Defence
Safety Authority

DSA 03.OME Part 2 (JSP 482) - Defence Code of Practice (DCOP) and Guidance Notes for In-Service and Operational Safety Management of OME

Defence OME Safety Regulator

DOSR

DSA VISION

Protecting Defence personnel and operational capability through effective and independent HS&EP regulation, assurance, enforcement and investigation.

PREFACE

AUTHORITY

1. This document is crown copyright and the intellectual property rights of this publication belong exclusively to the Ministry of Defence (MOD). However, material or information contained in this publication may be reproduced, stored in a retrieval system or transmitted in any form provided it is used for the purposes of furthering safety and environmental management.

STATUS

2. This document:

a. Is uncontrolled when printed.

b. Will be updated as part of a continuous improvement programme but at least 12-monthly from the period of document issue date.

REQUESTS FOR CHANGE

3. Proposed changes, recommendations or amendments to DOSR Regulations and Guidance publications can be submitted by anyone using the DOME Request for Change Function (RFC) available for every Dome publication in the DOME library located **here** or by completing the Word version of the Change Proposal Form available from the DOME Library, see figure 1 below for the location.

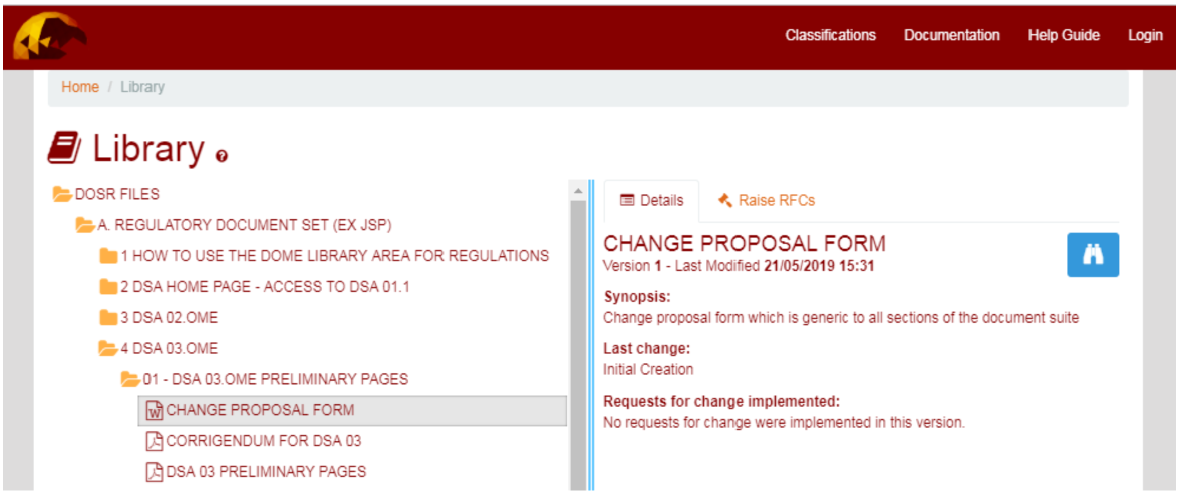

Figure 1. Change Proposal Form (Word version) Location

4. Any post and grammar change proposals can be approved or rejected by the DOSR PRG Authors without involvement of the associated Working Group.

5. Technical change proposals will need to be submitted to the associated Working Group for review and approval or rejection.

6. When incorporating changes care is to be taken to maintain coherence across regulations.

7. Changes effecting Risk to Life will be published immediately.

8. Other changes will be incorporated as part of routine reviews.

REVIEW PROCESS

9. The DOSR PRG team will ensure these OME Regulations remain fit for purpose by conducting reviews through the DOSR Governance Committees, involving all Stakeholders.

FURTHER ADVICE AND FEEDBACK

10. The document owner is the DOSR. For further information about any aspect of this document, or questions not answered within the subsequent sections, or to provide feedback on the content, contact:

Job Title	DOSR-Policy, Regulations and Guidance
E-mail	DSA-DOSR-PRG@mod.gov.uk
Address	Juniper #5004, Level 0, Wing 1, Abbey Wood North, Bristol, BS34 8QW

AMENDMENT RECORD

Version 1.0					
No	**Section**	**Para**	**Amendment Summary**	**Agreed**	**Date**

Intentional Blank Page

CHAPTER 10

SECTION 6

QUANTITY DISTANCES AND OTHER EXPLOSIVES LICENSING CRITERIA FOR UNDERGROUND STORAGE

CONTENTS

Paragraph

Figures

Annexes

1 SECTION SIX

1.1 Definition of Underground Storage

Following the restructure of NATO working groups in April 2003 the NATO working party responsible for Military Ammunition and Explosives, formally AC258, has been reformed as AC326 Sub-Group 5. AC326 SG5 have responsibility for producing a Manual of NATO Safety Principles for the Storage of Military Ammunition and Explosives - AASTP1. This publication defines ‘Underground Storage’ as being confined to those sites having sufficient thickness of cover to ensure that an explosion within will not cause failure of the cover. In the UK, it is doubtful whether any buried storage facilities have sufficient cover thickness to qualify under this criterion. Nonetheless, it is usual to refer to all earth (or rock) covered storage facilities with a substantial thickness of cover as ‘Underground Storehouses’. This term would not include such structures as Igloos or mounded buildings with shallow earth cover.

1.1.1 Practically all UK military underground storehouses consist of a single storage chamber with a much narrower simple tunnel or adit giving access direct from the open air. The cover on these sites would be expected to rupture in the event of an explosion in the underground facility. For information regarding underground facilities which would not be expected to experience disruption of the cover in the event of an explosion, or for more complex geometry, the NATO Manual AASTP-1 should be consulted.

1.2 Types of Underground Storage

1.2.1 There are two types of underground storage sites used to store explosives:

(1) Chambers. These are specially constructed chambers connected to the outside by smaller cross section tunnels, typically horizontal. The chambers and tunnels would typically be lined with masonry, reinforced/plain concrete or metal segments in UK.

(2) Natural Rock Caverns. These are little used in UK and will not be considered further. However, the explosives licence limits for the underground facilities in Gibraltar are based on the recommendations of an ESTC site survey.

1.2.2 The chamber and tunnels may be constructed in natural rock, or pre-constructed in open cut with an adequate thickness of artificial cover. Part natural and part artificial cover is often found in one underground storehouse. The chance of communication of explosion to another explosives storage chamber depends on the thickness and types of the rock between the chambers.

1.3 Overhead Cover

1.3.1 Many old facilities in UK were constructed to resist free fall bomb attack in World War II, for which purpose a cover thickness of 10 m to 15 m of soft rock was considered adequate. Artificially added material is essentially unconsolidated and is considered ‘soft’. There may be a horizontal layer of concrete covering the storage chamber set about half the cover thickness above the top of the chamber as additional bomb protection. This is not considered to add significantly to the confinement of the overburden on the storage chamber.

2 EFFECTS FROM UNDERGROUND EXPLOSIONS

2.1 Loading Density

2.1.1 Due to the confinement associated with underground explosives storage sites certain explosion effects, generally considered not to be significant for explosions in above ground storage, will be more significant and require consideration. The effects will be more pronounced as the volumetric loading density of the explosives increases. A loading density of 75 kgm^{-3} is unlikely to be exceeded in above ground sites. This contrasts sharply with explosives loading densities, more than an order of magnitude greater, in a typical borehole used in blasting situations where the explosives are in contact with the rock surface of the borehole. This observation is important since most of the criteria related to ground shock, Chamber Interval and some of the debris throw considerations are based on data from explosions in boreholes or analogous situations.

2.2 Blast

2.2.1 An explosion in an underground chamber will produce a high gas pressure accompanied by heat and flame, giving rise to a supersonic blast wave which will sweep through all tunnels and chambers connected to the initial chamber. The initial pressure will increase with the explosive volumetric loading density within the chamber, being proportional to the cube root of the loading density. Where a tunnel reaches the surface, the underground blast wave will give rise to a blast wave in the air broadly like that of a surface explosion, although some directional effects can be expected

2.2.2 There is also a possibility of propagation by hot gases or flame, which could flow from pre-existing crevices between the chambers. Quasi-static action of the explosion gases may also open incipient cracks and crevices extending between the two chambers, providing a potential route for propagation of the explosion by the hot gases

2.3 Ground Shock

2.3.1 The high gas pressure will be transferred to the surroundings of the chamber, giving rise to a ground shock wave that travels at a velocity higher than a shock wave in air. This shock wave can cause spalling of the rock face or walls of another nearby chamber, possibly causing a reaction in any explosives present there. Some types of explosive articles, generally considered as robust, will be significantly less vulnerable to rock spall or flame induced initiation.

2.3.2 The ground shock and the more or less sustained high pressure within the initial chamber may, depending on the cover thickness, cause breakthrough of the rock/earth cover of the chamber. This may cause ejection of the rock, etc, forming the cover, and release of the high-pressure gases from the chamber. This will give rise to an additional blast wave in the air, like that from a surface explosion. In the UK, it is expected that the chamber cover would be easily breached, and therefore debris from the crater and air blast issuing from the crater must also be considered. Typically, these effects, centred on the storage chamber, may well be found to be more significant in the determination of QDs in the arc around 180° from the exit axis where adit blast is at a minimum.

2.3.3 Ground shock effects from underground explosions are much more significant than from those above ground and therefore require consideration in their own right. It must be borne in mind that Process Buildings may be as vulnerable to ground shock as private houses. The usual assumption that PBD are always significantly less than IBD may not hold true if ground shock is the limiting effect.

2.4 Fragments and Debris

2.4.1 Any primary fragments and debris will be swept down the access tunnel by the blast flow and will be projected in a relatively narrow angle directly away from the adit. This fan of debris will also contain any loose material that was present in the tunnel before the explosion and may also comprise material from the tunnel lining and any structure or portal built at the tunnel exit. It is anticipated that some debris will be projected to great distances along the centre line of the adit in a manner like the projection of a shell caused by the sudden build up and release of gases from the chamber into the tunnel system (analogous to the breech and muzzle action of an artillery piece).

2.5 Breach of Earth Cover

2.5.1 In most UK underground storage sites, it is expected that the chamber cover will be easily breached and therefore debris from the crater and air blast issuing from the crater must also be considered. Typically, these effects, centred on the storage chamber, may well be found to be more significant in the determination of QDs in the arc around 180 from the exit axis where adit blast is minimal.

2.6 Directional Effects

2.6.1 Directional explosion effects from a potential incident in an underground storehouse place serious limitation on the orientation of underground facilities. This is obviously applicable to the direction of the access tunnel, but also applies to crater projections particularly where the cover surface is inclined.

3 TYPES OF QUANTITY DISTANCE

3.1 Inside Quantity Distances

3.1.1 These are the minimum permissible intervals between chambers containing explosives, and between tunnel mouths and Process Buildings sited outside the underground storage site. There are two kinds of Inside Quantity Distances for underground storage:

(1) Chamber Interval.

(2) Process Building Distance.

3.2 Outside Quantity Distances

3.2.1 These are the minimum permissible distances between chambers containing explosives and inhabited buildings, places where members of the public congregate, and traffic routes outside the underground storage site. There are two kinds of Outside Quantity Distances:

(1) Inhabited Building Distance (IBD).

(2) Public Traffic Route Distance (PTRD).

4 DETERMINING QUANTITY DISTANCES

4.1 HD 1.1 and SsD 1.3.3

4.1.1 Chapter 4 describes the behaviour of an explosion of HD 1.1 mass exploding explosives. Explosives of SsD 1.3.3, which would have only a mass fire risk in above ground incidents, will be likely to react similarly to HD 1.1 in the heavy confinement inherent in an underground storehouse.

4.1.2 Although there is a common origin for the energy causing blast, ground shock, projections, etc, it is convenient to consider these physical effects separately as if they were independent. They can be considered in any order but, to bring the constraining effect to the earliest attention, experience shows that the order given below is often the most effective. The adit blast may be overwhelmingly significant in determining QDs in a particular direction. Having determined this, an approximate estimation of another effect, e.g. ground shock, may be sufficient to indicate that it will not be a constraint in determining QDs.

(1) Adit Blast Effects.

(2) Crater Blast Effects.

(3) Ground Shock Effects.

(4) Adit Debris Effects.

(5) Cover Debris Effects.

4.2 **SsD 1.3.4, SsD 1.2.1 and SsD 1.2.2**

4.2.1 Explosives classified as SsD 1.3.4, SsD 1.2.1 and SsD 1.2.2 are expected to respond underground in an intermittent manner without a massive explosion causing blast and ground shock phenomena. The results of these repeated explosions will depend on the types of explosives involved but will be considerably less than those produced by HD 1.1 and SsD 1.3.3.

4.2.2 For this reason, QDs do not apply to HD 1.2 and SsD 1.3.4. The mixing of HDs in underground storage is subject to the same aggregation rules as for aboveground storage with the additional proviso that SsD 1.3.3 explosives (but not those classified as SsD 1.3.4) are considered to react as HD 1.1 and must therefore be aggregated first as HD 1.1 before any further aggregation is considered.

4.3 **HD 1.4**

4.3.1 Explosives of HD 1.4 stored underground do not require QDs.

4.4 **HD 1.5**

4.4.1 If explosives of HD 1.5 are to be stored underground, they are to be treated as if they belonged to HD 1.1.

4.5 **Net Explosives Quantity**

4.5.1 The location of a single chamber storage site with respect to another, and to other ES, is based on the total NEQ in the individual chambers unless the total quantity is so subdivided that an incident involving any one of the smaller concentrations will not produce simultaneous initiation of others. Because of the unknown effect of confinement, any determination of TNT equivalence or effective NEQ, determined for above ground storage, should be treated with caution when considering underground storage.

4.5.2 Connected chamber storage sites containing HD 1.1 and HD 1.3 are considered as one single storage site for determining QDs unless adequate precautions are taken to prevent propagation of the explosion from one chamber to another.

5 CALCULATION OF QUANTITY DISTANCES

5.1 Chamber Interval

5.1.1 A separation between chambers is required to prevent either propagation, or damage to stocks, by rock spall in an explosive event. The Chamber Interval is the shortest distance between the natural walls of two adjacent chambers, ignoring any chamber linings of masonry, concrete or metal.

5.2 Outside Quantity Distances

5.2.1 Outside QDs will be measured in the following ways:

(1) A distance determined by blast, debris or flames propagated through the tunnel is measured from the centre of the tunnel outlet to the nearest wall or point of the location to be protected, using the extended centre line of the main passageway as a reference line for directional effects.

(2) A distance determined by ground shock, or by blast propagation or debris throw from a crater is measured from the nearest natural wall of a chamber containing explosives to the nearest wall or point of the location to be protected, taking account of relative levels.

5.2.2 Tables of QD for Chamber Interval and Crater Debris Throw are given at Annex A. Because of the number of variables that must be considered, it is not considered appropriate to present tables related to Ground Shock or Adit Blast.

6 CHAMBER INTERVAL

6.1 General

6.1.1 The Chamber Interval is the shortest distance between the natural walls of two adjacent chambers. Since the interval is measured in three dimensions, it may not be obvious from a simple plan of the site. There are two basic levels of protection offered:

(1) Where the prevention of propagation of explosion is sufficient, some damage to stocks of explosives in the acceptor chamber and difficulties in the recovery of stock must be acceptable.

(2) Where the prevention of damage to explosives as well as the prevention of propagation in the acceptor chamber is required.

6.1.2 Variation of Chamber Interval with NEQ for the various degrees of protection advised in the paragraphs below are presented at Annex A.

6.2 Prevention of Propagation by Rock Spall

6.2.1 The Chamber Interval to prevent propagation by high velocity rock spall is:

D1 (= $0.6\ Q^{1/3}$), a minimum distance of 5 m must be maintained.

6.2.2 It should be noted that, although propagation between chambers will be prevented when this separation distance is used, there may be significant damage to the explosives being stored. This is the minimum separation required and if smaller distances are used then prevention of propagation will not be assured.

6.3 Prevention of Damage and Propagation by Rock Spall

6.3.1 The Chamber Interval to prevent spalling of the surface of the chamber rock face depends on the geology of the rock. A minimum Chamber Interval of 5 m must be maintained, however. For different rock types the appropriate Chamber Interval is given below:

(1) For Sandstone, and other soft rock, use $D2 = 1.4\ Q^{1/3}$

(2) For Limestone[1] e.g. (DM Crombie and DM Plymouth), use $D3 = 1.7\ Q^{1/3}$

(3) For Granite, and other hard rock, (e.g. Dean Hill), use $D4 = 2.0\ Q^{1/3}$

6.3.2 Increased protection may be given to the stocks in the acceptor chamber using structurally adequate reinforced concrete walls, roof and floor. These must be adequately separated from the natural rock wall. If the reinforced concrete or other lining is bonded to the natural rock wall, spalling of the innermost surface is likely to occur.

6.3.3 Some underground chambers may be provided with free-standing linings to physically separate the storage volume from the flaking or wet rock walls. These, if constructed of corrugated iron or thin brick or concrete blocks, do not afford protection to the stocks in the acceptor chamber against rock spall and must be ignored in any calculation of QDs. The quasi-static pressure built up in the donor chamber will be little affected by their presence and loading densities must be calculated using the whole volume of the rock chamber.

6.4 Propagation by Flames and Hot Gases

6.4.1 The quasi-static pressure from the confined explosion may form cracks and crevices in the rock wall (or open existing lines of weakness) which may reach the adjacent chamber and thus permit hot gaseous explosion products to flow into the acceptor chamber and hazard the explosives therein. This is considered unlikely with a Chamber Interval of $2.0Q^{1/3}$ or greater.

6.5 Faulted Rock Geology

6.5.1 The above recommended separation distances between chambers do not apply where the local rock is known to be faulted, inhomogeneous, or to lack coherence. Specialist advice should be sought from ESTC.

7 ADIT BLAST

7.1 Introduction

7.1.1 The determination of axial adit blast pressure is dependent on the loading density of explosives of HD 1.1 or SsD 1.3.3 using the total volume of chamber(s) and tunnel(s), and the cross-section of the tunnel mouth.

7.1.2 There is no reduction for facilities with multiple tunnel exits. If the volume of the whole underground facility cannot reliably be estimated, it is recommended that the Chamber Loading Density is decreased by 15% to allow for typical tunnel volumes.

TP[1]PT Limestone rock refers to hard ‘carboniferous’ material and not to chalk or soft or oolitic limestone.

7.2 **Inhabited Building Distance (5kPa)**

7.2.1 The formula used to calculate distances directly in front of the adit is:

$$R = 77 \times Dm \times (LD)^{1/3}$$

Where:

(1) R is the distance in metres to the 5 kPa pressure contour (measured from the tunnel mouth along the axis of the tunnel).

(2) (LD) is the loading density in kg TNT per cubic metre of total volume of tunnel and chamber etc:

$$LD = \frac{NEQ}{\text{VOLUME OF CHAMBER + VOLUME OF TUNNEL}}$$

(c) Dm is the hydraulic diameter of the tunnel mouth (equal to the diameter of a circular tunnel), given by the following expression:

$$Dm = \frac{\text{4 x AREA OF TUNNEL MOUTH}}{\text{PERIMETER OF TUNNEL}}$$

Also, can be expressed as: $Dm = \frac{4A}{U}$

Where: Dm = Hydraulic diameter of Tunnel mouth in m
A = Cross sectional area of tunnel mouth in m^2
U = Perimeter of tunnel in m

7.2.2 The reduction for non-axial directions uses the following multiplication factor:

$$\frac{1}{\left[1+\left(\frac{\theta}{56}\right)^2\right]^{0.74}}$$

Where θ is the angle from the centre line of the tunnel, in degrees, measured from the centre point of the tunnel (in accordance with para 5.2.1(1), above).

7.2.3 It is assumed that the tunnel has no ‘pinch’ or throttle smaller than the hydraulic diameter of the tunnel mouth and that the depth of cover is sufficient to prevent significant venting through the cover. Note that no account is taken of the relationship of chamber and tunnel diameters or of the tunnel wall roughness.

8 **CRATER BLAST**

8.1 **Details**

8.1.1 Whether crater blast needs to be considered in the calculation of inhabited building distances depends on the minimum thickness of rock or soil, etc, above the actual storage chamber or chambers. Where the cover thickness is:

(1) □ $0.1Q^{1/3}$, the crater blast should be considered equal to that from an above ground PES. Use full above-ground IBD (i.e. $22.2Q^{1/3}$)

(2) > $0.1Q^{1/3}$, but □ $0.2Q^{1/3}$, use ½ of the above ground IBD.

(3) > $0.2Q^{1/3}$, but □ $0.3Q^{1/3}$, use ¼ of the above ground IBD.

(4) > $0.3Q^{1/3}$, the IBD from any crater blast will be negligible in comparison with the IBD required for ground shock and debris throw effects from the crater.

8.1.2 Distances are measured from the nearest natural rock wall of the chamber(s). It should be noted that this point of origin may be significantly removed horizontally from the mouth of the tunnel, the origin of the adit blast wave.

9 GROUND SHOCK

9.1 Ground Shock Distances

9.1.1 The ground shock distances are measured from the nearest wall of the actual storage chamber to the wall or point of the ES. If the rock is homogeneous the distances will be the same in all directions. To make allowance for geological variability in different directions, it is recommended that simple determinations be made of the seismic velocity of the compressive wave along radii distributed about the chamber or proposed chamber site. Because of the limited number of measurements of velocity which are practicable, these radii should be orientated in the direction of targets likely to be vulnerable to ground shock. In the absence of velocity measurements or detailed knowledge of the geology of the rocks in the vicinity it is proposed that the most conservative distances recommended in the tables be used. The presence of any major geological faults or defects between the chamber and target is likely to reduce the effect of ground shock and thus ‘fail safe’.

9.2 Inhabited Building Distance

9.2.1 To protect buildings, typically having brick walls nominally 230 mm thick, against severe structural damage from ground shock, the particle velocity set up in the ground by shock must be limited. The tolerable particle velocities vary with the type of rock, or ground, on which the target building is constructed. Typical types of cover, with approximate velocity data, are given below along with formulae to calculate the distance at which the tolerable particle velocity can be expected. Q is the NEQ in kg TNT equivalent and fBDB is the de-coupling factor, dependant on the explosives loading density in the chamber. An estimation of fBDB can be made using the graph given in TAnnex BT. It may be noted that the effect of explosive loading density is less than the velocity of sound on the calculated QD and excessive precision in determining density is not justified. The density to be determined is that within the chamber(s), as follows:

(1) Sand, gravel, clay in ground water, velocity of sound 1000 ms to 1500 ms - the maximum tolerable particle velocity of 60 mm/sec occurs at a distance of:

$$0.9\ f_D\ Q^{4/9}$$

(2) Sandstone, or other similar soft rock, velocity of sound 2000 ms to 3000 ms - the maximum tolerable particle velocity of 115 mm/sec occurs at a distance of:

$4.8\ f_D\ Q^{4/9}$ (e.g. DM Crombie and DM Plymouth)

(3) Granite, Limestone or other hard rock, velocity of sound 4500 ms to 6000 ms - the maximum tolerable particle velocity of 230 mm/sec occurs at a distance of:

$5.4\ f_D\ Q^{4/9}$ (e.g. DM Dean Hill)

9.2.2 It will be noted that the QD varies by a factor of 6 depending on the type of rock. Unless the whole area is composed of hard rock (e.g. granite), unlikely in lowland UK, a conservative ‘worst case’ approach may be grossly pessimistic. An approximate determination of the velocity of sound in the rock may lead to marked reductions in ground shock related QD in underground storage of explosives.

9.3 Process Buildings

9.3.1 Ground shock will affect Process Buildings in the same way as dwelling houses so that logically there would be no difference between IBD and PBD for brick structures. However, a reinforced concrete building may be more resistant to ground shock than a brick building. A specially constructed reinforced concrete building may be designed to be as shock resistant as required. Specialist Civil Engineering advice should be sought, through CIE(MOD) staff, in these circumstances.

9.4 Alternative Method of Calculating IBD

9.4.1 An alternative method of calculating the required inhabited building distance is to use the general formula:

$$kf_D \; Q^{4/9}$$

9.4.2 To facilitate the estimation of the constant ‘k’ in the practical situation, an approximate graph has been constructed and is given at Annex B. It is assumed some determination or estimation of the velocity of sound in the rock, or ground, between the chamber and the target sites has been made.

10 DEBRIS

10.1 Adit Debris

10.1.1 There are many factors that could affect the generation and subsequent projection of debris from the adit of an underground facility because of an accidental explosion inside it. The debris may result from the picking up and projection of items in the chamber or tunnel, from the beak-up of the lining of the tunnel or chamber, from the fragmentation of the weapon casings and packaging as a direct result of the explosion, or from any combination of these. No attempt has yet been made to determine the relative significance of these effects or to quantify the amount of debris that could be expected to be generated. The actual projection of such debris will depend on the energy released in the initial explosion and how that energy is then propagated into the tunnel system.

10.1.2 Recent calculation work has identified that an important aspect is how this initial energy release is modified by the type and consistency of the rock within the chamber, resulting in significantly less energy being available for propagation of the blast wave and gases into the tunnel.

10.1.3 The resulting blast flow, which is considered to be the most important element in the projection of debris from within the tunnel system, will be dependent on:

(1) The relative volumes, cross-sections and geometry of the chamber and tunnel.

(2) The roughness and consistency of the tunnel walls.

(3) The length and curvature of the tunnel.

(4) The presence of any constrictions.

10.1.4 None of these effects have been quantified, but nevertheless, debris issuing from the adit of an underground magazine is considered to present a significant problem in an arc 10° on either side of the tunnel axis, with both direction and orientation being measured from the tunnel mouth. It is difficult to be precise about the level of hazard within this fan, particularly as the database of available trials and accident information is very limited. Debris from inside the chamber and tunnels is considered to present a serious hazard in line with adits. To protect against this, a fixed distance of 600 m to inhabited buildings is to be observed in an arc of 10° either side of the tunnel axis (i.e. 20° total angle). This 600 m fixed distance is conditional on the tunnel and its surroundings being kept clear of all loose material.

10.1.5 It is essential that the tunnel itself and its surroundings are kept clear of loose material, including rocks, transport equipment, etc as far as is reasonably practicable. In addition to such inert projections, it must be borne in mind that explosive items, particularly robust explosives that are present in the tunnel when an explosion occurs, may also be projected. However, there is no evidence to suggest that such items would generate an explosive hazard in their own right.

10.1.6 If an ES exists directly in front of the adit then a vertical faced, earth backed traverse in front of the tunnel mouth may be constructed to divert any projections. The protected area will be bounded by a line subtended at an angle of 7.5° from the perimeter of the tunnel opening measured from the parallel to the axis and extending both horizontally and vertically (see Fig 1). It must be borne in mind that tests have demonstrated that such a traverse effectively redirects the projections down either side of the traverse and will only stop them if it is fitted with a re-entrant facility of a sufficient depth and overall volume. Although it is possible to provide an internal fragment trap in association with an angled tunnel, this will only stop a proportion of the projections escaping and is not sufficient on its own to protect an ES in line with the tunnel axis.

10.2 **Cover Debris**

10.2.1 Unless the cover is sufficient to remain essentially intact in the event of an underground explosion, rock and structural material from the cover will be projected as debris. The hazard from this debris depends on the quantity of explosives and both the scaled thickness ($CQ^{-1/3}$) and the type of rock. Annex A, Table 2 (for soft rock), and Table 3 (for hard rock), give the distances at which debris risk is considered to be tolerable for inhabited buildings for scaled cover up to 1.0 $mkg^{-1/3}$ and 0.8 $mkg^{-1/3}$ respectively. For greater values of scaled cover, debris throw can be neglected.

10.2.2 The tables relate to a loading density of 270 kgm^{-3}, which is considered well above any achievable value in practical storage underground. Although the effect of appreciable changes in the loading density is not known precisely, an approximate allowance is made by multiplying the distance in Table 2 or Table 3 by a correction factor read from Table 4. The values in Table 2 and Table 3 are based on data using a variety of explosives and are taken to correspond to TNT.

10.2.3 The values in Annex A, Table 2 and Table 3, are based on a flat terrain over the storage site. If the cover is sloping in such a way as to favour debris throw in the direction of an ES, the distances are to be increased by using the following correcting multiplication factors:

(1) Cover slope <10° to the horizontal - no enhancement necessary.

(2) Cover slope >10° but <25° - use an enhancement factor of 1.25.

(3) Cover slope >25° but <35° - use an enhancement factor of 1.5.

(4) Cover slope >35° - use an enhancement factor of 1.25.

11 PROCESS BUILDING DISTANCES

11.1 Underground

11.1.1 If a Process Building is constructed underground, the separation from the storage chambers holding HD 1.1 or SsD 1.3.3 explosives must be in accordance with the requirements for Chamber Intervals (see para 6.1). Attention must be paid to other chambers, etc, used for storage in addition to the storage facility associated with the Process Building.

11.2 Above Ground

11.2.1 Where a Process Building is built above ground and in the vicinity of an underground explosives facility, it must be sited such that it would normally be expected to experience a side-on blast pressure no greater than 20 kPa. This blast pressure may be produced from crater breakthrough as well as any adit blast effect. Debris from crater breakthrough must also be considered in addition to adit projections. In the absence of a protective roof on the Process Building and an effective screening traverse to resist the projections, the IBD will be used, including the minimum 270 m in front of the adit for HD 1.1 and SsD 1.3.3 explosives in the underground storehouse.

11.3 HD 1.2, HD 1.3 and SsD 1.4

11.3.1 For HD 1.2, SsD 1.3.4 or HD 1.4 explosives, no restrictions on siting are considered necessary.

11.4 Adit Blast Quantity Distance

11.4.1 The appropriate distance for siting of Process Buildings from the mouth of a tunnel or adit is given by the formula below:

$$Rm \times 27.4 \times Dm \times (LD)^{1/3}$$

11.4.2 This only predicts blast peak over pressure, and other factors, such as adit debris throw, ground shock, etc, must also be taken into consideration, as described in earlier paragraphs.

12 PUBLIC TRAFFIC ROUTE DISTANCES

12.1 General

12.1.1 The distance to a major traffic route from an underground storehouse containing HD 1.1 or SsD 1.3.3 explosives is to be the full IBD. For less busy main routes 2/3 IBD may be used.

12.1.2 Similarly, IBD and 2/3 IBD will apply to the projected debris hazard from crater breakthrough and adit debris from HD 1.1 and HD 1.3 explosives.

12.2 Ground Shock

12.2.1 It is not considered that ground shock from an underground explosion of HD 1.1 or SsD 1.3.3 explosives would directly hazard traffic, either road or rail. However, the presence of a potentially vulnerable civil engineering structure such as a bridge or tunnel must not be overlooked. This would require specialised advice on structural vulnerability. HD 1.2, SsD 1.3.4 or HD 1.4 explosives stored underground will not normally require QD separation from public traffic routes.

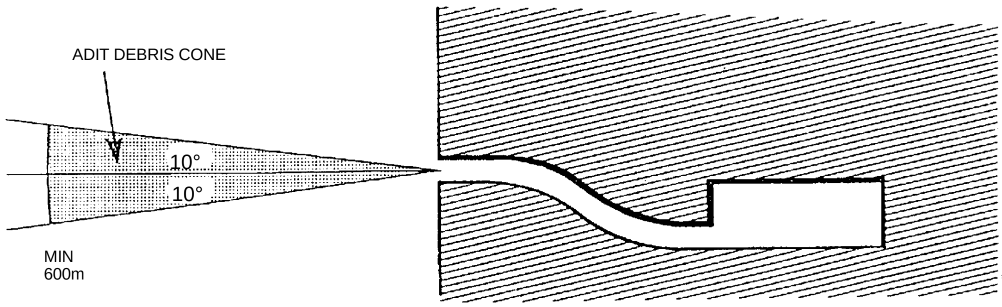

Fig 1 Adit Debris Cone

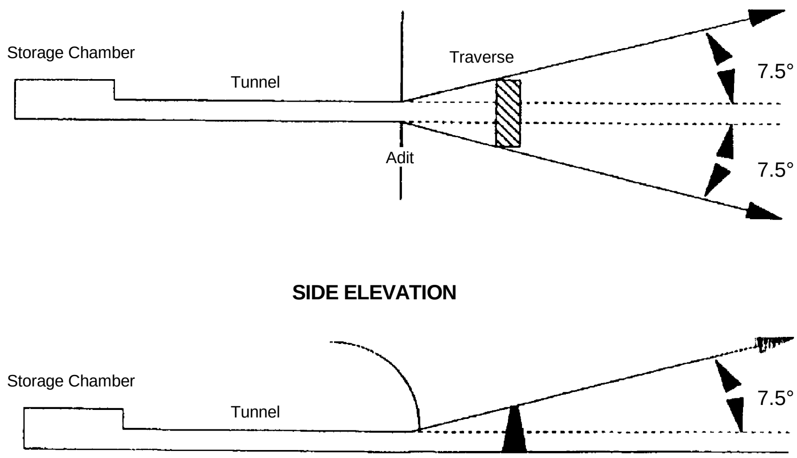

Fig 2 Recommended Coverage for Adit Traverse

13 SEPARATION OF ABOVE GROUND STORAGE FACILITIES FROM UNDERGROUND STORAGE

13.1 General

13.1.1 Above ground explosives storage facilities are not to be built immediately above underground storage facilities. If it is necessary to consider siting explosives storage facilities in such a location, then they must be built to ensure that they would lie outside of any potential crater and are constructed to withstand the anticipated debris, blast and ground shock effects.

13.2 Above Ground Storage Facilities in Proximity to Adits

13.2.1 Where it is necessary to locate an above ground PES in the vicinity of the adit of an underground magazine, it is essential that it is located outside of the arc 10□ either side of adit centre line. This will ensure, to a large degree of confidence, that the debris projected from the adit will not directly affect the PES. Additionally, to provide a degree of protection from blast, the PES should preferably, wherever reasonably practical, be located outside of an arc 30° on either side of the adit centre line, but the guiding principle is that the PES be built to withstand the anticipated blast loading.

13.2.2 No quantified guidance can be given on crater debris effects, but it is anticipated that any above ground PES located close to the adit of an underground magazine is likely to be completely buried in the debris from the break-up of the overhead cover. It must therefore be of substantial enough construction to provide protection to prevent immediate propagation to its contents.

Intentional Blank Page

CHAPTER 10

SECTION 6

ANNEX A

QUANTITY DISTANCE TABLES FOR UNDERGROUND STORAGE

CONTENTS

TABLE 1 CHAMBER INTERVAL FOR HAZARD DIVISION 1.1				
1.1 **Q** **(kg)**	1.2 **D1** **(m)**	1.3 **D2** **(m)**	1.4 **D3** **(m)**	1.5 **D4** **(m)**
1000	6	14	17	20
1200	6.4	15	18	21
1400	6.7	16	19	22
1600	7	16	20	23
1800	7.3	17	21	24
2000	7.6	18	21	25
2500	8.1	19	23	27
3000	8.7	20	25	29
3500	9.1	21	26	30
4000	9.5	22	27	32
5000	10.3	24	29	34
6000	10.9	25	31	36
7000	11.5	27	33	38
8000	12	28	34	40
9000	12.5	29	35	42
10 000	12.9	30	37	43
12 000	13.7	32	39	46
14 000	14.5	34	41	48
16 000	15.1	35	43	50
18 000	15.7	37	45	52
20 000	16.3	38	46	54
25 000	17.5	41	50	58
30 000	18.6	44	53	62
35 000	19.6	46	56	65
40 000	20.5	48	58	68
50 000	22.1	52	63	74
60 000	23.5	55	67	78
70 000	24.7	58	70	82
80 000	25.9	60	73	86
90 000	26.9	63	76	90
100 000	28	65	79	93
120 000	30	69	84	99
140 000	31	73	88	104
160 000	33	76	92	109
180 000	34	79	96	113
200 000	35	82	99	117
250 000	38	88	107	126
300 000	40	94	114	134
350 000	42	99	120	141
400 000	44	103	125	147
500 000	48	111	135	159
Distance Functions	$D1 = 0.6Q\ P^{1/3P}$	$D2 = 1.4Q\ P^{1/3P}$	$D3 = 1.7Q\ P^{1/3P}$	$D4 = 2.0Q\ P^{1/3P}$

It is essential to study the text in Chapter 10, Section 6 when using Table 1 since they are complementary.

It is essential to study the text in Chapter 10, Section 6 when using Table 2 since they are complementary.

TABLE 2 DEBRIS THROW FOR SOFT ROCK FOR HD 1.1 AND SSD 1.3.3

1.6 **Q (kg)**	1.7 **D1 (m)**	1.8 **D2 (m)**	1.9 **D3 (m)**	1.10 **D4 (m)**	1.11 **D5 (m)**	1.12 **D6 (m)**	1.13 **D7 (m)**	1.14 **D8 (m)**	1.15 **D9 (m)**
1000	68	80	85	87	85	77	56	38	20
1200	73	86	92	93	92	83	60	41	21
1400	78	92	97	99	97	89	64	43	22
1600	82	97	103	105	103	94	68	46	24
1800	86	102	108	110	108	99	71	48	25
2000	90	107	113	115	113	103	74	50	26
2500	99	117	124	126	124	113	82	55	28
3000	107	126	133	136	133	122	88	59	31
3500	114	134	142	145	142	129	94	63	33
4000	120	142	150	153	150	137	99	67	34
5000	131	155	164	168	164	150	108	73	38
6000	142	167	177	181	177	161	117	79	41
7000	151	178	189	192	189	172	124	84	43
8000	159	188	199	203	199	182	131	89	46
9000	167	197	209	213	209	191	138	93	48
10 000	175	206	218	223	218	199	144	97	50
12 000	188	222	235	240	235	215	155	105	54
14 000	200	237	251	256	251	228	165	112	58
16 000	212	250	265	270	265	241	175	118	61
18 000	222	262	278	283	278	253	183	124	64
20 000	232	274	290	296	290	264	191	129	67
25 000	254	300	318	324	318	290	210	142	73
30 000	274	323	342	349	342	312	226	153	79
35 000	292	344	365	372	365	333	241	163	84
40 000	308	364	385	393	385	351	254	172	89
50 000	338	399	422	431	422	385	279	188	97
60 000	364	430	455	464	455	415	300	203	105
70 000	388	458	485	494	485	442	320	216	111
80 000	410	483	512	522	512	467	338	228	118
900 00	430	507	537	548	537	490	355	240	124
100 000	449	530	561	572	561	512	370	250	129
120 000	484	571	605	617	605	551	399	270	139
140 000	515	608	644	657	644	587	425	287	148
160 000	544	642	680	694	680	620	449	303	156
180 000	571	674	714	728	714	651	471	318	164
200 000	596	704	745	760	745	680	492	332	171
250 000	653	771	817	833	817	745	539	364	188
300 000	704	831	880	898	880	803	581	393	202
350 000	750	885	938	956	938	855	619	418	216
400 000	792	935	990	1010	990	903	654	442	228
500 000	868	1025	1085	1107	1085	990	716	484	250
Distance Functions	D1 = 4.00 $QP^{0.41P}$	D2 = 4.72 $QP^{0.41P}$	D3 = 5.00 $QP^{0.41P}$	D4 = 5.10 $QP^{0.41P}$	D5 = 5.00 $QP^{0.41P}$	D6 = 4.56 $QP^{0.41P}$	D7 = 3.30 $QP^{0.41P}$	D8 = 2.23 $QP^{0.41P}$	D9 = 1.15 $QP^{0.41P}$
CQ $-P^{1/3P}$	0.10	0.20	0.25	0.30	0.35	0.40	0.50	0.60	0.80

NOTE

If the scaled thickness ($CQ^{1/3}$) value is greater than 0.80, cover debris throw can be ignored.

It is essential to study the text in Chapter 10, Section 6 when using Table 3 since they are complementary.

TABLE 3 DEBRIS THROW FOR HARD ROCK FOR HD 1.1 AND SSD 1.3.3

1.16 **Q (kg)**	1.17 **D1 (m)**	1.18 **D2 (m)**	1.19 **D3 (m)**	1.20 **D4 (m)**	1.21 **D5 (m)**	1.22 **D6 (m)**	1.23 **D7 (m)**	1.24 **D8 (m)**	1.25 **D9 (m)**
1000	65	77	85	87	85	77	65	41	25
1200	70	83	92	93	92	83	70	44	27
1400	75	88	98	99	98	88	75	47	29
1600	79	93	103	105	103	93	79	50	31
1800	83	97	108	110	108	97	83	53	32
2000	86	102	113	115	113	102	86	55	34
2500	95	112	124	126	124	112	95	60	37
3000	102	120	134	136	134	120	102	65	40
3500	109	128	142	145	142	128	109	69	43
4000	115	135	151	153	151	135	115	73	45
5000	126	148	165	168	165	148	126	80	49
6000	136	160	178	181	178	160	136	86	53
7000	144	170	189	192	189	170	144	92	57
8000	153	180	200	203	200	180	153	97	60
9000	160	189	210	213	210	189	160	102	63
10 000	167	197	219	223	219	197	167	106	65
12 000	180	212	236	240	236	212	180	114	71
14 000	192	226	252	256	252	226	192	122	75
16 000	203	239	266	270	266	239	203	129	79
18 000	213	251	279	283	279	251	213	135	83
20 000	222	262	291	296	291	262	222	141	87
25 000	243	287	319	324	319	287	243	154	95
30 000	262	309	344	349	344	309	262	166	103
35 000	279	329	366	372	366	329	279	177	109
40 000	295	348	387	393	387	348	295	187	116
50 000	323	381	424	431	424	381	323	205	127
60 000	349	410	457	464	457	410	349	221	137
70 000	371	437	487	494	487	437	371	236	145
80 000	392	462	514	522	514	462	392	249	154
90 000	412	485	539	548	539	485	412	261	161
100 000	430	506	563	572	563	506	430	273	168
120 000	463	545	607	617	607	545	463	294	181
140 000	493	581	647	657	647	581	493	313	193
160 000	521	614	683	694	683	614	521	331	204
180 000	547	644	717	728	717	644	547	347	214
200 000	571	672	748	760	748	672	571	362	224
250 000	626	737	820	833	820	737	626	397	245
300 000	674	794	884	898	884	794	674	428	264
350 000	718	846	941	956	941	846	718	456	281
400 000	759	893	994	1010	994	893	759	481	297
500 000	831	979	1090	1107	1090	979	831	527	326
Distance Functions	$D1 = 3.83\ Q^{0.41}$	$D2 = 4.51\ Q^{0.41}$	$D3 = 5.02\ Q^{0.41}$	$D4 = 5.10\ Q^{0.41}$	$D5 = 5.02\ Q^{0.41}$	$D6 = 4.51\ Q^{0.41}$	$D7 = 3.83\ Q^{0.41}$	$D8 = 2.43\ Q^{0.41}$	$D9 = 1.5\ Q^{0.41}$
$CQ^{-1/3}$	0.10	0.20	0.30	0.35	0.40	0.50	0.60	0.80	1.00

NOTE

If the scaled thickness ($CQ^{1/3}$) value is greater than 1.00, cover debris throw can be ignored.

It is essential to study the text in Chapter 10, Section 6 when using Table 4 since they are complementary.

TABLE 4 CORRECTION FACTOR FOR LOADING DENSITY FOR USE WITH CRATER DEBRIS THROW DISTANCES GIVEN IN TABLE 2 AND TABLE 3

1.26 **Loading Density ($kg\ m^{-3}$)**	1.27 **Correction Factor**
10	0.57
20	0.66
30	0.70
40	0.74
50	0.76
60	0.79
70	0.80
80	0.82
90	0.84
100	0.86
200	0.97
(270)	(1.00)
300	1.05
400	1.10
500	1.14
600	1.18
700	1.20
800	1.23
900	1.26
1000	1.30
1100	1.31
1200	1.32
1300	1.33
1400	1.33
1500	1.33

Intentional Blank Page

CHAPTER 10

SECTION 6

ANNEX B

GRAPHS FOR DE-COUPLING FACTOR AND GROUND SHOCK

CONTENTS

Fig

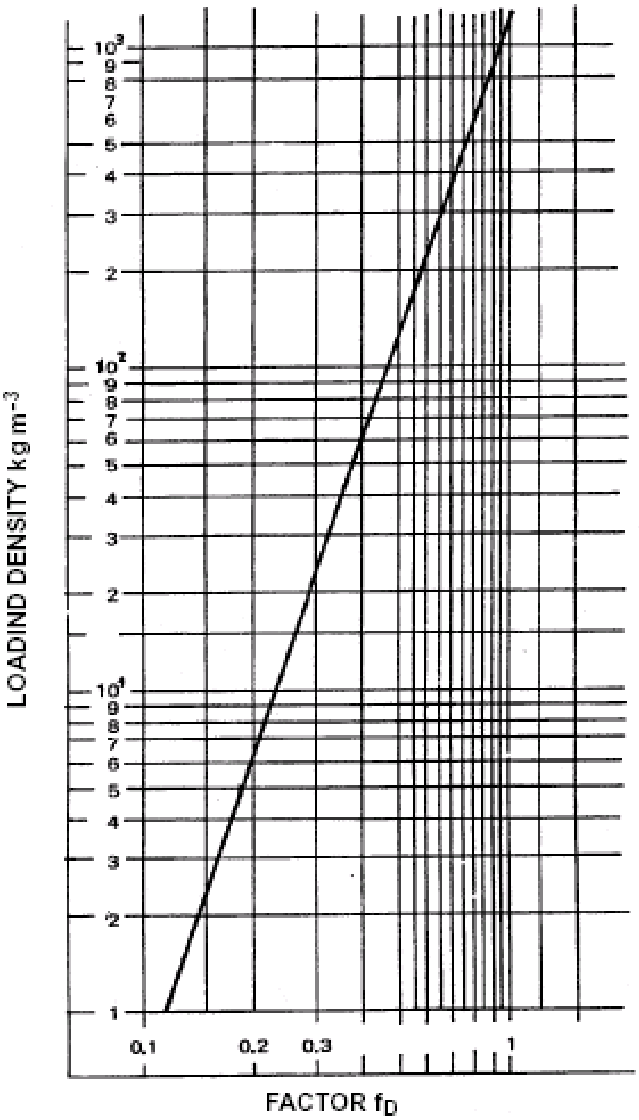

Fig 1 Graph for De-coupling Factor

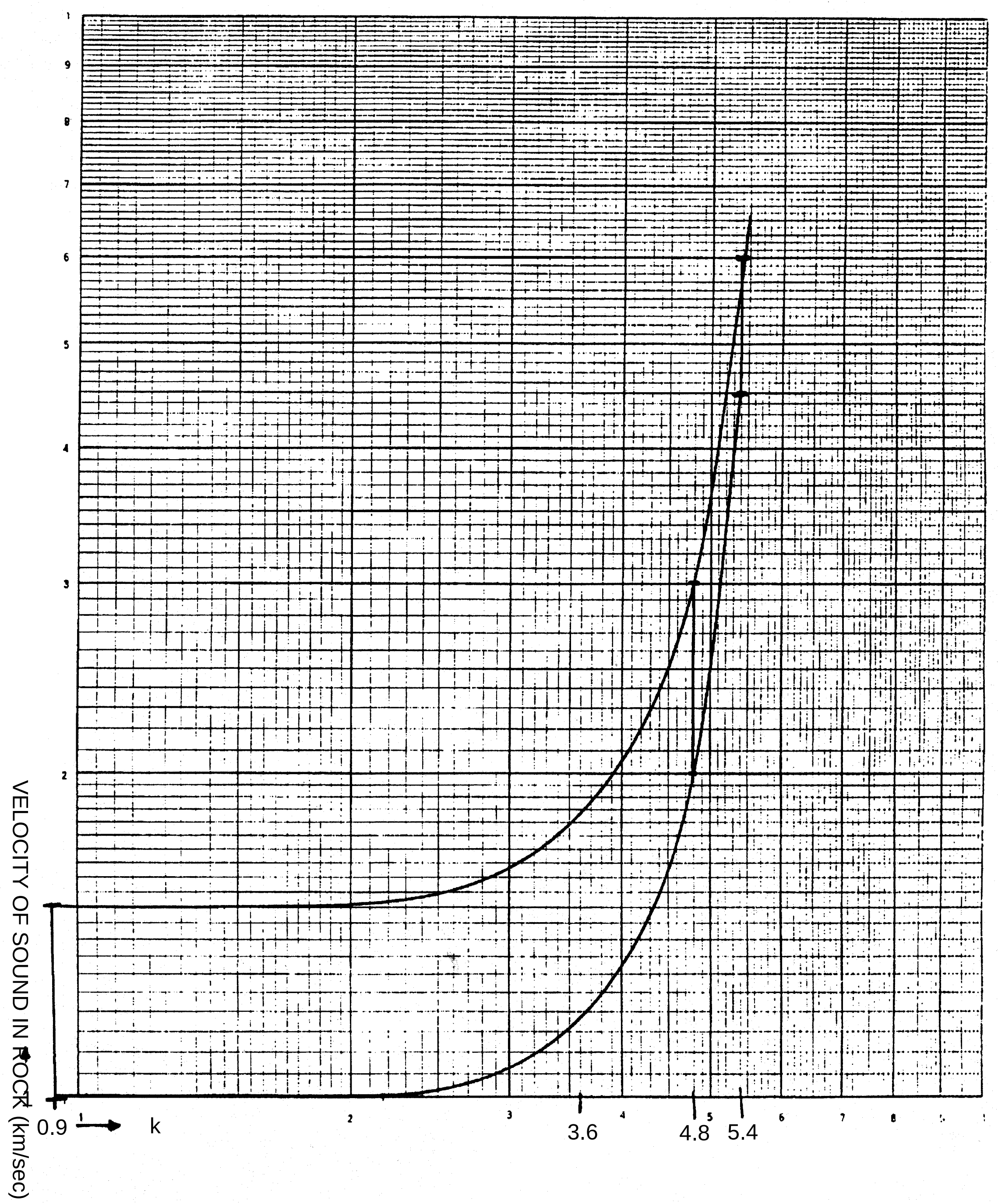

Fig 2 Graph for Ground Shock