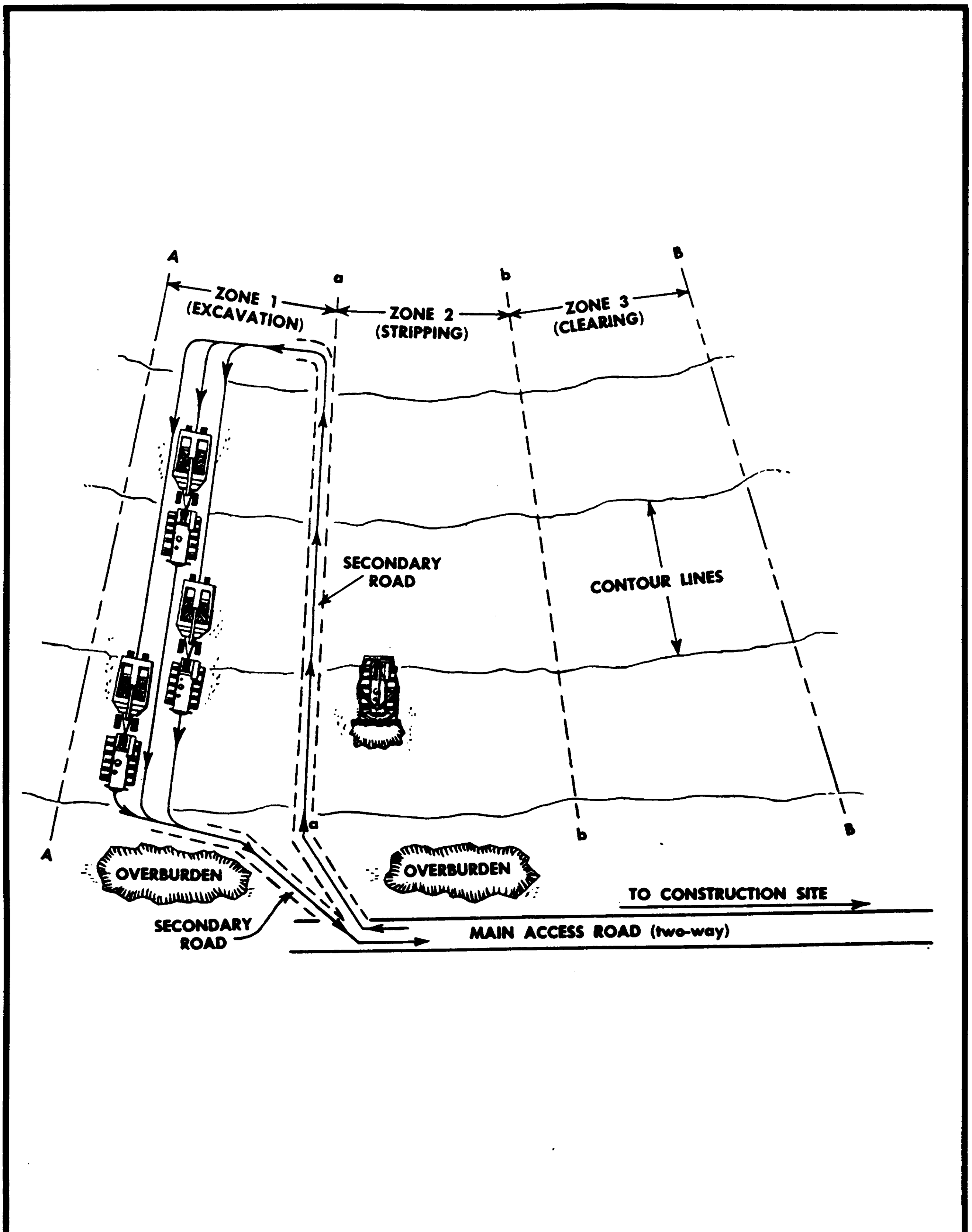
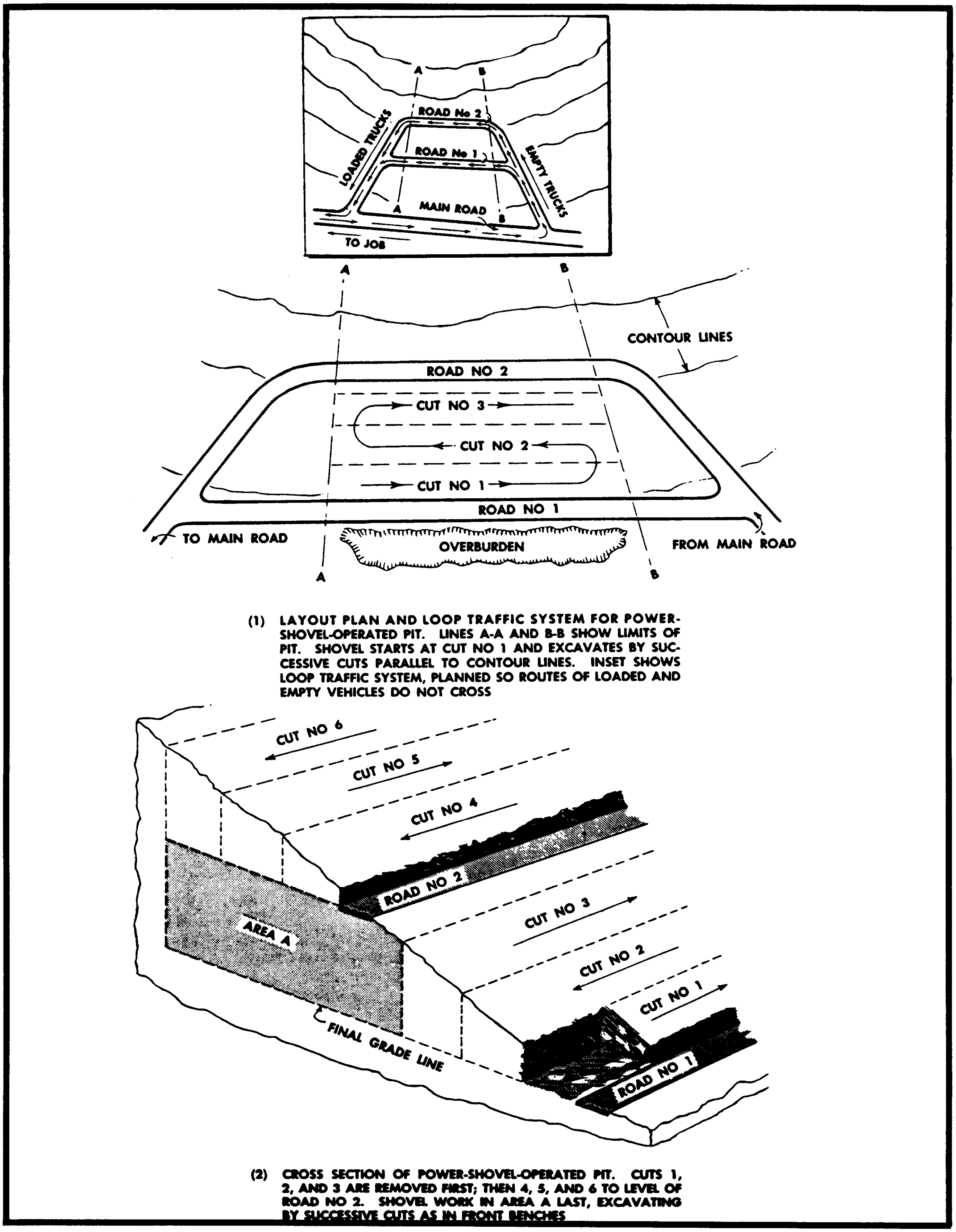


Figure 5-4-2 Layout of Scraper Pit on Hillside



(1) LAYOUT PLAN AND LOOP TRAFFIC SYSTEM FOR POWER-SHOVEL-OPERATED PIT. LINES A-A AND B-B SHOW LIMITS OF PIT. SHOVEL STARTS AT CUT NO 1 AND EXCAVATES BY SUCCESSIVE CUTS PARALLEL TO CONTOUR LINES. INSET SHOWS LOOP TRAFFIC SYSTEM, PLANNED SO ROUTES OF LOADED AND EMPTY VEHICLES DO NOT CROSS

(2) CROSS SECTION OF POWER-SHOVEL-OPERATED PIT. CUTS 1, 2, AND 3 ARE REMOVED FIRST; THEN 4, 5, AND 6 TO LEVEL OF ROAD NO 2. SHOVEL WORK IN AREA A LAST, EXCAVATING BY SUCCESSIVE CUTS AS IN FRONT BENCHES

Figure 5-4-3 Layout and Cross-section of Hillside Pit Using Power Shovels method is to begin the shovel digging on a downgrade of not over 10 per cent, until it is working against a face of suitable height. When the initial cut is advanced by the shovel and the face is not more than 1.8 or 2.4 metres in height, trucks are kept on the surface for loading to keep the swing of the shovel as short as possible. Trucks should not be placed too close to the cut to prevent the weight of the loaded trucks from collapsing the cut. When the initial cut is completed, the shovel widens the pit by making additional cuts. Trucks are spotted in the first cut for loading while the shovel is making the second cut and so on. The shovel continues to dig deeper with each successive cut until the (desired maximum height of face is reached. As the pit widens from successive cuts, it assumes a circular shape. Either loop traffic within the pit or one-way traffic may be established depending on such factors as gradient of entrance, outside traffic pattern, trafficability of pit floor, area within the pit and quantity of equipment in the pit. If more shovels are available than can operate efficiently on the face around one level, then a second lower level is started inside the first, beginning near the first. Development of the second and succeeding levels is the same as for the first. (Figure 5-4-5).

d. **Narrow Pits.** Certain types of deposits, such as those of old streambed origin, are not of sufficient width for circular development. A simple method of excavation involves development in straight line benches (Figure 5-4-6). The shovel or dozer digs the first cut to a depth sufficient to provide a desirable height of working face. The cut is continued at this level with trucks being loaded over the bank. Then the shovel reverses its direction, making a second cut alongside the first. A dozer is used to level the first cut for trucks. Succeeding excavation operations are in parallel straight cuts. If the deposit is deep enough, a second and third level are developed, beginning at one side of the pit rather than in the center. The depth at which this type of deposit may be worked is usually limited by the elevation of the ground water table. Operation of deep narrow deposits tends to develop faces of great height. Due caution must be exercised to avoid endangering personnel and equipment by cave-ins or slides.

11. **Excavating with Draglines.** Draglines are best used to excavate below the track level of the machine. It is the most practical piece of equipment for underwater digging and is particularly adapted to submerged gravel pit operations. Typical dragline jobs include the recovery of sand, gravel or coral from streambeds, lake bottoms, lagoons or beaches. Figures 5-4-7 and 5-4-8 depict the layout and development of pits using this equipment.

12. **Excavating with Clamshells.** Clamshells are best suited for excavating loose materials (sand, gravel, crushed stone and the like), loading bins, hoppers and trucks, loading or unloading loose materials from railway cars and barges, and for stockpiling. Unconsolidated material can be excavated at, above or below the ground level. The clamshell is capable of raising and dumping its load at heights equal to the distance from tip of boom to ground less the length of the clamshell bucket, allowing adequate clearance for the bucket when opening.

13. **Loading Ramps.** A loading ramp, or chinaman, is a structure built expressly for the purpose of loading material into hauling units with earthmoving equipment. Loading ramps are mainly used on jobs when trucks or other hauling equipment are available, and when loading equipment is not available. Load ramps are designated by the method used to discharge material, by the manner in which material is loaded into them and by the system by which the hauling vehicles approach and depart.

a. **Chutes.** The most elementary type of loading ramp is the plain chute illustrated in Figure 5-4-9. Care is required in spotting trucks, particularly at night.

b. **Chute-with-gate.** (Figure 5-4-10). This type of loading ramp is an improvement added to the simple chute. It permits stocking of materials, but an extra man is required to operate the gate.

c. **Single-end Trap, Truck-back-in.** (Figure 5-4-11). This type of loading ramp is best adapted to a situation in which comparatively small quantities of material must be provided immediately. It can be constructed in the least time and with a minimum of building material, but it is slow to operate. It requires only one dozer and is suited for bank excavation. A small excavation at right angles to the bank may be required to accommodate the rear end of trucks. When large

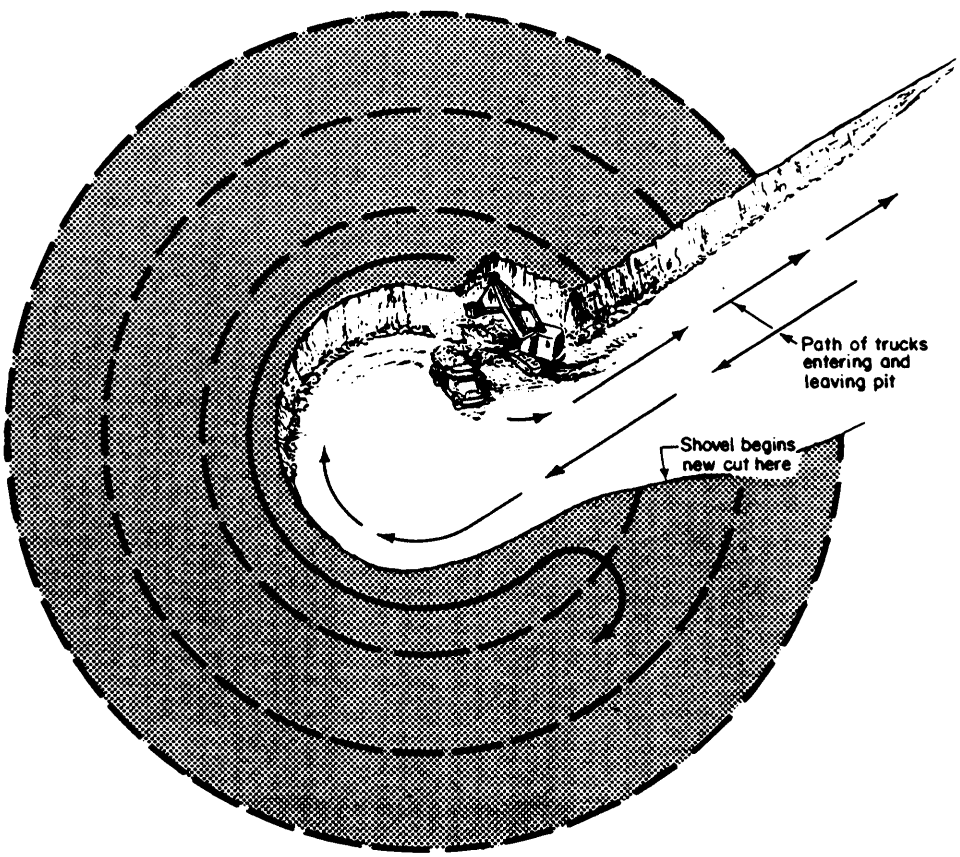


Figure 5-4-4   Layout and Development of a Subsurface Pit Using Circular Bench Method

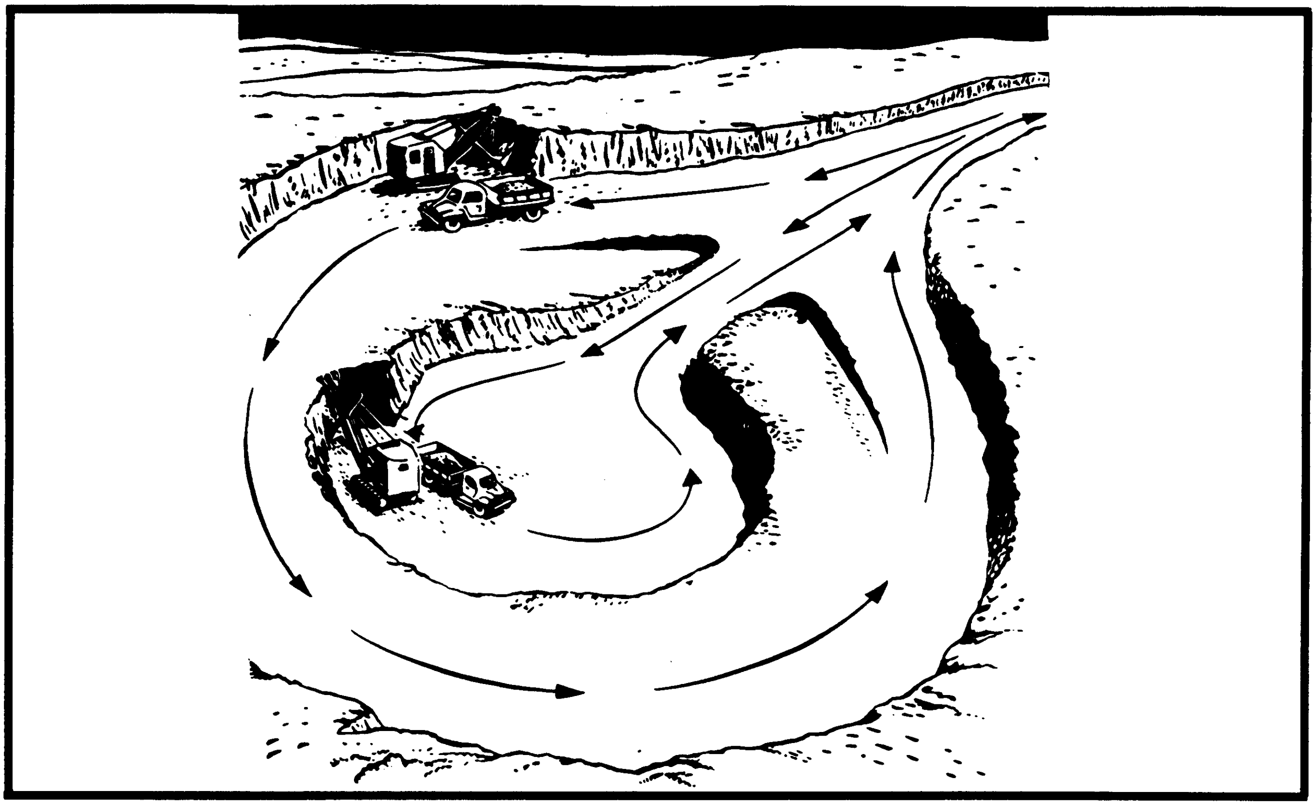


Figure 5-4-5 Power Shovels in Circular Pit Below Surrounding Ground Level

quantities of material are desired and sufficient equipment and trucks are available, this type of loading ramp can be widened to permit multiple truck loading.

d. **Single-end Trap, Truck-drive-through.** (Figure 5-4-12). This loading ramp is a modification of the single-end trap, truck-back-in type to facilitate closer control of truck loading and better traffic regulation. It requires more building materials and the structure requires greater strength.

e. **Single-end Trap and Grizzly.** (Figure 5-4-13). This type is useful when a grizzly is required to remove rocks or lumps from material. Heavy wire mesh or pierced steel plank may be used for grizzly construction instead of 51 by 204 mm or larger lumber. A grizzly may be adapted to or combined with any other type of loading ramp. A dozer is used to remove the accumulation of material retained on the grizzly.

f. **Double-end Trap, Truck-drive-through.** (Figure 5-4-14). This type of loading ramp can be operated with dozers or tractor-drawn scrapers. It permits simultaneous operation of two pit faces, provided that two-way traffic is properly supervised. It requires excavation and time to install, and is difficult to drain. Double loading can be accomplished by extending the loading ramp similar to the overhead-with-ramps type (Figure 5-4-15). Additional gates permit stocking of material to allow uninterrupted movement of earthmoving equipment.

g. **Double-end Trap, Overhead-with-ramps.** (Figure 5-4-15). This modification of the double-end type saves excavation, but at a sacrifice of gravity aid in loading the ramp. It is particularly adaptable to high ground-water conditions with limited drainage, or other grade restricting considerations. Single or double loading can be accomplished. Distance between posts must be sufficient to clear a dozer or grader used for removing spillage in the truck roadways. Gates provide the same advantage as mentioned for the truck-drive-through type.

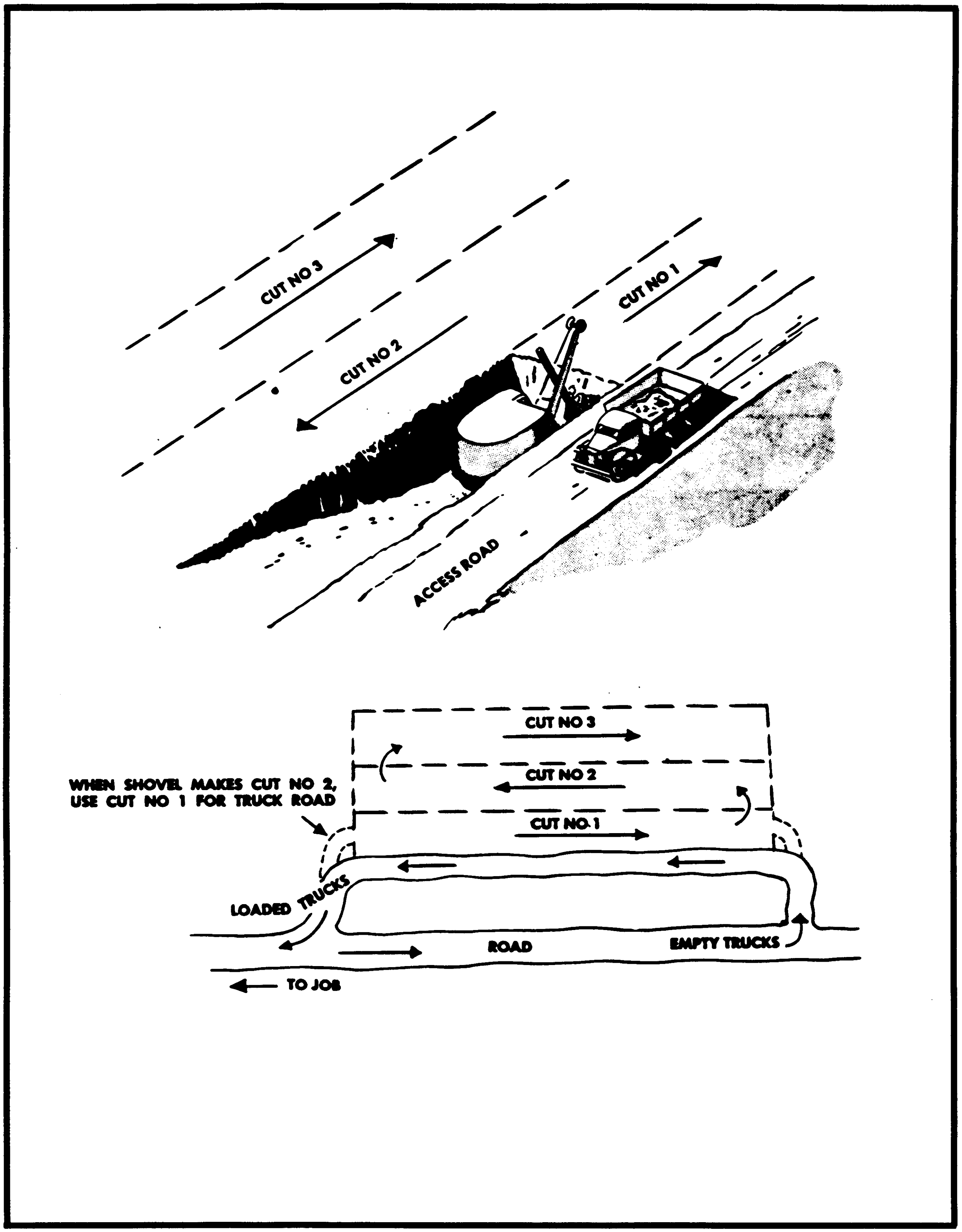


Figure 5-4-6 Below-Ground-Level Pit with Straight Cuts

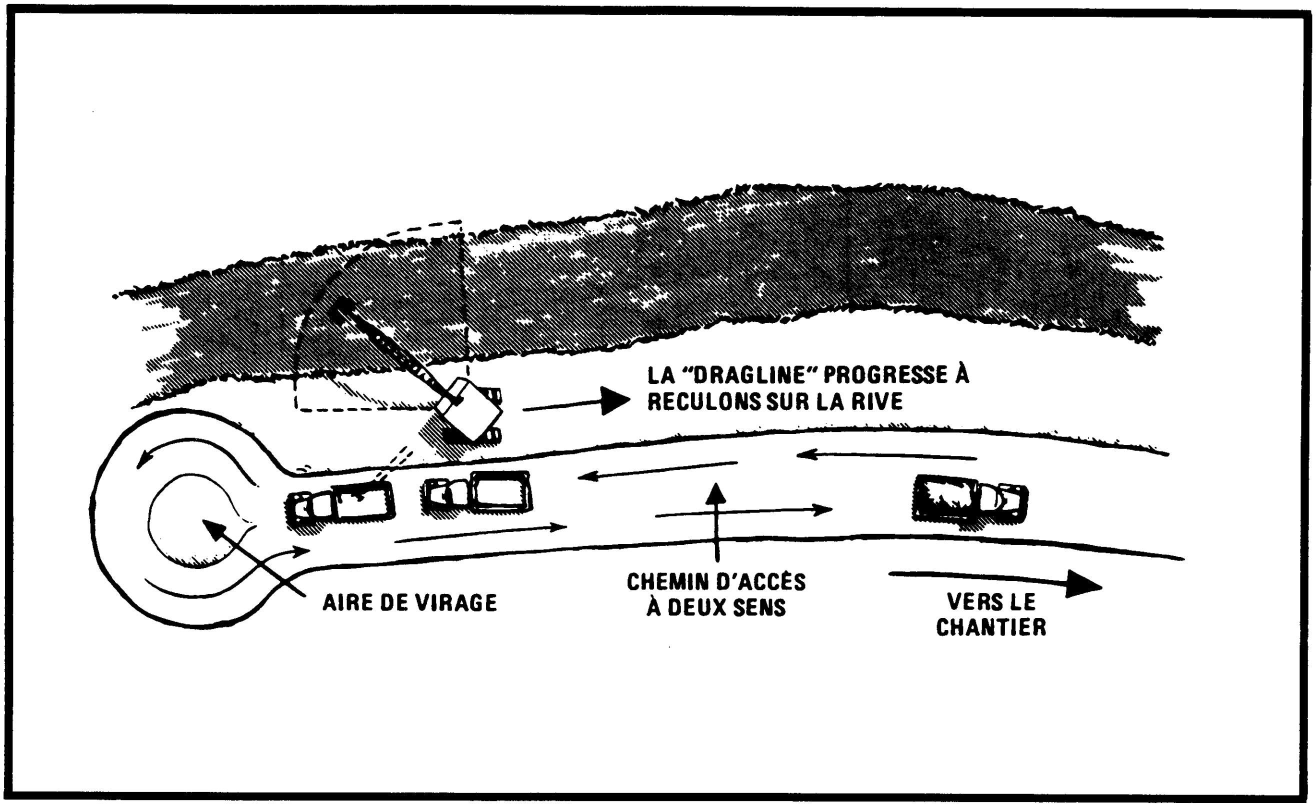


Figure 5-4-7 Dragline à l'oeuvre le long d'un cours d'eau

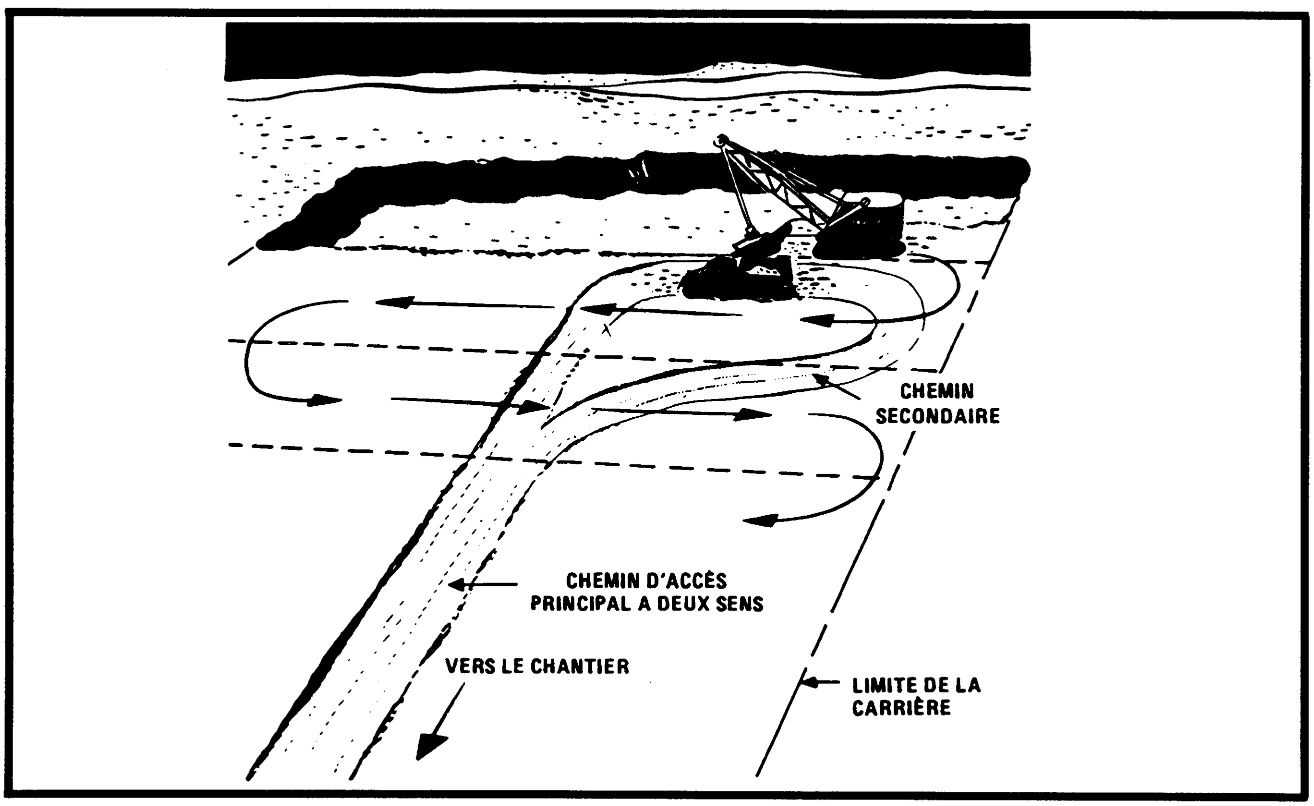


Figure 5-4-8 Dragline exploitant le sous-sol d'une plage

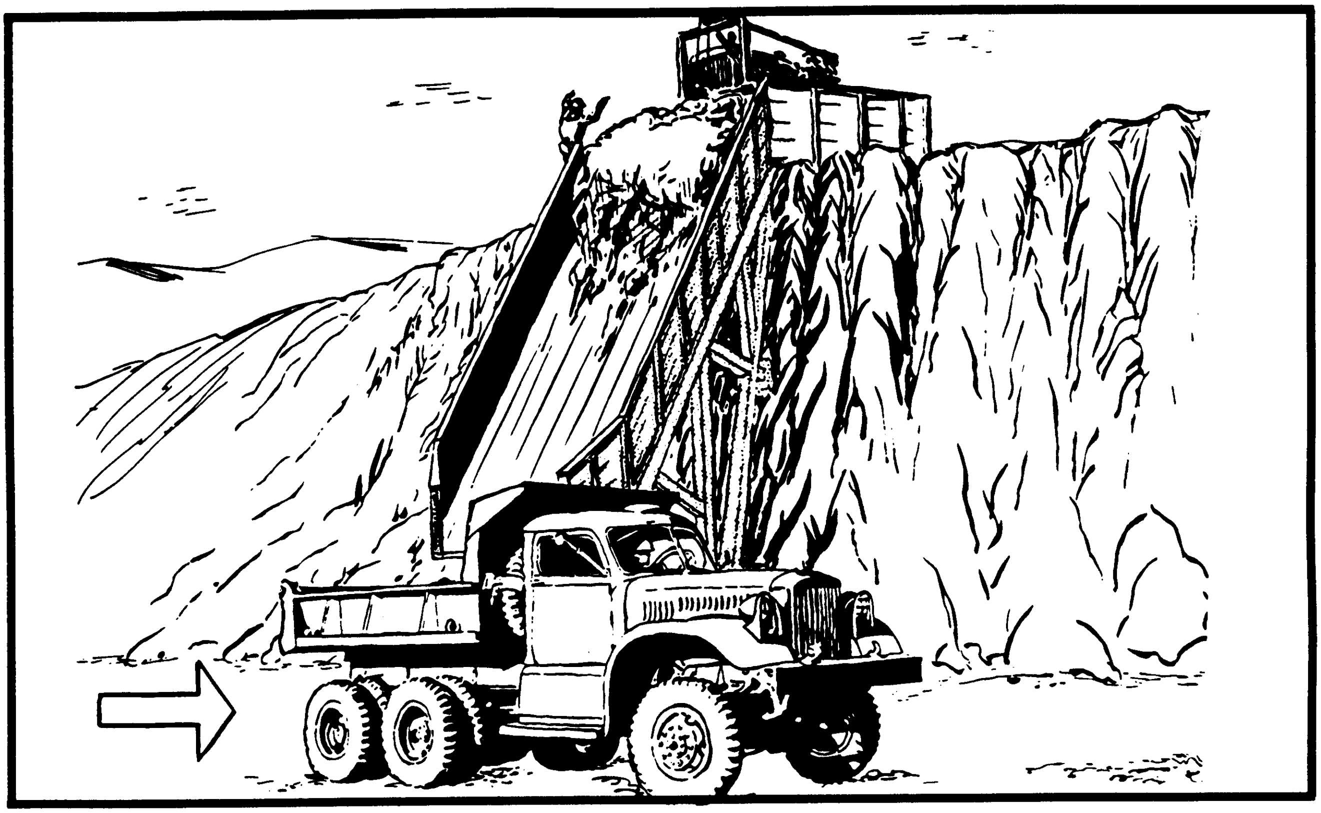


Figure 5-4-9 Simple Chute Loading Ramp

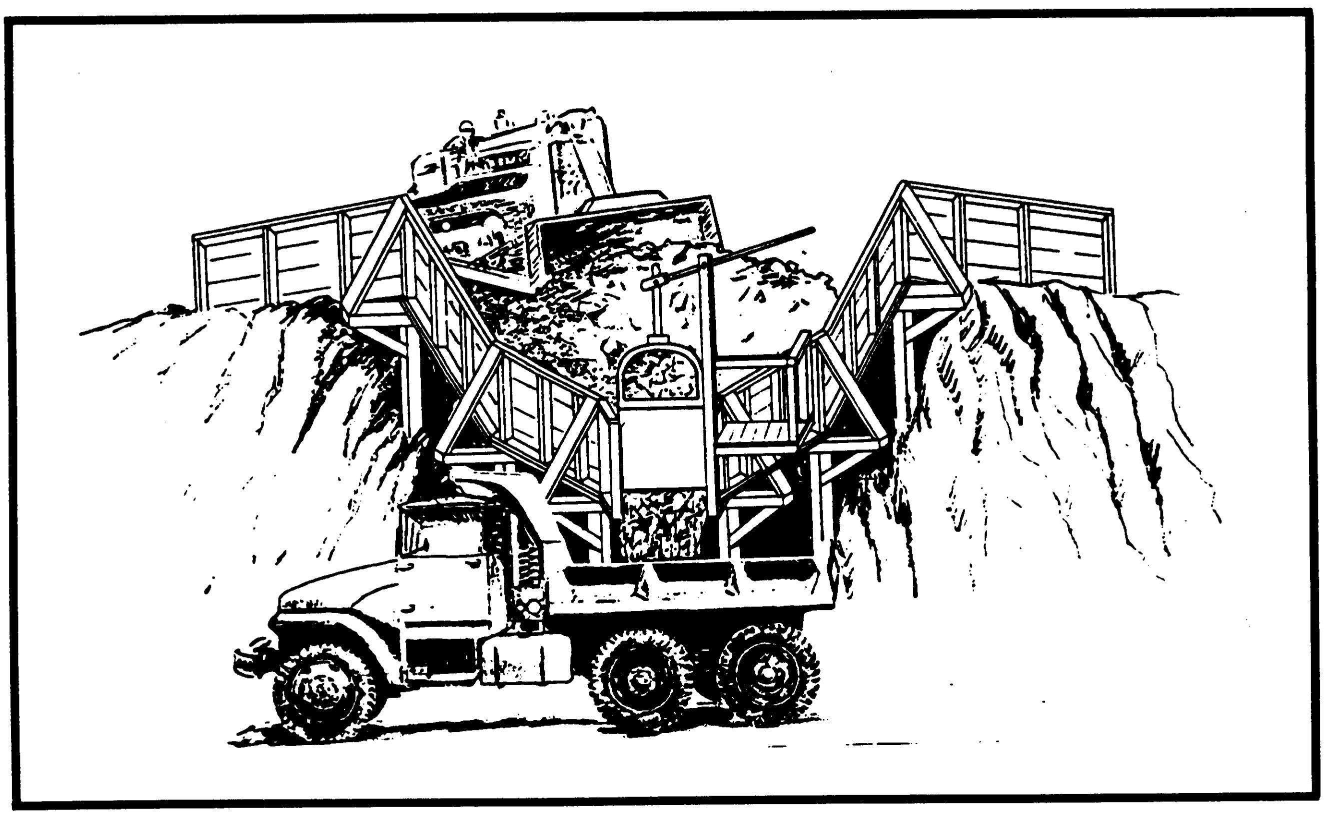


Figure 5-4-10 Chute-With-Gate Loading Ramp

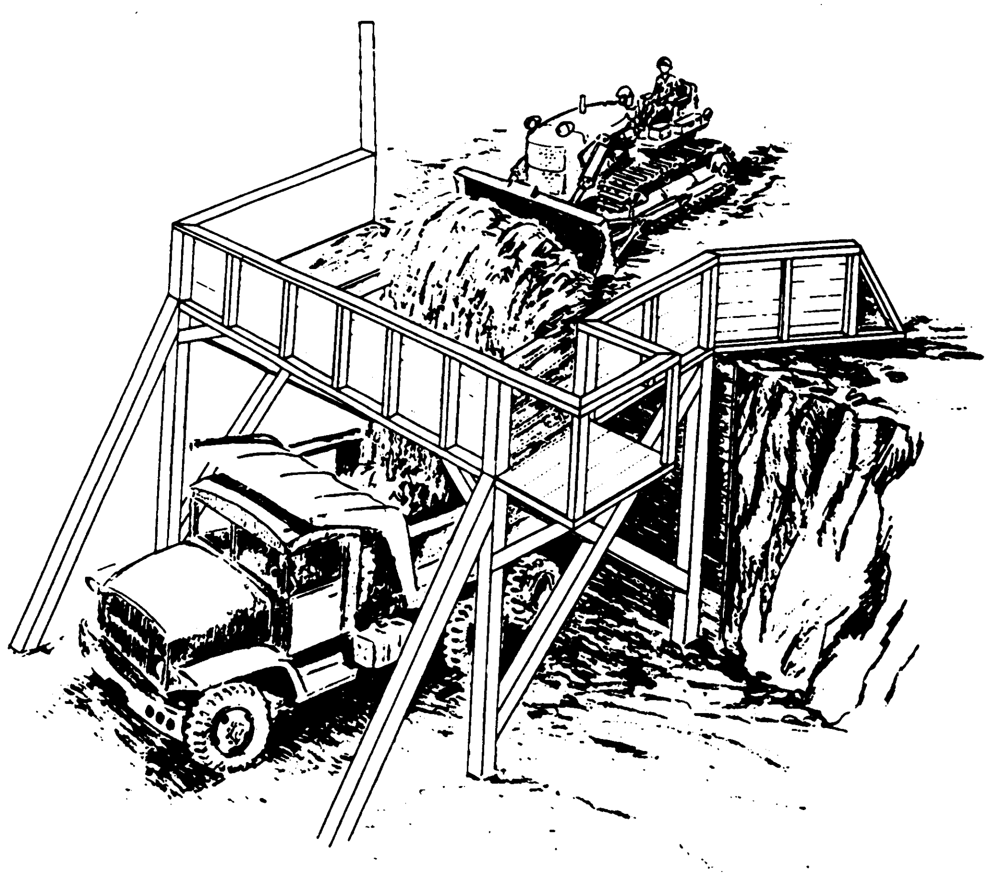


Figure 5-4-11 Single-End Trap, Truck-Back-In Loading Ramp

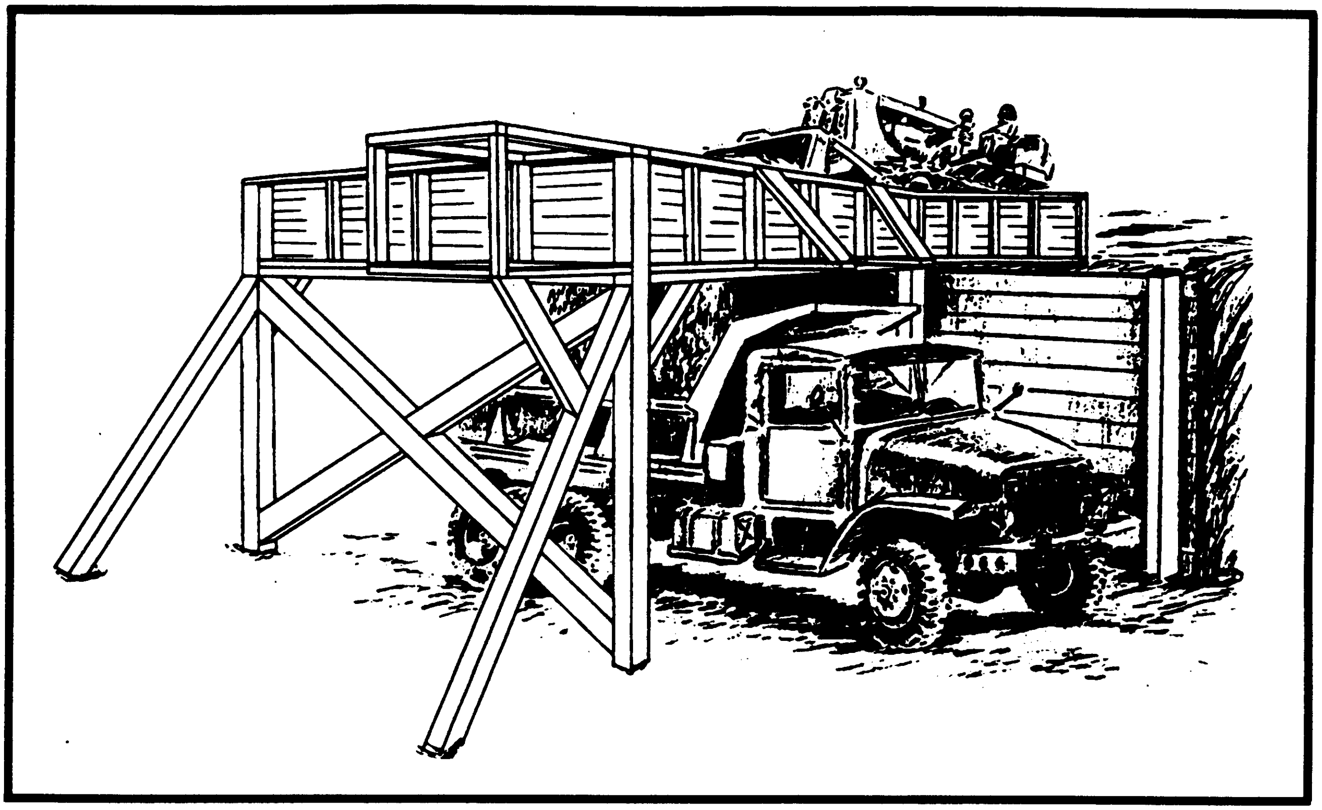


Figure 5-4-12 Single-End Trap, Truck-Drive-Through Loading Ramp

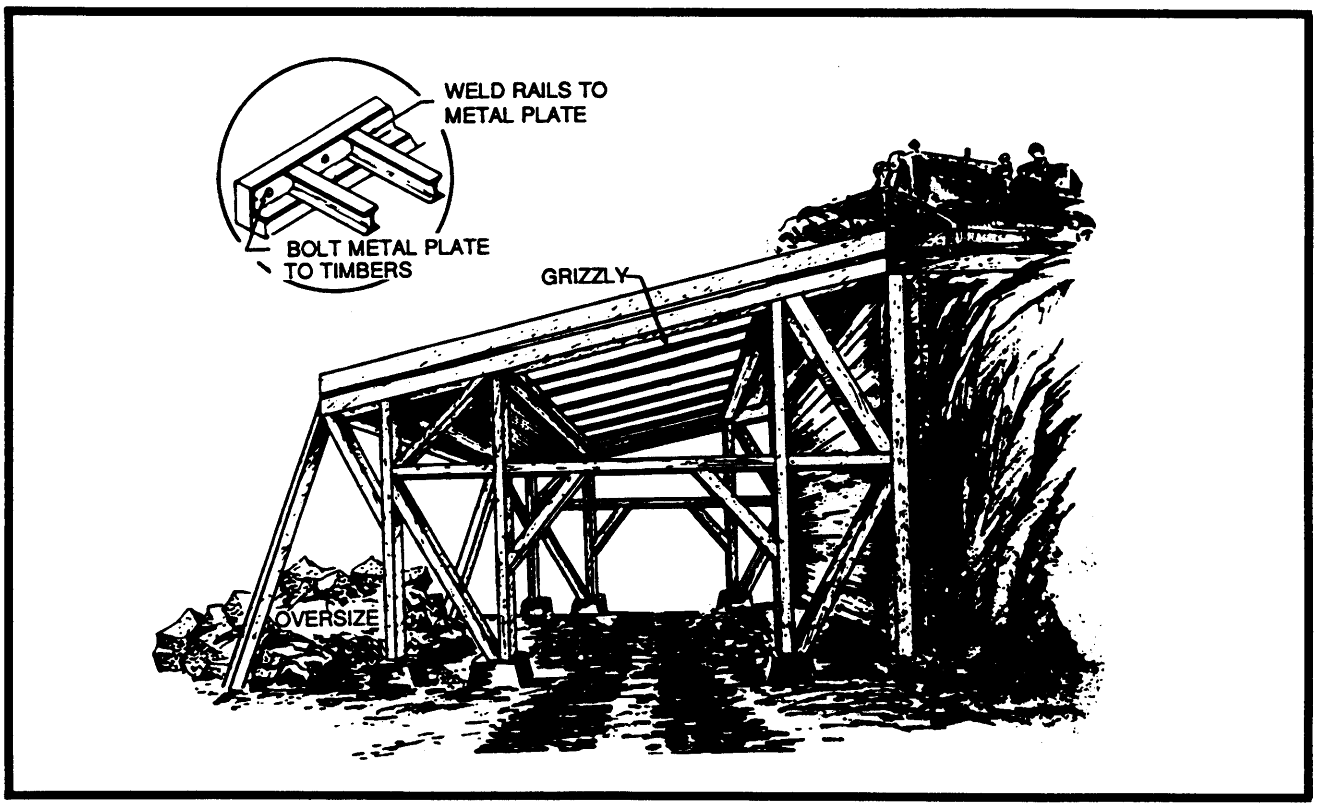


Figure 5-4-13 Single-End Trap and Grizzly Loading Ramp

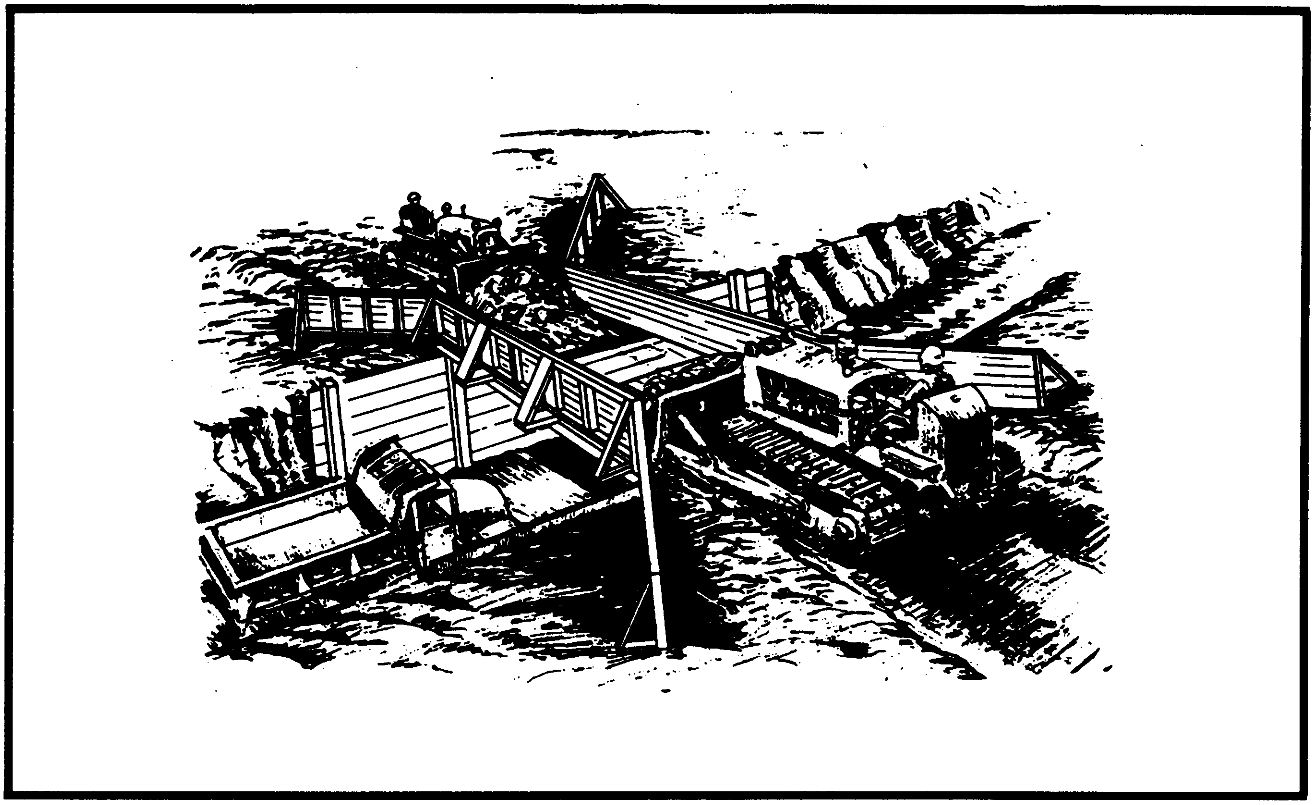


Figure 5-4-14 Double-End Trap, Truck-Drive-Through Loading Ramp

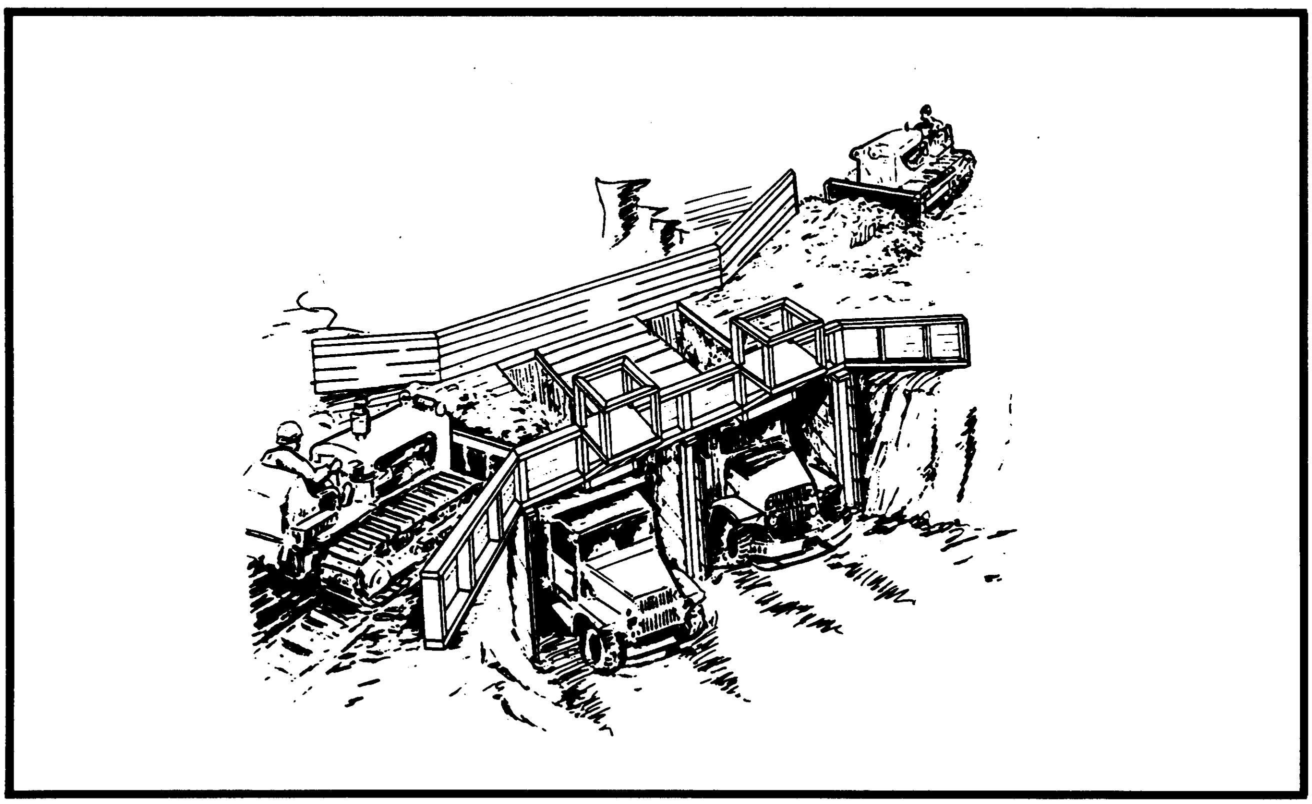


Figure 5-4-15 Double-End Trap, Overhead-With-Ramps Loading Ramp

h. **Design of Loading Ramps.** The most frequent mistake in the construction of loading ramps is inadequate strength. stamps must be designed to support the heaviest equipment used, plus an impact factor of 50 per cent, and approximately 20 tons of earth.

14. **Handling Equipment.** Paragraph 13 discussed methods of material loading which are used for in situ material. However, in situ material is not always suitable for construction. In many instances it will be necessary to process pit material before it meets the job specifications. This results in some additional handling equipment.

a. **Power Shovels.** Power shovels should be provided for loading material. The capacity of the shovel required depends on the rate of production.

b. **Clamshells.** Clamshells should be provided to load processed material from stockpiles to trucks or to charge hoppers.

c. **Dump Trucks.** Dump trucks are necessary to haul material from the pit to the processing plant and haul processed material to the construction site. Such trucks, when handling large material continuously, should have 50 mm planking bolted to the track bed to prevent wear and tear to the bed.

d. **Front-end Loaders.** FELs depend on the pushing and crowding action of the tractor for loading. A FEL is quite mobile and easily discharges its load. It is used for handling stockpiled and windrowed material, and can be used to excavate bank or pit materials.

e. **Conveyors.** There are a number of motordriven belt conveyors having a standard length of about 15 metres. They may be used singly or in series to load vehicles or hoppers with stockpiled material.

f. **Bucket Loaders.** This type of equipment consists of a power driven endless chain to which buckets are attached so that material is loaded on the upward travel of the chain and unloaded on the downward travel. Such loaders are used to load stockpiled material into overhead hoppers and vehicles.

g. **Dragline and Cableways.** Crawler-mounted draglines or cableways with dragline buckets are effective for removal of sand and gravel from narrow, fast-flowing streams or rivers where the operation is relatively permanent. Usually the material taken from streambeds is replaced by stream action nearly as fast as it is removed. Cableways may be fastened to deadmen or to counterweighted mobile towers. Towers provide lateral movement of the cableway and permit a greater area to be excavated.

15. **Processing Equipment.** The production of any pit material that requires additional processing is dependent upon the capacity of the processing equipment. To obtain maximum efficiency, it is necessary to supply sufficient material to keep the processing equipment operating continuously. When crushing and screening equipment is used, the operation expands to an operation similar to quarrying. Chapter 3 outlines operations that involve processing equipment.

SECTION 5

PIT ORGANIZATION

GENERAL

1. This section provides a general description of a pit operation organization and discusses records that should be maintained at the pit.

PIT ORGANIZATION

2. **General.** The fundamental pit operation organization consists of the headquarters office, five operation sections and one support section. The operation sections include a stripping operation, a pit operation, an equipment maintenance operation, road maintenance and delivery. Figure 5-5-1 shows the equipment that may be found in these sections. The actual equipment is based on what is available and what is required for the particular operation.

3. **Pit Operations HQ.** Pit operations HQ is responsible for the overall control and administration of site activities. This section includes the pit site commander, the site second-in-command and administrative clerks.

4. **Stripping Operations.** This section is responsible for clearing, stripping and spoiling all overburden material. In addition to the equipment operators this section may have personnel to cut trees or to guide equipment.

5. **Pit Operations.** This section is responsible for the excavation of the material.

6. **Equipment Maintenance Operations.** This section is responsible for the maintenance and repair of all equipment on site.

7. **Road Maintenance Operations.** This section is responsible for routine maintenance of roads and traffic areas.

8. **Delivery Operations.** This section is responsible for the delivery of materials to the construction site(s). Depending on the size of the operation, this responsibility may be undertaken by another organization or unit.

9. **Support Section.** This section is responsible for providing general support not assigned to the other sections. This includes POL, rations and supplies.

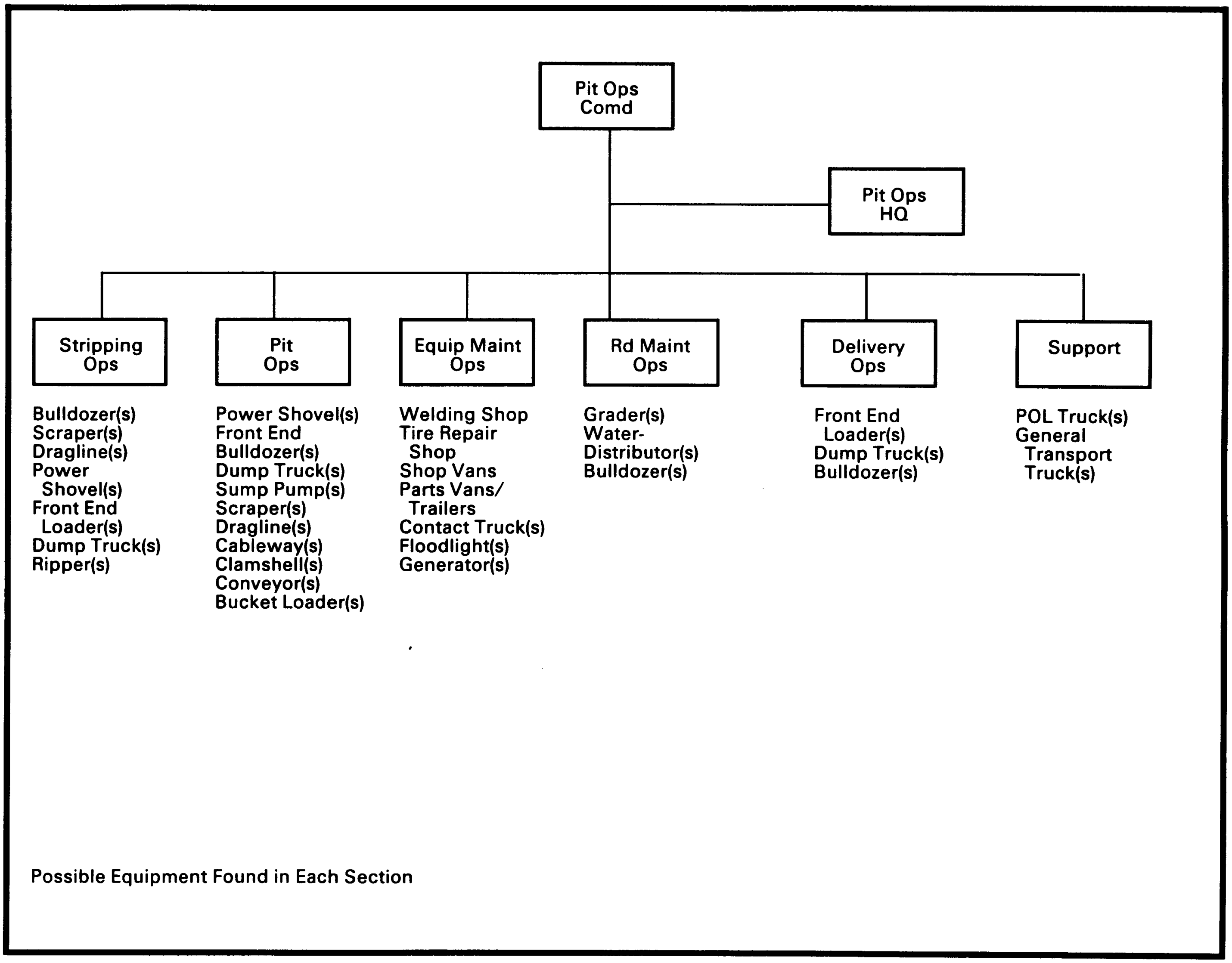


Figure 5-5-1 Pit Organization Chart

PIT RECORDS

10. **General.** It is important to maintain accurate records to provide a historical evolution of the site and to monitor production.

11. **Development Records.** The development records monitor the evolution of the site. These records include all work done to the site from start to finish. They include sketches, profiles and cross-sections as well as a record of equipment and personnel used on the site.

12. **Daily Work Log.** The daily work log records the daily progress of operations. It includes a summary of the production and delivery of material. It summarizes the equipment and personnel used in the daily operation of the various activities as well as the consumption of water, POL, utilities, etc.

13. **Production Log.** This log records all the material excavated and delivered and the area of the pit that each load serial was excavated from.

SECTION 6

SUMMARY

GENERAL

1. Before any activity commences on the selected pit site, it is important that the operation has been planned. This master plan includes the pit layout, the development of the pit and the organization that will be used in the operation of the pit. Well thought out and defined plans result in smooth and efficient operations throughout the life of the pit.

2. Annex B to Chapter 3 presents a generalized flow chart for quarry operations. This flow chart can also be used for pit operations with the activities referring to rock excavation being omitted. If further material processing is not required in the pit operations, the activities referring to processing can also be omitted.

CHAPTER 6

SELECTION OF EQUIPMENT

SECTION 1

INTRODUCTION

GENERAL

1. **General.** The array of equipment used in both pit and quarry operations is extensive. Furthermore, no two operations have the same amount or type of equipment. The equipment used in any operation is dependent on many variables. These variables include equipment availability from higher formations, the site conditions which demand certain pieces of equipment or eliminate the need for other pieces, the size of the operation, the method of operation, the output required by the project construction schedule, and the amount and training standard of personnel. Certain pieces of equipment included in this manual are not in the Canadian Forces inventory. They have however, been included to meet contingencies such as rental or use of Allied Forces equipment.

AIM

2. The aim of this chapter is to discuss the selection of the proper equipment for pit and quarry operations.

SCOPE

3. **Scope.** This chapter includes the following sections:

   a. the influence of equipment transportability and maintenance facilities;

   b. production estimates; and

   c. types of equipment.

SECTION 2

TRANSPORTATION AND MAINTENANCE

GENERAL

1. **General.** Equipment used in pit and quarry operations must be transported to the site by some means and must also receive maintenance in order to ensure continued productivity. This section outlines the influences that transportability and maintenance have on the selection of equipment.

TRANSPORTABILITY

2. **General.** Military pit and quarry operations are liable to occur anywhere in Canada, Europe or the world. For this reason it will be necessary to transport the equipment to these locations by either air, land or sea. The limitations created by transporting equipment are size and weight.

3. **Air.** Long range transport of equipment by air can occur by loading equipment into fixed-wing aircraft. Short range air transport may be accomplished by slinging the load from helicopters. For transporting equipment into isolated locations without an airstrip, low altitude parachute extraction (LAPES) or paradropping equipment may be necessary. When any of these means of transportation are used, equipment selection will be heavily influenced by size, weight and drop durability.

4. **Land.** Almost all equipment made is designed to be transportable by rail and truck. Weight is usually not a problem in land transport, but size should be checked. A route reconnaissance should be conducted to confirm height restrictions of tunnels or underpasses. It may be necessary to partially dismantle equipment because of these restrictions.

5. **Sea.** The restrictions in sea transportability are very limited. However, a staff check should be made on dimension restrictions to ensure the vessel can transport the equipment.

MAINTENANCE

6. **General.** Equipment maintenance is an important factor which influences production in pits and quarries. Maintenance includes both daily maintenance and periodic maintenance as well as start-up and shut-down maintenance. Some of the facilities required for maintenance are outlined in Chapter 3, Section 3.

7. **Maintenance Factors.** If the luxury of selecting equipment is given, the maintenance factors that should be considered include:

a. the technical complexity of maintenance (ie, is it simple enough for the operator to perform or does it require a technician?);

b. availability of trained personnel to perform the various maintenance requirements;

c. availability of spare parts;

d. frequency of maintenance and downtime effects on production;

e. the availability, capability and cooperation of the manufacturer to overhaul and/or rebuild the equipment upon request; and

f. effects of extremes in weather on equipment operation, production rate and maintenance requirements.

SECTION 3

PRODUCTION ESTIMATES

GENERAL

1. **General.** An important aspect of equipment selection is the relation of the desired output to the production that a piece of equipment may provide. Consideration of this aspect enables the selection of the type, quality and quantity of equipment to be tailored to the operation. This section describes the principles of production estimation and provides references which contain data and/or the detailed production estimation procedure for specific types of equipment.

PRINCIPLES OF PRODUCTION ESTIMATION

2. **General.** Production estimates are fundamentally determined as the product of the quantity of material moved or processed per cycle and the number of cycles per hour. The determination of the output per cycle involves a considerable number of factors.

3. **Material State.** There are three turns to describe material state. These are bank metres, loose metres and compacted metres.

   a. Bank cubic metres (bm3 or bcm) is one cubic metre of material as it lies in its natural state.

   b. Loose cubic metre (lm3 or lcm) is one cubic metre of material which has been disturbed and has expanded in volume as a result of loading.

   c. Compacted cubic metre (cm3 or ccm) 4 one cubic metre of material which has been compacted and has been reduced in volume as a result of compaction.

   d. Load factor (LF) is the ratio between loose cubic metres and bank cubic metres and is expressed as:

$$LF = \frac{1cm}{bcm}$$

4. **Output Considerations (Hauling and Lifting Equipment).** The output of a piece of equipment depends on the three factors of operational efficiency, equipment capacity (found in tables) and cycle time.

   a. **Operational Efficiency.** A unit seldom reaches maximum production due to many reasons which include the supervisor's lack of knowledge, poor state of maintenance of the equipment, weather, terrain, and deficiencies in operator's skills and techniques. To account for this, production is multiplied by an efficiency factor. This factor should be computed from the past experience of the unit. Where this cannot be determined, the values given in Figure 6-3-1 may be used.

Working Hours	Type of Tractor	Efficiency Factor

50 min/hr	Track Wheel	0.84 0.84
40 min/hr	Track Wheel	0.67 0.67

Figure 6-3-1 Efficiency Factors

b. **Equipment Capacity.** Equipment capacity refers to specifications of the piece of equipment. It includes bucket size, blade sizes, power versus speed capability, rolling and grade resistance, and power limitations with respect to traction, altitude, etc. This information is found in specifications provided by the manufacturer or can be generalized from the type and class of equipment.

c. **Cycle Time.** Cycle time is the time it takes a piece of equipment to complete a circuit of its operation. This time should be kept to a minimum. It is determined from experience, tables or measurement and consists of fixed time and variable time.

(1) Fixed time is the time spent during a cycle in other than hauling and returning. It involves the time for loading, turning, accelerating, decelerating and dumping. These are fixed regardless of how far the material is moved.

(2) Variable time is the time spent on transporting material and returning empty. The time to do this varies with distance and speed.

SPECIFIC PRODUCTION RATES

5. **Hauling and Lifting Equipment.** Production tables for crawler tractors, wheeled tractors, graders and power shovels are found in B-CE-320-002/PT-001, Engineer Field Manual, Volume 2, Engineer and Assault Pioneer Field Pocket Book. Production rates can also be found for various earthmoving, compaction, grading, ditching, lifting, loading and hauling equipment in US Dept of the Army TM 5-331 A and TM 5-331 B, as well as from manufacturers' data.

6. **Rock Processing Plants.** The calibration of a plant and its hourly production rate go hand in hand because production rate cannot be established until the plant is calibrated. There are three procedural steps in calibrating a plant and six procedural steps in determining the expected rate of production. These steps are:

a. **Plant Calibration:**

(1) screen selection,

(2) roll crusher setting, and

(3) jaw crusher setting.

b. **Plant Production:**

(1) jaw crusher capacity,

(2) roll crusher capacity,

(3) sieve analysis,

(4) initial gradation check,

(5) screen capacity, and

(6) final gradation check.

7. It should never be taken for granted that the hourly output of a particular plant 4 the same as the capacity designation in its nomenclature. Factors such as product size required, rock toughness and the capacity of other pieces of equipment in the sequence of rock processing can reduce capacity. It should also be understood that once the plant is properly calibrated, production will be maximized and little can be done to improve hourly output. Plant production estimates are managerial tools for planning and coordinating other quarry operations.

8. Plant calibration can be made from information provided by the manufacturer for the plant supplied. It can also be determined from US Dept of the Army TM5-331C. Similarly plant production is calculated from manufacturers' data or TM5-331C.

SECTION 4

TYPES OF EQUIPMENT

GENERAL

1. **General.** Pit or quarry operations are heavily dependent on equipment. Figure 6-4-1 summarizes most of the larger pieces of equipment that should be considered when planning a pit or quarry operation. Drilling equipment, rock processing plants and auxiliary power units (APUs) are discussed in greater detail in this section.

DRILLING EQUIPMENT

2. **General.** There are two types of drills commonly used in quarry operations. These include hand-held drills and mounted drills.

a. Hand-held drills are pneumatic rock drills capable of drilling vertical and horizontal holes. They are comparatively light (20 kg) and can drill to depths of up to 5.5 metres with diameters of 25 to 51 mm. Drill steel is available in lengths of 0.6 to 5.5 metres. The rate of drilling is dependent upon rock hardness, diameter of hole and operator skill. A skilled operator can average approximately 2.5 metres of 51 mm diameter hole per hour in medium rock.

b. Mounted drills are used to drill vertical, horizontal or sloped holes up to 7.3 metres in length with diameters of 61 mm to 127 mm. A mounted drill consists of a large portable drill mounted on a steel frame or tower with an air motor feed which keeps a constant pressure on the drill steel. The rate of drilling is fairly uniform and will average approximately 4.5 metres of 57 mm diameter hole per hour in hard rock. The track-mounted drills feature a great deal of manoeuvrability.

SERIAL	TYPE OF EQUIPMENT	CAPACITY/RANGE	REMARKS	COMMERCIAL AVAILABILITY
1	Drills	Wide variety	See Chapter 6, Section 4, Paragraph 2	Atlas Copco, Ingersoll-Rand, Cummins, Allis-Chalmers, Caterpiller
2	Compressors	59 L/S to 280 L/S Skid or trailor mounted	Used with serial 1 in quarry operations	Broomwade, Ingersoll-Rand, Sullair, Atlas Copco, Davey
3	Dozers	Wide variety of sizes	Used in several phases of both pit and quarry operations	Caterpillar, Fiat-Allis, Clark, Komatsu, Case, Allis-Chalmers, International Harvester
4	Rippers	Single or triple tooth	See Section 3	Caterpillar, Komatsu
5	Scrapers	5 to 41 cubic metres self propelled or towed	Use in overburden removal as well as hauling in pit operations	Caterpillar, Fiat-Allis, Clark, Werner, International Harvester
6	Power Shovels	Wide variety of sizes, tracked or wheel mounted	May be used in both pit and quarry operations	Caterpillar, Hitachi, Allis-Chalmers, Cummins, Clark, Dominion, Case
7	Front End Loaders	Tracked or wheel mounted with production rates from 38-268 cubic metres/hour	May be used in both pit and quarry operations	Allis-Chalmers, Caterpillar, Case, Drott, Eimco, Massey Ferguson, International Harvester, Clark
8	Backhoes	Tracked or wheel mounted with production rates from 0.5 to 2.5 cubic metres	May be used in both pit and quarry operations	Allis-Chalmers, Euclid, International, Case, Ford
9	Dump Trucks	Wide variety of sizes	Used in both pit and quarry operations	Terex, Caterpillar, General Motors, Ford, International
10	Graders	Wide variety of sizes	Used mainly in road construction and maintenance	Caterpillar, Allis-Chalmers, Walco, Champion, First-Allis
11	Processing Plant, Components	Feeders- 50 to 1800 TPH Crushers- 5 to 700 TPH Conveyors- wide variety of sizes Screens- wide variety of sizes	See Chapter 6, Section 3, Paragraphs 3 and 5 to 8	Telsmith, Cedaripids, Kolman, Suntract, El Jay, Powerscreen (conveyors only)

(The amount of each type of equipment varies with the scale of the operation and equipment availablity

Figure 6-4-1 Types of Equipment

ROCK PROCESSING PLANTS

3. **General.** Rock processing plants consist of components in a configuration that crushes, sizes and sorts material. These components include feeders, crushers, screens and conveyors and are built as either portable or static units. Portables include components mounted on semi-trailer lowbeds that make them easily transportable by road. Both portable and static unit plant components can be prepared for transportation by air. The number of conveyors, crushers, screens and feeders required vases with the site, material and output demands on the quarry. Figure 6-4-2 presents a configuration with two gyrashere crushers and two screens to separate sizes as well as numerous conveyors to move material to other units or stockpiles.

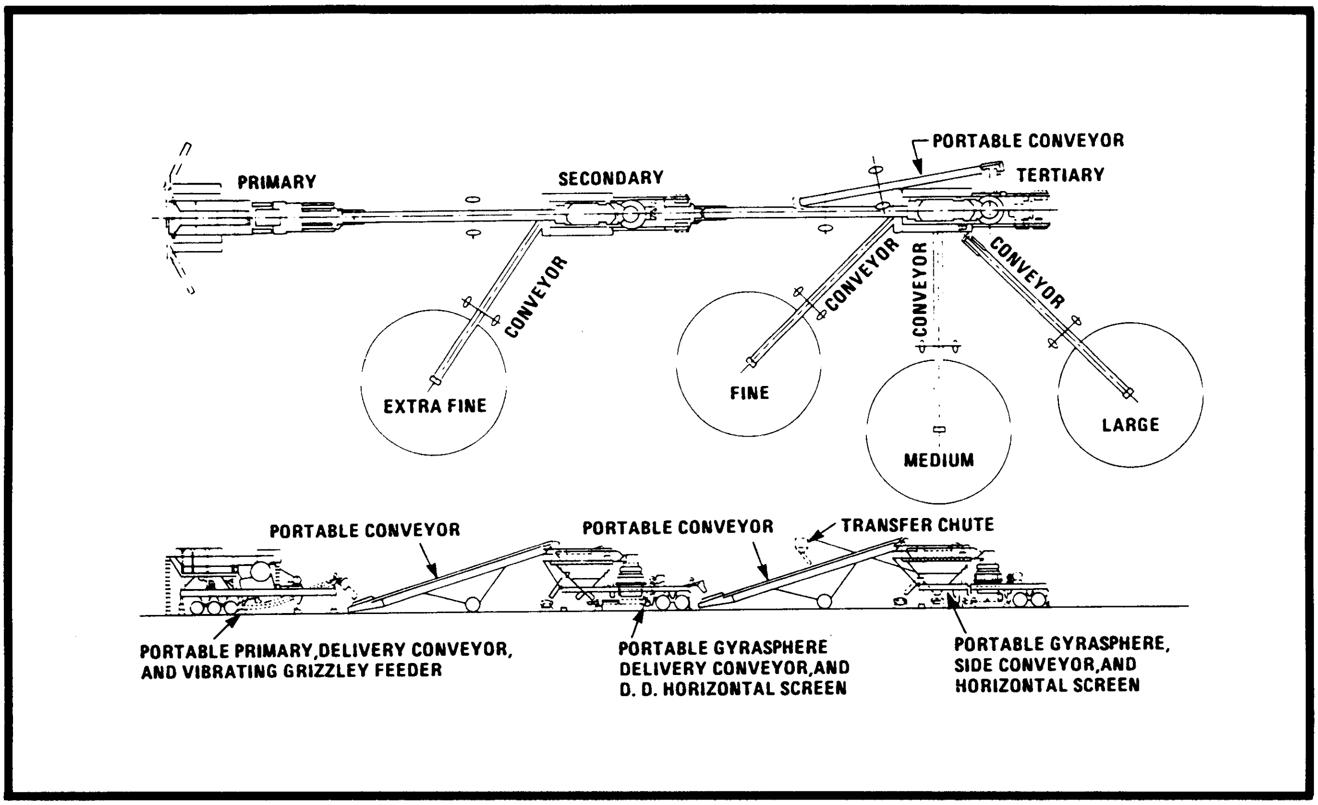


Figure 6-4-2 Typical Rock Processing Plant

AUXILIARY POWER UNITS

4. **General.** Pit and quarry operations require electric power for site lighting, and maintenance facilities. Also power may be needed for processing plant components without integral power units. Auxiliary power units (APUs) are used where local power 4 not available. The selection of the APU is dependent of the site power demand.

SECTION 5

SUMMARY

GENERAL

1. The selection of equipment for a pit or quarry operation is dependent on many variables. The selection criteria should include a consideration of the transportability of the equipment, the maintenance requirements and the production output.

CHAPTER 7

EXCAVATIONS IN PERMAFROST AND FROZEN GROUND

SECTION 1

INTRODUCTION

GENERAL

1. **General.** Excavation of permafrost and seasonally frozen ground requires special consideration. Because mechanical excavation equipment such as scrapers, loaders and shovels may not be able to dig into the frozen material, a mechanism is required to loosen the ground before excavation can take place.

AIM

2. The aim of this chapter is to discuss some methods to loosen frozen ground for subsequent mechanical excavation.

SCOPE

3. This chapter will discuss:

   a. thawing,

   b. ripping, and

   c. explosive aids.

SECTION 2

METHODS OF LOOSENING FROZEN GROUND

GENERAL

1. **General.** There are several ways to loosen frozen ground for excavation. These include thawing, ripping or using explosives.

THAWING

2. **General.** Thawing frozen ground may be done either naturally or artificially.

3. **Natural Thawing.** Natural thawing involves the use of solar radiation to thaw the top several centimetres of ground. The thawed layer is then scraped away and used while the sun continues the thawing action. This process is time consuming when there is a considerable depth of excavation required or where a large area such as a road or airfield cut is involved. The intensity of solar radiation also affects the thawing rate. This method is generally unacceptable in pit or quarry operations.

4. **Artificial Thawing.** Artificial thawing involves the use of steam or hot water, heated materials or chemicals.

   a. Steam or hot water can only be applied to a small area. This method is commonly used to thaw holes in frozen ground for piles or poles. It requires a special steam jet or heating equipment for hot water. Because frozen ground is similar to soft to medium rock in hardness, drilling is a suitable alternative to steam jets or hot water in quarry operations.

   b. Heated material such as hot sand and tarpaulins may also be used to thaw local areas. This requires sand, tarpaulins and a means of healing the sand such as a Herman Nelson heater.

   c. Chemicals can be used to lower the freezing temperatures of an area. Salt may be used, however, it becomes ineffective as temperatures drop well below freezing.

   d. **Miscellaneous.** Fires may also be built over an area to be thawed. Although it has been used to thaw frozen ground to a depth of two-thirds to 1 metre, it is slow and inefficient.

RIPPING

5. **General.** Ripping frozen ground is more effective than thawing. Because ripping is successful in fairly rocky ground, it is generally successful in frozen ground. Chapter 3, Annex A, provides guidelines on ripping which may be used for frozen ground conditions.

EXPLOSIVE AIDS

6. **General.** Employing explosives to loosen soil for subsequent excavation is reasonably quick and effective. Demolition parameters in permafrost or frozen ground are a function of the type of soil and its properties. There are three methods to loosen frozen ground by explosives. These are the shot hole method, the blast hole method and the slot method.

7. **Shot Hole Method.** This method is used where the depth of freezing is less than 1.2 metres. The

explosives are placed in holes up to 75 mm in diameter and a depth of 95 per cent of the depth of freezing. The spacing of holes and rows of holes (staggered or square grid pattern) is from 0.8 to 1.4 times the depth of charge. The size of the charge is determined from the following formula:

C = q x d3 (Equation 7-1)

where:

C = charge weight in kg
q = 0.50 kg/m3 for coarse grained soils
0.60 kg/m3 for clayer silts and 0.80 to 1.00 kg/M3 for clays and construction waste (in permafrost, increase these values by 20 to 30 per cent)
d = depth of charge burial in metres

The shot hole dimensions must be large enough to accommodate the weight of the charge and at least one-third of the hole must be filled with stemming such as sand.

8. **Blast Hole Method.** This method is used where the depth of freezing is greater than 1.8 metres. The explosives are placed in holes from 75 mm to 140 mm in diameter and a depth of 85 to 90 per cent of the depth of freezing. The charges should be divided if the frozen layer exceeds 2.5 metres. In this case the top charge should be one-third of the charge weight and the bottom charge should be two-thirds of the weight with stemming filling the space in between. The spacing of holes and rows of holes (staggered or square grid pattern) is from 0.8 to 1.4 times the depth of the bottom charge. The size of the charge is determined by Equation 7-1 above. The borehole dimensions must be large enough to accommodate the weight of the charge.

9. **Slot Method.** This method is used where the ground is frozen from 0.8 to 2.0 metres deep. If this method is used in frozen ground greater than 2 metres in depth, the ground must be cut in layers. The explosives are placed in slots cut in the frozen ground by a disc or a ripper. The slots are from 100 to 300 mm wide and the depth of the slots is 90 per cent of the depth of freezing. The distance between slots is not less than 90 per cent of their depth and not more than 1.8 metres. If slots are more than 1.5 m deep, divided charges should be used and they should be separated by a layer of stemming 300 to 500 mm in thickness. The top charge, which is one-third the total weight of explosives, should be divided and placed every 500 mm while the bottom charge should be continuous. Divided top charges are also stemmed horizontally. A detonating fuse is placed through the length of the slot prior to charging. (See Figure 7-2-1). Charges are placed in center slots leaving the uncharged outer slots as pre-shear slot. The specific consumption of explosives is determined from the following formula:

EQ7-2

$$C = 1.5B \frac{d}{b} f(x) \qquad \text{(Equation 7-2)}$$

where:

C = charge consumption in kg/m3

B = 0.006 for frozen sand
0.008 for silt
0.010 clay

d = depth of charge in metres

b = width of the bucket of the excavator in metres
(equation 7-2 ensures the largest frozen lump after blasting is less than two- thirds of the bucket width)

EQ7-2b

$$x = \frac{a}{d}$$ (where a is the distance between slots in metres)

f(x) = a function of x determined from the table in Figure 7-2-2

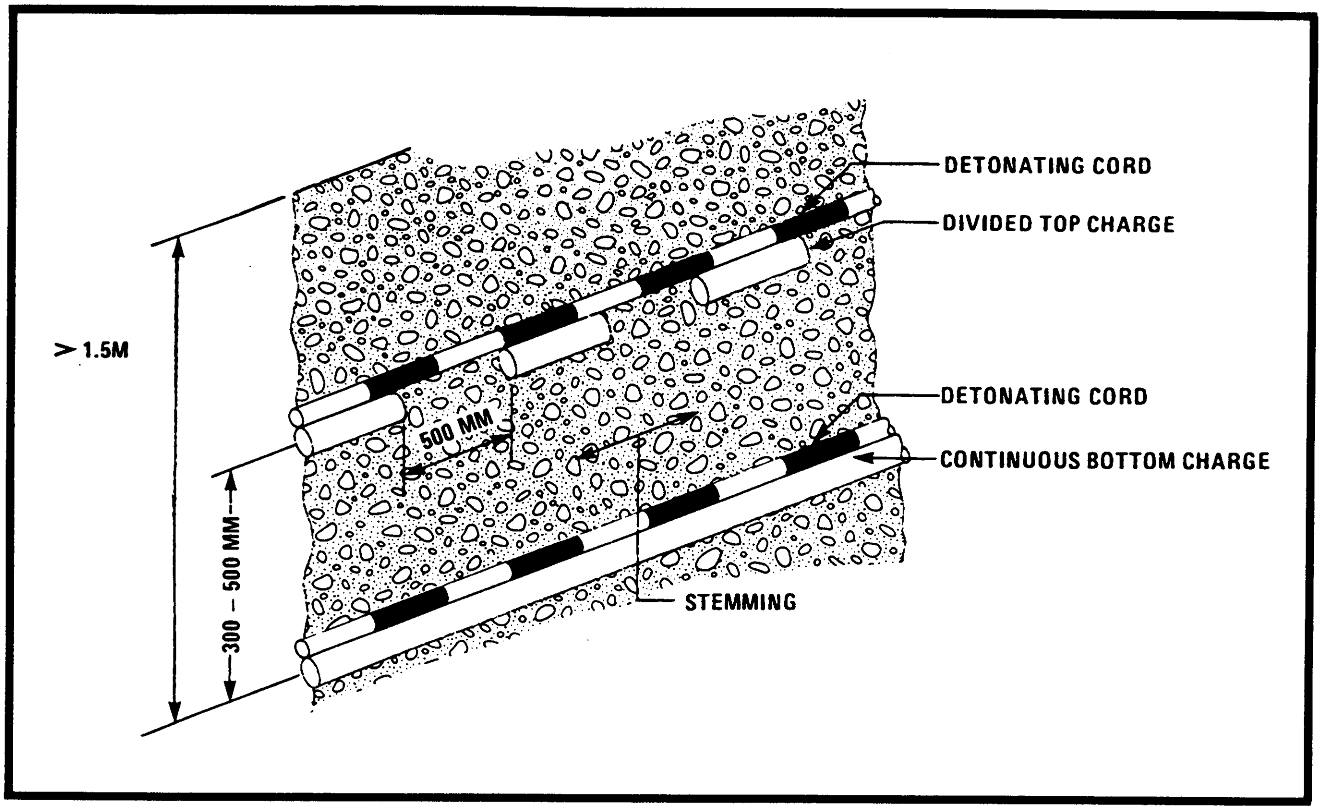


Figure 7-2-1 Slot Method Charges Loading > 1.5M

x	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4
f(x)	4.1	3.4	3.2	3.1	3.2	3.4	3.6	4	4.2	4.9	5.3	6.1

Figure 7-2-2 Values of f(x) for Determining Explosives Consumption in the Slot Method of Loosening Frozen Ground

10. **Method of Blasting.** The charges should be initiated electrically and should use delays from 15 to 25 ms using a pattern such as those shown in Figure 7-2-3. This improves fragmentation and control over the nature and direction of ground fracture. It also reduces the seismic effect on structures and the amount of flyrock.

11. **Flexibility.** These methods provide guidelines on loosening frozen ground for subsequent mechanical excavating. If it is found in the field that there is excessive flyrock or insufficient fragmentation, the charge loads and/or depths should be adjusted in order to provide the best results for the site conditions at hand.

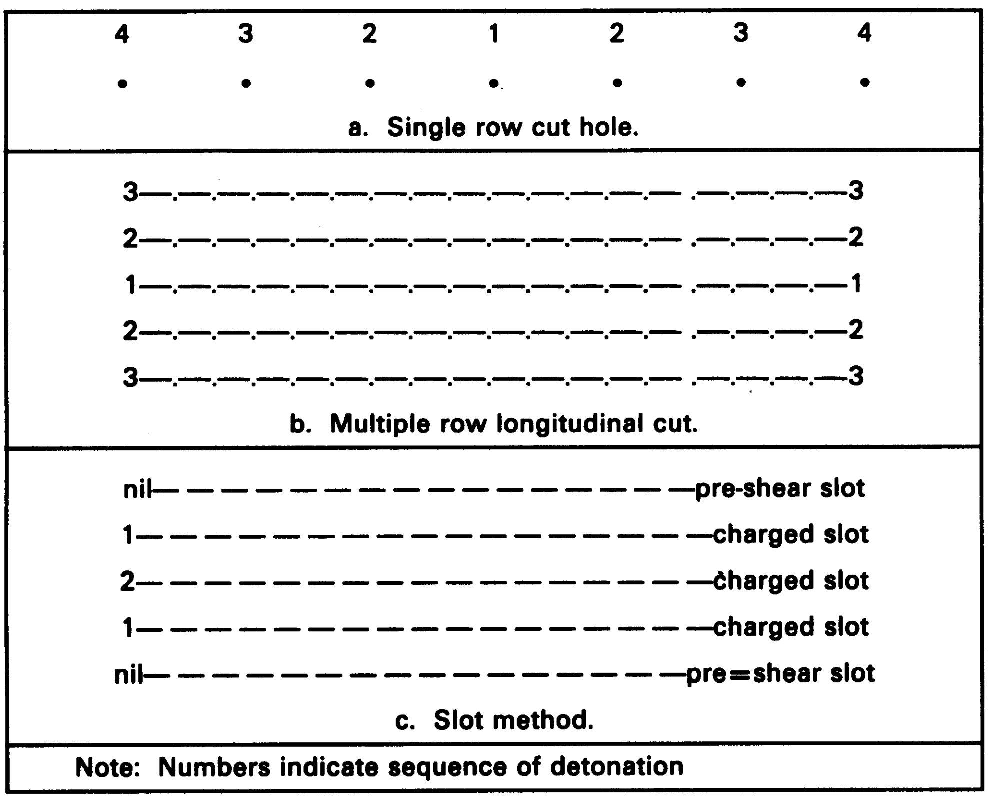


Figure 7-2-3 Layout of Delay Action Blasting

SECTION 3

SUMMARY

GENERAL

1. **General.** It may be possible to loosen ground for mechanical excavation by thawing or by the use of rippers or explosives. Thawing is generally slow while the use of explosives is quick and reasonably effective.

REFERENCES

1. The following publications have been referred to and should be used in conjunction with this manual.

a. B-CE-320-002/PT-001, Engineer Field Manual, Volume 2, Engineer and Assault Pioneer Field Pocket Book.

b. B-GL-320-009/FP-001, Engineer Field Manual, Volume 9, Demolitions, Part 1, All Arms and B-GW-320-009/FP-002, Engineer Field Manual, Volume 9, Demolitions, Part 2, Engineers and Assault Pioneers.

c. US Army TM 5-332 Pits and Quarries.

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f. Canadian Industries Limited, Blasters' Handbook, CIL, Montreal Quebec.

g. Canadian Standards Association CAN3-A23.2-M-77.

h. American Society for Testing and Materials:

(1) 1979 Annual Book of ASTM Standards, Part 14; and

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DEFINITIONS OF EARTHMOVING EQUIPMENT

Angle Dozer

A steel, angled blade which is attached to a vehicle to push earth from place to place and shape the ground.

Backhoe

An excavating apparatus in which a bucket is hinged on a rigid boom and is drawn towards the machine during operation.

Bulldozer

A steel, straight push blade which is attached to a vehicle to push earth from place to place and shape the ground

Dozer

Commonly refers to a tractor mounting either a bulldozer or angle dozer blade.

Dump

A self-propelled vehicle having an open cargo body designed to transport and dump or spread material.

Earthmill

A large, high volume trencher used for the construction of anti-tank ditches and similar obstacles.

Excavator

The generic name of power operated digging machines.

Front-end Loader

A self-propelled machine with a scoop, integral front-mounted supporting structure, and linkage, that loads material into the scoop through forward motion of the machine and lifts, transports and discharges material.

Grader

A self-propelled machine having an adjustable bade positioned between font and rear axles to cut, move and spread material, usually to grade.

Industrial Tractor

An agricultural type tractor normally fitted with a scrop and a small backhoe. The bucket on the backhoe may be replaced with a variety of hydraulically- operated attachments.

Shovel

An excavating apparatus in which a bucket is hinged on a rigid boom and is pushed away from the machine during operation.

Tractor

A prime mover on wheels or backs (crawler) used to push or tow equipment.

Tree Spade

A commercial device adapted for military use to dig a hole capable of holding one person.

Trencher

Equipment used for the continuous digging of trenches. R may be of ladder or wheel type.