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# Types of buildings for explosives facilities

UN SaferGuard
Securing ammunition, protecting lives

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# Foreword

Ageing, unstable and excess conventional ammunition stockpiles pose the dual risks of **accidental explosions at munition sites** and **diversion to illicit markets**.

The humanitarian impact of ammunition-storage-area explosions, particularly in populated areas, has resulted in death, injury, environmental damage, displacement and disruption of livelihoods in over 100 countries. Accidental ammunition warehouse detonations count among the heaviest explosions ever recorded.

Diversion from ammunition stockpiles has fuelled armed conflict, terrorism, organized crime and violence, and contributes to the manufacture of improvised explosive devices. Much of the ammunition circulating among armed non-State actors has been illicitly diverted from government forces.[1] In recognition of these dual threats of explosion and diversion, the General Assembly requested the United Nations to develop **guidelines for adequate ammunition management**.[2] Finalized in 2011, the International Ammunition Technical Guidelines (IATG) provide voluntary, practical, modular guidance to support national authorities (and other stakeholders) in safely and securely managing conventional ammunition stockpiles. The UN SaferGuard Programme was simultaneously established as the corresponding knowledge-management platform to oversee and disseminate the IATG.

The IATG also ensure that the United Nations entities consistently deliver high-quality advice and support – from mine action to counter-terrorism, from child protection to disarmament, from crime reduction to development.

The IATG consist of 12 volumes that provide practical guidance for 'through-life management' approach to ammunition management. The IATG can be applied at the guidelines' **basic, intermediate, or advanced levels**, making the IATG relevant for all situations by taking into account the diversity in capacities and resources available. Interested States and other stakeholders can **utilize the IATG for the development of national standards and standing operating procedures**.

The IATG are reviewed and updated at a minimum every five years, to reflect evolving ammunition stockpile-management norms and practices, and to incorporate changes due to changing international regulations and requirements. The review is undertaken by the UN SaferGuard Technical Review Board composed of national technical experts with the support of a corresponding Strategic Coordination Group comprised of expert organizations applying the IATG in practice.

The latest version of each IATG module can be found at www.un.org/disarmament/ammunition.

[1] S/2008/258.

[2] See also the urgent need to address poorly-maintained stockpiles as formulated by the United Nations Secretary-General in his Agenda for Disarmament, *Securing Our Common Future* (2018).

# Introduction

This IATG module details the general, and, in some cases, recommended mandatory requirements, for the design of buildings that are to contain explosives for either storage or processing. Most potential explosion sites (PES) are a *de facto* potential hazard to personnel, other explosives facilities, and other buildings that are in the vicinity. Correct building design, construction and siting is essential in order to make effective use of the quantity distances (QDs) calculated.[3]

This IATG module will describe the potential consequences of explosive events that may occur and the subsequent effects on the building containing the explosives and other nearby buildings. It will also describe how correct building design will mitigate these effects and it provides descriptions and schematics of some typical ammunition storage buildings.

[3] See IATG 02.20 *Quantity and separation distances*.

# Types of buildings for explosives facilities

## 1 Scope

This IATG module will describe possible scenarios and effects resulting from unplanned explosive events in explosive facilities, how various building designs will respond to such events, and how the design of those buildings and their associated QD's may be optimised to produce safe and efficient explosive storage.

## 2 Normative references

A list of normative references is given in Annex A. These documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

A further list of informative references is given in Annex B in the form of a bibliography, which lists documents that contain additional information related to the contents of this IATG module. .

## 3 Terms and definitions

For the purposes of this module the following terms and definitions, as well as the more comprehensive list given in IATG 01.40 *Glossary of terms, definitions and abbreviations,* shall apply.

The term 'ammunition process building (APB)' refers to *a building or area that contains or is intended to contain one or more of the following activities: maintenance, preparation, inspection, breakdown, renovation, test or repair of ammunition and explosives.*

The term 'exposed site (ES)' refers to *a magazine, cell, stack, truck or trailer loaded with ammunition, explosives workshop, inhabited building, assembly place or public traffic route, which is exposed to the effects of an explosion (or fire) at the potential explosion site under consideration.*

The term 'explosive storehouse (ESH)' refers to *any building or structure approved for the storage of explosive materials*.

The term 'national technical authority' refers to *the government department(s), organisation(s) or institution(s) charged with the regulation, management, co-ordination and operation of conventional ammunition storage and handling activities.*

The term 'potential explosion site (PES)' refers to *the location of a quantity of explosives that will create a blast, fragment, thermal or debris hazard in the event of an accidental explosion of its content.*

In all modules of the International Ammunition Technical Guidelines, the words 'shall', 'should', 'may' and 'can' are used to express provisions in accordance with their usage in ISO standards.

a) **'shall' indicates a requirement**: It is used to indicate requirements strictly to be followed in order to conform to the document and from which no deviation is permitted.

b) **'should' indicates a recommendation**: It is used to indicate that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required, or that (in the negative form, 'should not') a certain possibility or course of action is deprecated but not prohibited.

c) **'may' indicates permission**: It is used to indicate a course of action permissible within the limits of the document.

d) **'can' indicates possibility and capability**: It is used for statements of possibility and capability, whether material, physical or casual.

# 4 Explosive effects

Various physical effects are produced by an explosion and the aim of explosives storage is to reduce the effects of an explosion should it occur. This is done by a combination of factors such as imposing the correct quantity or separation distances (QD) for the explosives being stored, ensuring that Compatibility Group (CG) mixing rules are adhered to and ensuring the storage building design is suitable.

## 4.1 Fragments and debris

Various types of fragments and debris will be generated by a Hazard Division (HD) 1.1 explosion. Fragments are produced by casings of explosive articles, as well as the packaging. These fragments will have speeds of around 3000m/s and be of varying mass, dependent upon the ammunition nature generating them, but the mass will range from 1g upwards. These fragments can kill or injure personnel and may initiate adjacent ammunition and explosives if of sufficient energy.

Debris comes from structural materials, including earth from barricades or cover, arising from the break-up of the potential explosion site (PES). Debris has much lower velocity than fragments (10m/s to circa 500m/s), and consequently do not travel as far, but could kill or injure personnel and even initiate adjacent explosives if they can transfer sufficient energy.

Some debris projection is directional in effect and less debris is projected from the corners of a structure, increasing to a maximum when at right angles to each face of the structure. This applies to all sides of the structure irrespective of whether a barricade[4] is present.

There is also a debris crater formed by the expulsion of material from the seat of the explosion. This has no directional effects and normally has a low velocity, so does not travel far from the source of the explosion. Though crater debris can present an impact hazard to personnel and could even initiate adjacent explosives if the material has enough energy, it is generally not a consideration, as fragments and structure debris have significantly greater mass and velocities and therefore present the greater threat.

Fragments and projections can travel significantly further than the Inhabited Building Distance (IBD), which represents a 1% probability of an average person being hit by a fragment that could seriously injure and possibly kill them. This probability is further defined as one hazardous fragment of 80 joules hitting within an area that measures $56m^2$. Because of the significant real estate required to provide complete protection, this hazardous fragment density has been internationally recognized as the acceptable level of risk from an accidental explosion event. For intentional explosion events, such as at a detonation range, protective distances are based on maximum fragment throw, which is calculated or based on testing.

## 4.2 Fire and thermal radiation

The flame and heat effects of an explosion are highly dependent upon the explosive types involved. The detonation of any explosive results in the production of a fireball. However, explosives in HD 1.1 produce a very short-lived flame, which is of negligible hazard in comparison with the blast and fragment effects.

[4] See IATG 05.30 *Barricades.*

On the other hand, explosives of HD 1.3 differ from detonating explosives of HD 1.1 because, unless they are heavily confined, their reaction does not result in the generation of the high-pressure gases and subsequent blast wave associated with HD 1.1 explosives. The total energy release by a HD 1.3 classified item is comparable with that of a detonation but is released over a longer period, typically seconds or longer as opposed to milliseconds (ms). This energy is released in the form of an intense flame and associated thermal radiation and may cause hazard by the direct impingement onto explosives and personnel.

Burning HD 1.3 material produces combustion gasses which, when burning within a structure, can generate significant internal gas pressure which may be sufficient to cause a breaching/bursting of a structure and the generation of structural debris. The debris will be larger and will have relatively lower velocities. The effects are governed by the amount of HD 1.3 present and burning, the rate of burning, the venting area present in the facility, as well as the structural hardness of the structure. The effects are comparable to a rupture of a pressure vessel that has exceeded its internal pressure limit.

## 4.3 Ground shock

When an HD 1.1 high order detonation takes place on or near the ground, shock loading is imparted to the ground surface. Energy is also transmitted through the air to form air-induced ground shock, and some through the ground as direct-induced ground shock. Air-induced ground shock occurs when the air blast shock wave strikes the ground surface and induces a stress impulse. The directly induced ground shock results from the energy of the detonation wave being transferred directly into the ground. The net ground shock experienced is a combination of the two.

The size and effect of the ground shock are affected by the soil type and air temperature and density through which the shock travels, and by the distance from the seat of the detonation. The effects of ground shock are small compared with air blast, and are generally ignored for aboveground structures. However, for underground storage, the effects and consequences of ground shock must be assessed.

## 4.4 Blast

The air blast from an explosion involving HD 1.1 is in the form of a pressure increase or shock front which expands radially from the centre of the explosion at supersonic velocity. When this shock front impinges on a rigid object such as a building, a higher pressure is produced due to reflection of the wave. As the wave expands from the explosion, it decays in strength, lengthens in duration and decreases in velocity. In general, strength decay is an inverse cube root function of distance.

In addition to the shock wave for each pressure range, a positive particle or wind velocity is produced by the shock front that causes a dynamic pressure on objects in its path. In the free field, these pressures are functions of the air density and particle velocity. In addition, a negative (-) wind velocity (also called a negative phase) will also be produced as air rushes back in after an explosion in order to equalize air pressure. This negative phase can cause further significant damage to structures already impacted by the positive phase pressure loading.

The damaging effects of blast overpressure result from the impulse associated with the blast wave, and which is the inverse of the blast pressure. Higher net explosive quantities (NEQs) produce higher pressures of longer duration, resulting in higher impulses that act on surrounding exposed sites (ES). The longer the duration, the greater “work” associated with the energy acting on the structure, corresponding to greater damage potential to the structure. For example – 5kPa incident overpressure from a 5kg detonation generates an impulse of 23.3Pa-s; whereas 5kPa incident overpressure from a 50,000kg detonation generates an impulse of 501Pa-s. When designing a protective construction or conducting an analysis to determine the adequacy of a building design, the blast impulse is the value that is used to determine the adequacy of a structure to protect its inhabitants battered by the positive pressure blast wave.

## 4.5 Summary of effects

The sensitivity of ammunition and explosive stocks to blast over-pressure, structural motion, fire, and impact by fragments varies with the type of ammunition or explosives being stored. Except where extremely high over-pressures occur (mbar), most explosives, particularly military ones, are insensitive to the effect of direct blast over-pressure. However, a combination of blast over-pressure and structural motion (e.g. wall displacement, roof collapse, or structural breakup) could cause translation or crushing of explosives, which may result in impact and subsequent initiation. Direct attack by low angle, high velocity primary fragments (as opposed to high angle, low velocity fragments) is predominantly the main cause of initiation of explosives at an un-barricaded or un-strengthened exposed site (ES). For more sensitive and less robust explosive substances, or light cased explosive articles, additional threats for initiation could be debris or spall from building walls.

It follows, therefore, that the hazard to explosives at an ES will depend on the ability of the ES structure to resist external explosion effects/blast loading without extensive structural deformation, and generally, to prevent perforation by fragments and debris. The primary design objective must be to prevent significant deformation of adjacent explosives storage structures from an explosion at a nearby PES and to introduce measures to stop fragment/debris penetration and prevent spalling from the internal faces.

The projection hazard from a PES cannot be easily related to the scaled distance for blast effects. However, it is generally accepted that there is likely to be a hazard from projections at all scaled distances less than twice the recommended Inhabited Building Distance (2 x $22.2Q^{1/3}$ ), the hazard being greater when the PES is not barricaded. Unless the ES (at the desired reduced distance) has been shown to provide equivalent protection as that afforded at the required minimum distance, the minimum distances should be applied as described in IATG 02.20 *Quantity and separation distances*.

## 4.6 Air blast effects

Blast overpressure effects at a given scaled distance can be easily predicted (see IATG 01.80 *Formulae for ammunition management)*. If it is assumed, for planning purposes, that the blast overpressure from a light structure is the same as that from a bare charge of equal net explosive quantity (NEQ), then the quantity distances at Table 1 are examples of the overpressure calculations for a given quantity of explosive at a set distance:

| Quantity Distance (m) (Q =NEQ in kg) | Peak Incident (Side-on) Overpressure Expected (kPa) |
|---|---|
| $44.4Q^{1/3}$ | 2 |
| $22.2Q^{1/3}$ | 5 |
| $14.8Q^{1/3}$ | 9 |
| $8.0Q^{1/3}$ | 21 |
| $3.4Q^{1/3}$ | 80 |
| $2.4Q^{1/3}$ | 180 |

**Table 1: Blast overpressure from a bare charge or light structure**

Earth covered structures will attenuate blast overpressure to the sides and rear, with the most reduction from the rear of the building. The figures at Table 2 are for a side-on orientated ECM containing up to 250,000 kg of explosives.

| Quantity Distance (m) (Q = NEQ in kg) | Peak Incident (Side-on) Overpressure Expected (kPa) |
|---|---|
| $19.0Q^{1/3}$ | 5 |
| $14.0Q^{1/3}$ | 8 |

| Quantity Distance (m) (Q = NEQ in kg) | Peak Incident (Side-on) Overpressure Expected (kPa) |
|---|---|
| $11.0Q^{1/3}$ | 9 |
| $6.0Q^{1/3}$ | 21 |

**Table 2: Blast attenuation associated with an explosion in an earth-covered ECM (side-on)**

# 5 Protection against explosive propagation

The protection of explosives at an ES from the effects of an explosion at a PES can be achieved by a combination of: 1) the provision of adequate separation distances between all explosive storage facilities; and 2) ensuring the buildings used for explosive storage are buildings designed to protect the contents from the effects of an explosion. An adequate separation distance will greatly reduce the effects of the blast, fragments and heat radiation to a level that makes the construction of a protective structure at the ES cost effective and the loss of their contents highly unlikely. Adequate separation distance also ensures that if events did occur at both a PES and an ES, the timing between the two events would be sufficient that the two blast waves would not coalesce into a single blast wave as if the event happened concurrently. Blast waves from two independent 10,000kg explosions would not be as far-reaching as coalesced blast waves from two storage sites, each containing 10,000kg, which would represent an explosion event of 20,000kg.

To provide maximum protection, ES should be barricaded (to stop high velocity, low angle fragments/debris which are the predominant threat to ES from HD 1.1 explosions), and either strong enough to withstand the force of the explosion, or light enough so that collapse and any debris formed will not initiate the contents. Buildings should preferably be able to resist the blast loading without extensive deformation and to prevent perforation by fragments and debris. From this it can be seen that different Hazard Divisions[5] pose different problems in the prevention of propagation.

## 5.1 Hazard division 1.1

The protection against propagation of explosions in open stacks should be achieved by the provision of adequate Quantity Distances (QDs) between storage locations and by effective barricading[6]. The QDs are intended to negate the effects of blast, fragmentation and radiated heat to levels at which propagation should not promptly occur.[7] Barricades are structures that are used to primarily intercept high velocity, low-angle fragments and either arrest them or reduce their velocity to levels below which propagation should not occur. When subjected to blast loading, a barricade should remain substantially intact for a sufficient length of time to enable the interception of fragments to be achieved.

Compartmentalised storage (such as dividing walls and internal barricades) and specialized techniques[8] can control the effects of an explosion and allow the application of the rules contained in IATG 02:20 *Quantity and separation distances,* by reducing the maximum credible event (MCE) and allowing QDs based on the worst-case MCE to be used. The function of such storage is to delay or totally prevent prompt propagation of an explosion between explosives items separated in this manner. Special walls can be designed to prevent prompt propagation for larger quantities of explosives, but the result is generally loss of all assets through significant damage of the munitions on the ES side of such walls. For this reason, the application of such storage and techniques should only be pursued after detailed examination and consideration.

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[5] See IATG 01.50 *UN Explosive hazard classification system and codes*.

[6] See IATG 05.30 *Barricades*.

[7] See IATG 02.20 *Quantity and separation distances*.

[8] See DDESB Technical Paper 15, *Approved Protective Construction*, Revision 3 (Annex B refers).

ESH and APBs constructed from masonry, unreinforced concrete, timber and suchlike are not suited to resist external blast loading. These materials are not ductile and sudden failure under load is likely to occur. Such failure will also be a source of structural debris that may initiate the explosives stored inside. Reinforced Concrete (RC) and earth-covered structures, however, are specifically designed to provide a level of protection against the most extreme blast hazard. They also protect explosives and personnel inside from any fragment and debris hazard and reduce the blast over-pressures to levels where damage or injury should not occur.

As PES, buildings made of masonry and concrete will be sources of significant structural debris that present a significant threat to surrounding ES.

## 5.2 Hazard division 1.2

Ammunition of HD 1.2 will not sustain propagation so normal construction materials such as concrete, brick and earth-covered structures may be used for the construction of ESH for HD 1.2. However, this will render the ESH unsuitable for the storage of HD 1.1. Timber and lightweight steel doors are not resistant to projection effects and should not be used.

HD 1.2 ammunition will, in the event of an explosion, produce a range of fragments and lobbed ammunition which will be projected from a PES. If comprehensive data is available for a particular ammunition nature, then the QD for HD 1.2 may be replaced by this more appropriate data taking into account the vulnerability of the ammunition, explosives and buildings at the other ES.

Munitions which explode during an accident will rarely function as intended i.e. detonate in their design mode. In a fire situation, explosive fillings may melt and expand, breaching their casings and then exploding via cook-off or burning to detonation reactions. These explosions may involve anything from 100% to very little of the fill, dependent on the amount of the filling that has escaped through the breach. The fragmentation produced by such reactions is totally different to that generated in a design detonation. The case splits open producing large (for a 105mm shell, for example, 2 - 3kg) but comparatively few fragments with velocities in the range of 10 - 500 m/s. These are likely to be projected further than the smaller fragments from the full detonation of similar munitions in a HD 1.1 reaction. Quantities of unexploded munitions, sub-assemblies or sub-munitions will be projected to considerable ranges and will, due to thermal or mechanical damage, be in a more hazardous condition than previously. As a result, a Storage sub-Division (SsD) should be created. SsD is applicable only to storage situations. .[9]

SsD 1.2.1 – ammunition of HD 1.2 giving fragments with a considerable range, defined as having a total applicable HE content greater than 0.136kg. These comprise those rounds and ammunition that contain a high explosive charge and may also contain a propelling or pyrotechnic charge. “Total applicable HE content” excludes any propelling or pyrotechnic charges. It is not possible to specify QD that allow for the maximum possible flight ranges of propulsive items but the likely range of packaged items, if involved in an accident during storage, is typical of SsD 1.2.1.

SsD 1.2.2 – ammunition of HD 1.2 giving fragments of moderate range, defined as having a total applicable HE content of less than or equal to 0.136kg. It will also typically comprise ammunition that does not contain H.E. and will include pyrotechnic rounds and articles, plus inert projectile rounds.

Test data can be used to move items from one SsD to another[10].

[9] This is a NATO, not UN classification, which has been, introduced as best practice.

[10] A further NATO classification in HD 1.2 also exists – HD 1.2.3. This is applicable to munitions that exhibit at most an explosion reaction in sympathetic reaction testing as per STANAG 4396 and a burning reaction in bullet impact, slow heating, and liquid fuel / external fire testing as per STANAGs 4241, 4382 and 4240, respectively. It is not included within IATG as few countries (with the exception of NATO members) possess such ammunition.

## 5.3 Hazard division 1.3

The thermal radiation from the fireball produced by the functioning of explosives in HD 1.3 can cause fire in another ESH and from there lead to an explosion in that ESH. The explosives most likely to produce a mass fire effect are propellants. They produce a fireball with intense radiant heat, fire brands and some fragments. The firebrands may be large pieces of burning propellant. It is possible that the wind could deflect the upper parts of a fireball away from the seat of the fire and towards an ES. This wind effect could increase flame radius by 50%. An asymmetrically constructed building such as an ECM or building with protective roof and walls, but with one relatively weak wall or a door, induces highly directional effects from the flames and the projection of burning packages.

Weak points in a PES structure may cause jetting of the fireball. Normal construction materials such as concrete and brick, and earth-covered structures may be assumed to be impervious to thermal radiation and flame impingement from fires involving HD 1.3. However, timber and lightweight steel doors are not resistant to the effects of fire and should not be used in construction.

As previously discussed in Clause 4.2 above, internal pressure building up in a structure, from the gas by-products generated by the fire, can cause the structure to burst or breech, generating structural debris.

This division includes some items which burn with great violence and intense heat emitting considerable thermal radiation (mass fire hazard), and others which burn sporadically. Items in this division may explode but do not usually form dangerous fragments. Firebrands and burning containers may be projected. For the purpose of determining QDs and defining mixing and aggregations rules, a distinction is made between the more hazardous propellant explosives of HD 1.3 (classified as SsD 1.3.1) and the less hazardous items and substances of HD 1.3 (classified as SsD 1.3.2).

## 5.4 Hazard divisions 1.4, 1.5 and 1.6

Any secure, weather-proof structure may be used to store explosives of HD 1.4. However, if a construction is being contemplated, then the effects of other PES and future potential storage requirements should be considered.

For HD 1.5[11] and HD 1.6, the national authority should provide storage advice. However, it is recommended to treat HD 1.5 as high value items worthy of a high level of protection at an ES.

# 6 Physiological effects of an explosion

Human body tolerance to blast is high and the degree of injury sustained by an individual is directly proportional to the amount of over-pressure received. The orientation of a person to the shock front, and the actual shape of the shock front, are significant factors in determining the type and level of injuries sustained. The release of air bubbles from disrupted alveoli of the lungs into the vascular system accounts for most fatalities. Rupturing of eardrums and injury to the body due to being propelled by the shock wave translation are also highly likely.

It is internationally agreed that fragments and debris are potentially lethal if their impact energy is ≥ 80 joules (see Clause 4.1). It is expected that, at the Inhabited Building Distance (IBD), the density of such lethal fragments will not exceed 1 per 56 square metres ($m^2$) on the ground surface.

## 6.1 Injuries from hazard division 1.1

Table 3 provides an idea of the effects of blast overpressure at various levels and the potential effect on the human body.

[11] See IATG 02.20 *Quantity and separation distances*.

| Injury Level | Maximum Blast Overpressure (kPa) |
|---|---|
| **Eardrum Rupture** | |
| Threshold of Lethality | 35 |
| 50% Rupture | 100 |
| **Lung Damage** | |
| Threshold of Lethality | 70 |
| 50% Lethality | 250 |
| **Body Translation** | |
| Threshold of Lethality | 100 -150 |
| 50% Lethality | 400 – 750 |

**Table 3: Blast injury levels**

The expected injuries to personnel at specific QD from explosions of HD 1.1 are as summarised in Table 4.

| QD | QD Type | Injury Summary |
|---|---|---|
| $8.0Q^{1/3}$ | Process Building Distance (PBD) | ▪ Serious injuries and fatalities from debris, firebrands, fragments, or building collapse.<br>▪ There is only a small chance of serious injury occurring due to direct blast effects. |
| $14.8Q^{1/3}$ | Public Traffic Route Distance (PTRD) | ▪ Personnel in the open may not be seriously injured by blast, but some injuries will occur as a result of fragments and debris, the extent of which will depend on the construction of the PES and the type of ammunition involved.<br>▪ Personnel in a building will have a high degree of protection from death or serious injury. Any injuries that do occur will be caused mainly by fragments from glass breakage and building debris. |
| $22.2Q^{1/3}$ | Inhabited Building Distance (IBD) | ▪ Injuries are unlikely as a direct result of blast effects, but could occur due to glazing fragments and flying or falling debris. |
| $44.4Q^{1/3}$ | Vulnerable Building Distance | ▪ Injuries are unlikely as a direct result of blast effects. Injuries that do occur will be caused mainly by glass and debris falling from buildings. |

**Table 4: Estimated injury levels**

## 6.2 Injuries from hazard division 1.2

The total fragment and debris hazard at the IBD would not be expected to exceed one potentially lethal fragment (≥80J) per 56m$^2$ of ground area. This hazard is generated over a longer time period, generally in excess of one hour (and possibly days) after the initial explosive event. It may not happen immediately as items may continue to react/explode long after the initial event. Because of this long duration effect, individuals have the opportunity to escape or to seek greater protection from the fragment threat.

## 6.3 Injuries from hazard division 1.3

For explosives of HD 1.3, the IBD is based on a thermal dose of 62.8kJ/m$^2$. Occupants of reasonably constructed inhabited buildings should not suffer injury unless standing in front of a window. They, and anyone caught in the open, are likely to experience reddening of any exposed skin areas.

# 7 Damage to buildings

The damage levels likely to occur to an ES of conventional construction from an explosion of HD 1.1 at a PES for different QD are as summarised in Table 5.

| QD | QD Type | Injury Summary |
|---|---|---|
| $2.4Q^{1/3}$ | Inter Magazine Distance (IMD) | ▪ Any buildings not designed to resist the blast loading will almost certainly be completely demolished. |
| $8.0Q^{1/3}$ | Process Building Distance (PBD) | ▪ Buildings not designed to resist the blast loading will suffer severe damage.<br>▪ Direct initiation of stored explosives is unlikely but the effects of the explosion could lead to a fire. |
| $22.2Q^{1/3}$ | Inhabited Building Distance (IBD) | ▪ Buildings not designed to resist the blast loading will probably only suffer minor damage, mainly to glazing, lightweight cladding, etc. |
| $44.4Q^{1/3}$ | Vulnerable Building Distance | ▪ Buildings not designed to resist the blast loading are likely to suffer only superficial damage to large panes of glass and other lightweight cladding. |

**Table 5: Estimated building damage levels**

Vulnerable constructions located between IBD and 2 x IBD (often the vulnerable building distance, VBD) may be damaged by an explosion. A structural assessment of the extent of the damage that would occur, including the possibility of collapse and fragment or debris penetration, should be made. Vulnerable buildings located beyond VBD should not be damaged and therefore do not require any assessment. Vulnerable buildings are dealt with in greater detail at Clause 9.2.

# 8 Types of buildings at explosives facilities

## 8.1 Light structured buildings

Light structured buildings are constructed of light frangible materials that should not produce very many dangerous projections when used as a PES. As an ES, this structure could collapse but the debris produced should not initiate explosives. This type of structure is typically a single-storey building, clad with lightweight steel, aluminium or glass reinforced plastic (GRP) sheeting or similar materials. Doors shall comply with Table 8.[12]

A light structure provides little resistance to high velocity fragments, lobbed ammunition or debris from an HD 1.1 and HD 1.2 explosive event, or from the fire hazard of a HD 1.3 event. As an ES, light structures should be barricaded to reduce the IMD but shall be barricaded where used as a Process Building.

## 8.2 Medium walled building

A medium-walled building is one constructed of a minimum thickness of 215mm solid or 280mm cavity masonry[13] walls or 150mm RC and a 150mm RC roof slab. Doors shall comply with Table 8. As an ES, this type of structure may collapse, and damage ammunition stored inside because it is not normally designed to resist blast over-pressure. The debris produced by a PES, dependent on the quantity of explosives involved, may have a high enough velocity to initiate explosives or seriously injure personnel within the ES. This type of building will not resist the penetration of high velocity fragments at an ES or PES and should be barricaded to reduce the IMD.

A medium walled building is reasonably effective in resisting fragments and lobbed items of HD 1.2 explosives and provides adequate protection against the fire hazard from HD 1.3 explosives. A medium-walled building is to be considered a light structure when determining QD for other than HD 1.2.

[12] This table is extracted from DSA03.OME part 2. UK MOD. November 2020

[13] Or unreinforced concrete block.

## 8.3 Heavy walled building

A heavy-walled building is one with a minimum of 680mm thick masonry or 450mm thick concrete walls, and a minimum 150mm RC roof. Doors shall comply with Table 8. A receptor barricade is not generally required because the heavy walls fulfil this function. However, if the stocks are vulnerable to attack by debris, a separate barricade should be provided, and consideration given to increasing the strength of the roof to prevent perforation and back-face spalling. If building doors are exposed to fragments from a PES, they should be shielded by a barricade.

As an ES this type of building will:

a) prevent initiation of explosives inside by preventing penetration of high velocity fragments, but it may collapse and damage stocks because it is not normally designed to resist blast;

b) be effective in resisting incoming fragments and lobbed munitions from HD 1.2 explosives, but only when the roof is constructed from RC; and

c) provide adequate protection against the fire hazard from HD 1.3 explosives.

As a PES, the building may intercept some, or all, of the high velocity primary fragments, but the amount of debris is generally increased by the nature of its heavy construction.

## 8.4 Earth covered magazine

An earth covered magazine (ECM, sometimes referred to as an igloo) is an explosives storehouse with earth cover of minimum thickness 600mm on the roof and earth cover to the sides and rear walls. The slope of the earth against the walls is dependent upon the material used. The structure and doors are designed to resist blast and high velocity fragments so that the contents will not be initiated or seriously damaged at the required IMD. The supporting structure for the earth cover can be constructed of corrugated steel and RC, but is normally an RC box structure. As an ES, this type of building behaves similarly to a heavy-walled building for all hazard divisions, with the additional advantage of having been specifically designed to resist the blast loading and, therefore, giving stored explosives complete protection from initiation at reduced IMD. As an ES, there are several categories of structural strength associated with the headwall and doors, based on their abilities to withstand specific external pressure loading and high velocity fragment threats, as discussed herein.

The doors and headwall do not normally require a barricade provided they have been designed to resist blast loading and high velocity fragment penetration. As a PES, an ECM has reduced QDs to the side and rear due to attenuation of the blast by the earth cover while blast and fragmentation effects may also focus out of the front. In order to gain the most efficient land usage where more than one ECM is used, ECMs should be orientated side-by-side with the headwalls on a common line. Where more than one row of ECMs is used, the front walls in one row should face the rear of the other ECMs in the second row.

## 8.5 Earth covered building

An earth covered building is any structure which has a minimum thickness of 600mm of earth on the roof and earth cover to the sides and rear walls, and which does not meet the standards of an ECM Doors must comply with Table 8. The slope of the earth against the walls is dependent upon the material used. A barricade should be provided to shield doors and walls that are not earth covered and which face a PES. As an ES, this type of building behaves similarly to a heavy-walled building for all hazard divisions.

## 8.6 Open bay or site

The floor of such a bay or site is preferably to be of concrete with any required battens firmly attached. Consolidated hard-core or other suitable material may be used, but this form of a base will require constant maintenance to keep vegetation under control. Barricades may be required.

### 8.7 Process building

An ammunition process building (APB) is a building or site in which explosives are manufactured or worked upon. This includes such facilities as missile test rooms, preparation buildings, explosives workshops and all maintenance and preparation procedure facilities. The use of an appropriate building type shall ensure that the requirements of IATG 02:10 *Introduction to risk management principles and processes* are met and that workers are employed at risk levels which are as low as is reasonably practicable (ALARP).

As an ES, this type of building must either be designed to survive and protect workers from an explosion at a PES, or have a relatively large separation distance from other PES in order to give protection to personnel rather than just to protect against initiation of the explosives contained within.

As a PES, an APB is classified according to its construction and the QDs determined using the total quantity of explosive that may be present at any one time unless effectively unitised. Due to the close proximity of explosives to workers within a PES, it may not be possible (other than for small quantities of explosives) to provide protection, and fatalities should be expected. However, the ALARP principle should be applied wherever reasonable and practicable to lessen the risk.

### 8.8 Container storage

Any container being used as storage e.g. an ISO or similar container shall be treated as an open stack when being used for storage of explosives. Barricades may be required.

## 9 Inhabited buildings and PES

Inhabited buildings are those that contain people but not explosives. The term is usually applied to buildings used by the general public outside an explosives area, but is also used for those buildings inside the area owned by the national authority that may be affected by a PES, e.g. soldiers' accommodation, administration areas, etc. All non-explosives inhabited buildings within the IBD of a PES should be designed to resist the expected blast over-pressure and should resist fragments and debris. However, and unusually, where the risk from fragments is low, a light structure that would collapse and produce debris that would not seriously injure personnel within may provide a cost-effective alternative.

The glazing in inhabited buildings is vulnerable to the effects of a blast even at VBD (the purple line) where there is still some risk of injury from flying or falling glass. Construction and glazing of inhabited buildings affected by a PES should comply, as a minimum, with Table 6.[14]

### 9.1 Structural considerations

Serious structural damage, caused by blast, to traditionally constructed low-rise buildings located between IBD and VBD should not occur. The breakage of glass and frangible cladding may occur, but the risk of serious hazard to occupants should be minimal. However certain types of construction are known to be susceptible to significant damage at and beyond the IBD and may cause injuries and fatalities disproportionate to the scale of the explosive event. This could happen as a result of construction materials used (e.g. extensive glazed areas) or from the risk of total collapse, which could crush and kill occupants who would otherwise be expected to survive in the open or in more traditional forms of construction. The term 'vulnerable construction' is used to describe these types of buildings and they require special attention when planning storehouse construction and calculating QDs.

[14] This table is extracted from DSA03.OME part 2. UK MOD. November 2020.

## 9.2 Vulnerable construction

Buildings of vulnerable construction should be sited at a minimum of $44.4Q^{1/3}$, but the variation and complexity of modern building materials, construction methods and national legal requirements and usage make it impossible to define universal regulations. A building classified as vulnerable may still be located at the normal IBD if the population is low or measures are taken to protect the population from the potential explosion hazards. Guidance to the types of building that might be described as being of vulnerable construction, and the factors that will influence the need to locate them outside the purple line from a PES, are as follows:

a) Type 1 - glazed or other frangible curtain wall construction. Buildings that are more than three storeys or 12m in height constructed with continuous non-load bearing curtain walling with individual glazed or frangible panels larger than $1.5m^2$ and extending over more than 50% or $120m^2$ of the surface of any elevation. This construction is typical of high-rise office buildings;

b) Type 2 - glazed wall construction. Buildings that are more than three storeys or 12m in height with solid walls and individual glazing panes or frangible panels larger than 1.5 $m^2$ and extending over at least 50% or 120 $m^2$ of any elevation. This construction is typical of that used in high-rise office buildings;

c) Type 3 - glazed or other frangible roof construction. Buildings that are of more than 400 $m^2$ plan area with continuous or individual glazing panes larger than 1.5 $m^2$ extending over at least 50% or 120 $m^2$ of any elevation. Type 3 buildings are typical of those in covered market buildings, shopping complexes and retail warehouses; and

d) Type 4 – sensitive structures. Building structures that may in themselves be susceptible to disproportionate damage (e.g. collapse, partial collapse or progressive collapse), including;

   1) unframed structures with limited continuity utilising non-ductile materials;

   2) large-span, tension or other special structures with critical load bearing elements;

   3) unusually weak structures such as historic or timber framed buildings; and

   4) buildings containing vulnerable elements such as pre-cast panel fixings or large span slender masonry panels which may be particularly susceptible to failure and lead to a falling debris hazard.

As a general guide, buildings that stand out by either size or construction type against a normal background of houses should be closely examined. Those buildings that fall within or near the vulnerable construction guidelines above, or where it is suspected that they may be particularly vulnerable to blast, should be assessed to identify any potential risks.

## 9.3 Other buildings

Large facilities of special construction or importance should be examined to ascertain if they are to be classed as being of vulnerable construction and a technical assessment must be carried out for each site. Where the facilities are assessed to be of vulnerable construction, the large facilities should be sited at a minimum QD of $44.4Q^{1/3}$. Examples are:

a) large factories;

b) multi-storey office or apartment buildings;

c) public buildings and structures of major value;

d) large educational facilities;

e) hospitals;

f) major transport centres such as ports, railway stations, airports, etc;

g) major public utilities such as water, gas and electric works;

h) facilities of vulnerable construction used for mass meetings such as assembly halls and fairs, exhibition areas and sports stadia; and

i) built-up areas, which are both large and intensely developed.

The construction of buildings in an explosives area which are normally unmanned, such as plant rooms, electrical sub-stations, pump houses and so forth, should be situated and protected to the level of the importance attached to the survival of the facility.

<table>
<tr><th colspan="2">Distance from PES</th><th rowspan="2">Structural Requirements</th><th rowspan="2">Glazing Requirements</th></tr>
<tr><th>QD</th><th>QD Type</th></tr>
<tr><td>$>44.4Q^{1/3}$</td><td>Vulnerable Building Distance (VBD) (Purple Line)</td><td>▪ Conventional design only.</td><td rowspan="6">▪ Single or double glazing acceptable.<br>▪ Laminated glass or anti-shatter film permitted.</td></tr>
<tr><td>$<44.4Q^{1/3}$</td><td>Vulnerable Building Distance (VBD) (Purple Line)</td><td rowspan="3">▪ Conventional design only.<br>▪ Vulnerable construction not allowed.<br>▪ Load-bearing brick structures permitted but note the requirements for the limitation of progressive collapse.</td></tr>
<tr><td>$<22.2Q^{1/3}$</td><td>Inhabited Building Distance (IBD) (Yellow Line)</td></tr>
<tr><td>$>16.0Q^{1/3}$</td><td rowspan="2">Closest Indirect Support Distance (Unhardened)</td></tr>
<tr><td>$<16.0Q^{1/3}$</td><td rowspan="4">▪ Conventional design but must have an RC slab at roof level of at least 150mm.<br>▪ Load-bearing brick structures permitted but note the requirements for the limitation of progressive collapse.</td></tr>
<tr><td>$>14.8Q^{1/3}$</td><td rowspan="2">Public Traffic Route Distance (PTRD)</td></tr>
<tr><td>$<14.8Q^{1/3}$</td><td rowspan="4">▪ Single or double glazing acceptable.<br>▪ Laminated glass only. The use of anti-shatter film is not acceptable.</td></tr>
<tr><td>$>11.1Q^{1/3}$</td><td rowspan="2">½ Inhabited Building Distance</td></tr>
<tr><td>$<11.1Q^{1/3}$</td><td rowspan="2">▪ Conventional design but must have a full structural frame and an RC slab at roof level of at least 150mm.</td></tr>
<tr><td>$>9.6Q^{1/3}$</td><td rowspan="2">Closest Direct Support Distance (Unhardened)</td></tr>
<tr><td>$<9.6Q^{1/3}$</td><td rowspan="3">▪ Specially approved designs.</td><td rowspan="3">▪ Specialist advice should be sought.</td></tr>
<tr><td>$>8.0Q^{1/3}$</td><td>Process Building Distance</td></tr>
<tr><td>$<8.0Q^{1/3}$</td><td>Special Facilities</td></tr>
</table>

**Table 6: Exposed sites construction requirements**

## 10 Design considerations (LEVEL 2)

The following design considerations shall be modified to meet national authority legal requirements. They should, however, be viewed as best practice as they are in line with the highest standards of ammunition storage and safety principles. Explosives facilities should be constructed so as to provide a specified level of protection against the hazards of accidental explosive events in an adjacent facility. The type of structure provided will depend on the protection level required and the type and quantity of explosives stored.

The final structural form of the storage or processing facility will depend upon the anticipated blast loading acting on the structure, and the anticipated fragment and debris distribution will determine if the roof and walls require reinforcing and the need for traversing.

However, there are certain standard design requirements that should be applied to any explosive storage namely:

a) facilities should be designed so that they are easy to keep clean and ensure that dirt and dust is kept to a bare minimum;

b) there must be adequate access to the facility and individual explosives stacks to enable ease of checking and movement of the explosives and to provide the free movement of air between stacks to assist with moisture control;

c) where possible, fixtures and fittings should be located so that they cannot be fouled by MHE or other equipment. If this is not possible, fixtures and fittings should be suitably protected;

d) electrical equipment should be designed for any unique hazards that might exist, explosive dusts, gases or vapours from processes being performed or the material being stored;

e) grounding and bonding for static charge control;

f) lightning protection consideration, especially if in an area where lightning strikes present a threat. Lightning protection can be constructed integral to the design of the structure, such as with an ECM where reinforcing steel in all the walls can be tied together to form a protective barrier;

g) gangways should be provided between stacks and the wall of an ESH. They should be permanently marked on the floor as a sterile area using yellow hatched markings;

h) ESH should be designed and equipped so that the inside temperature does not fall below 5°C or rise above 25°C. If these temperature conditions cannot be met, artificial heating or air conditioning to an approved standard should be installed; and

i) the surrounding area must be free of flammable materials. Undergrowth should be kept close cropped to the ground. Grass should very short to 6m from PES. The rest of the site should be kept in such a condition so as not to present an undue fire risk.[15]

## 10.1 Protective buildings for personnel (LEVEL 2)

Buildings which are required to provide protection for personnel, such as APBs and other occupied buildings at inside quantity distance (IQD), should be designed to resist blast loadings and penetration by fragments and debris. The following design requirements should be adopted:

a) all design considerations should be based on a 90% confidence level;

b) deflections of main supporting structural elements should be limited to 2° support rotations or deflections of span divided by 60. If mild-steel spall plates of suitable thickness are fixed to the internal face of RC surfaces to retain back-face spalling, a maximum support rotation of 4° or deflections of span divided by 30 may be adopted;

c) high velocity spalling of RC elements or members is unacceptable and should be prevented by the use of spall plates. Low velocity spalling may be accepted if it can be shown that it will not be dangerous to personnel; and

d) the glazing hazard standard shall be of low hazard – see Table 6 and Clause 11.11 for glazing specifications.

## 10.2 Design of pressure release structures (LEVEL 2)

Designing structures to fully contain the blast and fragments due to an internal explosive event is only practicable when very low quantities (≤10 kg) of explosives of HD 1.1, or larger quantities (≤50kg) of HD 1.3 are stored. Structures designed to store explosives of HD 1.3, or small quantities (≤100kg) of HD 1.1 can be designed to survive with limited damage by incorporating a frangible wall or panel to reduce the magnitude and duration of the internal blast parameters should an internal explosion occur. However, should construction of this type of building be considered then specialist advice should be obtained.

[15] See IATG 02.50 *Fire safety*.

## 10.3 Frangible materials and their properties (LEVEL 2)

Ideally, frangible materials should have low mass, break up into small harmless fragments at the PES, and be strong enough to resist fragments at an ES. Provision of a barricade to shield a vent panel against fragment attack negates the need for the material to be fragment resistant at an ES. However, the frangible wall or panel should satisfy security requirements.[16] The best method should be the use of a separate and approved security barset inside the vent panel, which does not compromise the vent operation. This system also has the advantage of improving resistance to external blast pressures. Restriction of gas flow through the reduced vent area should be taken into account in the design.

Frangibility of materials is dependent upon the strength and mass of the material used, but it is also affected by the applied blast loading. As the blast loading on the panel in typical storage situations is likely to be very large, the effects of material resistance may be ignored and the frangibility determined by considering only the mass of the panel. However, for smaller quantities of explosives this situation may not be the case and consideration of the material's resistance may be necessary.

To permit adequate venting, a frangible wall or panel should have a mass not exceeding 50kg/m$^2$ for HD 1.3 and 25kg/m$^2$ for HD 1.1. There should not be line of sight between frangible walls in an adjacent PES unless the separation distance is sufficient to prevent propagation by fragments, debris or projected burning propellant.

Any fixings used to secure frangible walls and panels to a structure shall be designed such that the frangible portion fails in the required manner. The suitability of materials used for frangible features will depend upon factors such as mass, durability and weather resistance. The following materials are listed in recommended order of preference:

a) glass reinforced plastic (GRP) - a high strength material that produces small lightweight projections of low velocity. The unit mass is dependent upon thickness but is typically 2.2kg/m$^2$ for a thickness of 1mm;

b) plywood - has a high strength to weight ratio, but if >25 mm thick it may produce heavy, sharp fragments. The unit mass is typically around 0.6kg/m$^2$ per mm of thickness;

c) fibrous cement sheeting - is lightweight and strong but produces sharp fragments that could be hazardous. The unit mass is between 2.5 - 3.3kg/m$^2$ per mm of thickness;

d) steel and aluminium sheeting - have low mass and high strength but they tend not to break up. They usually deform and should still be considered a hazardous projection risk. Aluminium has a unit mass of 2.7kg/m$^2$ per mm of thickness and steel 7.8kg/m$^2$; and

e) proprietary panels – are sandwiches made from thin metal sheeting with a lightweight insulating core such as styrofoam. They have low mass and are easily removed from fixings by an explosive event. However, they tend not to disintegrate and may pose an unacceptable projection hazard risk. The individual properties of this type of panel should be sought from the prospective manufacturer.

[16] See IATG 09.10 *Security principles and systems.*

## 10.4 Ammunition requiring special consideration (LEVEL 2)

### 10.4.1. Rockets and missiles

Unless tests have shown otherwise, rockets and missiles should always be regarded as self-propulsive. Rockets and missiles that are stored in a propulsive state should have walls thick enough to prevent their perforation in the event of accidental initiation. The rockets/missiles should be secured to the structure; alternatively, a structure designed to resist motor thrust such as a vertically faced barricade, located as close to the building as possible, may be provided. This barricade should be thick enough to prevent perforation by the rockets and the barricade length and height should exceed an angle of 10° from the door aperture.

The most suitable type of structure for storage of ammunition of this type is an ECM. The rockets should be positioned pointing towards the rear or sidewalls. However, if the missiles face the door, a door barricade may be required. Rockets in a non-propulsive state should be stored in structures suitable for the quantity and HD of the explosives present.

### 10.4.2. Storage of HD 1.1 shaped charge warheads

Trials have shown that shaped charge warheads will produce a shaped charge if they are initiated, even in a fire. The jet will be significantly less efficient than the designed effect but will still be capable of penetrating the walls of any storage structure. Therefore, warheads should be pointed towards earth backed walls or towards the floor. It is preferable to have several discrete layers, e.g. cavity walls with a vertical faced and earth backed barricade, between the stored warheads and the free field because this will help to disrupt the jet. The larger the shaped charge, the more penetrative any formed jet will be and the more difficult it will be to provide effective mitigation.

There are no specific QDs recommended to provide protection against the shaped charge effect, even from very large charges, since the jet represents only one fragment. Therefore, provided the above recommendations are followed, HD 1.1 QDs should be applied.

## 10.5 Construction to contain fragments and prevent lobbing (LEVEL 2)

Designing structures to contain projections or lobbed items of HD 1.1 is an extremely complicated procedure and very costly, so unless special circumstances arise, it should not be considered. It is only feasible to design such a structure when the NEQ is small, or when the NEQ is divided into smaller quantities by dividing walls that prevent the mass explosion of the entire content in the event of an accidental explosion in one of the units. The design of a structure to contain projections and lobbed items represents a more stringent requirement than that for dividing walls to prevent propagation. Where such a design is required, expert advice should be obtained.

## 10.6 Protection against projected objects (LEVEL 2)

Explosives storage buildings should provide protection against penetration by debris, low velocity fragments and lobbed munitions. This is achieved by a combination of appropriate separation distances and the minimum construction thicknesses listed below:

a) roof - 150mm in-situ reinforced concrete slab;

b) walls - 150mm in-situ reinforced concrete or 215mm solid brickwork; and

c) doors - 16mm mild steel or equivalent;

To give protection against high velocity fragments, a barricade or earth cover should be provided. However, if this is not possible, the following material thicknesses will generally be sufficient to prevent initiation of the explosives at an ES:

a) walls - 450mm in-situ reinforced concrete or 680mm solid brickwork;

b) doors - 50mm mild steel or equivalent; and

c) barricade - 2400mm of earth.

Specially designed structures can be constructed to provide protection from specific threats, but such structures must be designed by a specialist in this area.

# 11 Construction materials

## 11.1 Earth

Earth cover for earth covered buildings and ECM are also required to meet the requirements of the materials listed in Table 7.

| **Material Description** *(In preference order)* | **Grading Limits (1) (2)** | | | | **Design Slope (4)** *(Dependant on soil mechanics)* |
|---|---|---|---|---|---|
| | **Coarse Material** | | **Fine Material** | | |
| | **Maximum Particle Size** | **Maximum Content (% by Weight: 20 – 75mm)** | **Maximum Fines Content (% by Weight: <63µm)** | **Maximum Clay Content (% by Weight: <2µm)** | |
| Well Graded Sand | 6.3mm | o% | 15% (1) | 5% (1) | 1:1.5 to 2 ($33^0$ to $26^0$) |
| Well Graded Gravelly or Clayey or Silty Sand (inorganic) | 7.5mm | 5% (1) | 20% (1) | 5% (1) | 1:1.3 to 2.5 ($37^0$ to $21^0$) |
| Inorganic Fill (3) | Other inorganic material meeting the above grading requirements | | | | |

**Table 7: Construction materials for earth covered buildings[17]**

NOTE 1 Coarse and fine particles shall be uniformly distributed throughout the material to provide a homogenous fill.

NOTE 2 The material used should have a Uniformity Coefficient ($D_{60}$ / $D_{10}$) of 6 or greater.

NOTE 3 Rubble from demolished buildings or any other similar material shall not be used in the construction of barricades due to the risk of enhanced projection hazard.

NOTE 4 Slope stability requirements are defined in this IATG; design slopes tabulated are indicative only and will vary dependent upon:

a. The nature and strength of foundation soil and rock and depth to the water table;
b. The degree of compaction and surface preparation provided to the fill;
c. The fineness of the content and erosion potential of the fill materials;
d. The compaction moisture content where the fill materials are not free draining;
e. The provision of drainage measures to control short/long-term pore water pressures; and
f. The fill being reinforced with geo-synthetics, wire mesh etc.

## 11.2 Reinforced concrete (LEVEL 3)

In the following technical data, the standards referred to are indicative of the technical specifications the national technical authority may specify.

[17] These are the same requirements as for earth barricades. See IATG 05.30 *Barricades.*

The lowest grade of reinforced concrete (RC) permitted for use in construction of explosives facilities should be C35[18] with a nominal maximum aggregate size of 20mm. For conventional structures used as explosives buildings, the normal national technical authority reinforcement requirements should apply. Where there is a design requirement to consider dynamic loads, the following should also apply:

a) the arrangement, quality and quantity of reinforcement shall ensure satisfactory performance of RC elements subject to plastic deformation under blast loading. The requirements are significantly different and more stringent than for conventional structures;

b) main and secondary reinforcement shall be hot-rolled high-yield (HRHY) deformed steel bars to an equivalent of BS 4449:2005 + Amendment 2 2009 *Specification for carbon steel bars for the reinforcement of concrete*[19] Grade 460; and

c) shear reinforcement shall be hot-rolled mild steel bars (MS) to an equivalent of BS 4449 Grade 250.

Cold worked high yield reinforcing bars shall not be used in explosives structures because of the high strain rates and large deformations expected.

The minimum reinforcement quantities for blast resistant structures shall be:

a) 0.25% HRHY main bars each face;

b) 0.2% HRHY secondary bars each face;

c) 0.1% MS links for designed compression reinforcement; and

d) 0.04% MS links for nominal compression reinforcement.

Reinforcement shall be arranged so as to minimise laps where practical. Where laps in the main tension bars are necessary, they shall be 72 diameters long to allow for the reduced bond strength in cracked concrete. Reinforcement shall have full development lengths at slab/wall and wall/wall junctions.

Blast links shall be provided to enclose all layers of main and secondary steel in order to better contain the core concrete, to improve dynamic response, to increase shear capacity and to limit the size of back face spall fragments. Links shall be 'U' shaped, staggered and at maximum spacing of 300mm. Links shall generally be used in preference to diagonal lacing bars for reasons of economy and construction practicability. Links shall be adequately bent around reinforcing bars at corners and the minimum hook length shall be the lesser of 20 bar diameters each or two thirds of the slab thickness.

Open links conforming with shape code 77 to ISO 3766:2003 *Construction drawings - Simplified representation of concrete reinforcement* are acceptable provided that the hook allowance is increased to 40 diameters. The open end should face away from the potential explosion source i.e. in the primary tension face. Closed links conforming with shape code 79 to ISO3766 are acceptable provided that the over-lapping leg is placed through the thickness of the concrete section. The use of shape code 61 to ISO 3766 and shape code 51 to BS 8666:2005 *Scheduling, dimensioning, bending and cutting of steel reinforcement for concrete - Specification* are not permitted for use as blast links.

[18] See ISO 22965:2007 Series *Concrete.*

[19] There are, as yet, no ISO covering this particular subject, although ISO 15630-1 *Steel rod test methods* is referred to in the BS.

Reinforcement should generally utilise moderate sized bars (up to 25mm) at close centres in preference to large bars at large centres in order to better contain the core concrete, to improve dynamic response and to limit the size of back face spall fragments. Main and secondary reinforcement shall be provided equally in both faces of RC elements subject to blast loading in order to allow for reverse loading and rebound forces. Reinforcement in RC elements shall be bonded so as to preclude side flashing. This should include, as a minimum:

a) reinforcement crossovers to be welded at a maximum of 2.5 metre centres in both faces; and

b) any remaining reinforcement crossovers shall be wire-tied at every intersection.

## 11.3 Structural steel (LEVEL 3)

Structural steel members required to provide resistance to blast loadings shall be able to develop their full plastic capacity during support rotation, and only plastic sections are to be used. Other types are not permitted.[20]

Plastic deformations of structural purlins,[21] within the permissible limits given in Clause 10.1 may be used to produce an economic solution. To avoid brittle modes of failure, member support connections shall be 'over-strong' and designed to withstand the maximum capable support reaction of the section under plastic rotation.

The grade of steel used must remain ductile in the design environment and for the range of permissible deformations given. BS 4449 Grade 43C is generally acceptable.

Welded components, junctions or connections that are load-carrying and that are vital to surviving an accidental explosion should be:

a) subjected to an agreed non-destructive test regime to demonstrate the competence of the welds; and

b) normalised after fabrication by an agreed heat-treatment process to relieve stresses in the heat affected zones.

## 11.4 Brickwork (LEVEL 2)

Brickwork for use in the construction of explosives facilities is to have a minimum characteristic compressive strength of 27.5N/mm$^2$ in a 1:1:6 cement/lime/sand mortar mix. Bricks should be solid and frost resistant (e.g. Engineering Class A or B). Where it is impractical to obtain solid bricks, any hollows shall be laid upwards and completely filled with mortar.

The use of concrete blockwork as an alternative to brickwork may be suitable only if solid blocks with a minimum compressive strength of 15.0N/mm$^2$ are used. Concrete blocks may not necessarily meet security requirements for intruder resistance and may require additional measures. Alternatively, hollow blocks with steel reinforced and concrete-filled voids may be considered. However, if block walls are intended to act in pressure relief such as in HD1.3 storage, then these measures shall not be allowed.

[20] For multi-storey buildings the risks of progressive collapse after blast loading should be established. In physics and materials science, plasticity, also known as plastic deformation, is the ability of a solid material to undergo permanent deformation, a non-reversible change of shape in response to applied forces. Plasticity theory can be used for some reinforced concrete structures assuming they are under-reinforced, meaning that the steel reinforcement fails before the concrete does.

[21] Defined as *a horizontal structural member spanning between beams or trusses to support a roof deck.*

## 11.5 General comments on building materials not specified (LEVEL 2)

Generally, flammable materials shall not be used in explosives facilities and only non-combustible materials shall be used for the construction of facilities containing explosives. All construction shall be watertight, and all components shall be moisture resistant. The fixing of equipment to walls and roofs that may be subject to high shock loads should an explosion occur, shall be minimised due to the potential debris hazard that could arise from dislodged equipment, potentially with significant velocity.

### 11.5.1. Spark resistant materials and equipment fixing (LEVEL 3)

Facilities for the storage of bulk explosives sensitive to sparks or friction shall not have any exposed iron, steel, aluminium or aluminium alloy containing more than 1% of magnesium where it may come into contact with explosive substances. Where facilities are used for the storage of bulk explosives sensitive to sparks or friction, 'spark resistant' aggregates for the floor and walls are to be used in construction.

Where equipment fixings to concrete walls subject to high shock motions are unavoidable, they shall utilise under-reamed anchors, or other suitable types that have been demonstrated to be able to perform adequately in cracked concrete. Parallel expanding anchors shall not be used in such locations.

## 11.6 Roofs (LEVEL 2)

PES roofs should be either all heavy or all light. A heavy roof is defined as being one of at least 150mm thick RC, or its equivalent. Light roofs, which are normally pitched, shall be covered in a frangible material e.g. glass reinforced polyester or light metal sheeting. Metal trusses should normally be used, but on smaller buildings hardwood trusses may be acceptable. For concrete roofs that are not waterproof, a suitable waterproof finish, such as asphalt, may be fitted. If suitable propriety products are identified they may also be used as long as their fire rating is of the correct standard. Arrangements should be made on all roofs for rainwater discharge into open channels or gullies.[22] The recommended option should be the use of heavy roofs for all buildings but the decision on the type of roof used will depend on the explosives to be stored and local circumstances.

### 11.6.1. Special functions

Roofs, which are usually designed in combination with the supporting wall, may be designed to have special functions such as:

a) containment of fragments and the prevention of lobbed items. QDs for buildings designed to contain fragments and lobbed items should be dependent on the design specification of the actual building. In many cases, reduced QDs resulting from incorporating such roofs may be permitted;

b) shielding against blast, projections and lobbed items; and

c) exclusion of firebrands, projections and lobbed items with a resulting reduction in QDs. However, this reduction often depends on the provision of a shielding roof.

[22] The impact of snow and ice on ventilation and drainage in extremely cold climates should be considered.

## 11.7 Floors (LEVEL 2)

Floor design loadings shall be adequate to support the stored explosives and materiel handling equipment (MHE). The load area of a pallet will be of the order 10kN/m$^2$ of floor area. In some structures such as ECM storage, stacks up to 5 pallets high may be utilised which may give a loading of 50kN/m$^2$. Gangways and access requirements will reduce the average floor loading.

To make such floors dust free, they should be treated with sodium silicate (ICI Grade P84 or equivalent) or a similar approved substance. The floors of a PES to be used for the storage or processing of bulk explosives sensitive to spark or friction should be surfaced with gritless asphalt or other approved substance as per Clause 11.5. Other substances are also possible but formal approval should be sought from the national authority. Some facilities, particularly process buildings, may require to be fitted with conductive or anti-static floors.

## 11.8 External and internal walls (LEVEL 2)

PES designed as ESH do not require any internal or external decoration. In hot climates, external walls may be painted white to reflect heat. APB walls should have a smooth finish, free of cracks and crevices and be painted with an oil-based or washable paint. Lead based paint shall not be used. All corners should be rounded off and flat surfaces angled downwards to facilitate cleaning. Cladding and insulation specifications shall be based on those described at Clause 11.5 above. Asbestos shall not be used for this purpose.

## 11.9 Drainage (LEVEL 2)

Adequate drainage should be provided for all PES. To avoid the ingress of water through door openings, the external slab should fall away from the building. Any drains exiting sites where there are exposed explosives, such as APBs, laboratories etc., should have a suitable and readily accessible trap with removable covers fitted in order to intercept any explosive residues. Traps and drains shall be regularly cleaned to prevent any build-up of residue.

## 11.10 Doors (LEVEL 2)

Door construction may vary according to the required degree of protection to stocks from fragments and whether a door barricade is present. Door materials shall comply with the requirements set out in Table 8. Locks shall comply with the requirements of IATG 09.10 *Security principles and systems*.

<table>
<tr><th rowspan="2">Exposed Site Construction Type</th><th colspan="4">PES Holdings</th></tr>
<tr><th>HD1.1 / 1.2</th><th>HD1.3 / 1.4</th><th>No PES</th><th>Notes</th></tr>
<tr><td>Lightweight</td><td>As HD1.3/1.4</td><td rowspan="4">The main requirement is explosives safety, followed by physical security.<br>Generally to be as approved by IATG 09.10.</td><td rowspan="4">Prime requirement is explosives safety, followed by physical security.<br>Generally to be as approved by IATG 09.10.</td><td rowspan="4">The national authority shall lay down security standards, however, these should meet the minimum of IATG 09.10.<br>Similarly it should be noted that the door hinges should be suitable for the task.</td></tr>
<tr><td>Medium-walled<br>(150mm RC or 215mm brick)</td><td>16mm mild-steel plate.<br>Security requirements to be incorporated into the design.</td></tr>
<tr><td>Earth-covered ESH</td><td>16mm mild-steel plate.<br>Security requirements to be incorporated into the design.</td></tr>
<tr><td>Heavy-walled<br>(450mm RC or 680mm brick)</td><td>50mm mild-steel plate.<br>Security requirements to be incorporated into the design.</td></tr>
</table>

**Table 8: Minimum construction requirements for exposed site doors**

### 11.10.1. Fire doors (LEVEL 2)

Emergency escape doors for evacuation in fire, explosion or other emergency shall be located to satisfy national authority laws and regulations. These should also satisfy the requirements of IATG 02.50 *Fire safety*. It is suggested that there is a maximum escape distance of 9m where travel is possible in one direction only and 18m for more than one permissible direction. In storehouses where the provision of alternative means of escape is not possible, such as earth-covered storehouses and ECM, approval may be given to increasing the maximum single-direction travel distance to 18m.

Escape doors should not be fitted with locks but should have approved bolts on the inside and be provided with 'Ball'[23] type catches that will operate by pressure on any part of the door. Panic bolts or latches may be provided instead of 'Ball' catches if security or other considerations warrant it. One escape door may also be used for access and may be fitted with an approved lock in place of the bolts, however, this lock must only be operable from the inside of the building.

Door openings shall be of dimensions suitable for their required usage and should open outwards. Sliding, folding and up-and-over types are acceptable. These types of door shall be provided with, or have adjacent to them, an outwards opening personnel escape door.

An entrance step may be provided to protect stocks against ingress of dirt or water. The height of this step should not be excessive, and ramps should be fitted to protect MHE.

## 11.11 Windows and other glazing (LEVEL 2)

Flying glass is the main cause of injuries in explosive events. It should be a requirement to design all inhabited buildings inside the IBD to resist blast pressures, fragments and debris, so it is logical to design any glazing to minimise the risks posed. A summary of the glazing required within IQD is included in Table 6.[24] Windows shall not face a PES, or if they do, they shall be effectively barricaded.

Windows shall not normally be permitted in explosives buildings. Where this is unavoidable, they should be as small as possible and (for security) should be non-opening. Where opening windows exist, they shall be fitted with approved security grilles. Windows should be positioned where they will not admit direct sunlight, which could fall on explosives. If this is not possible, they should be covered or shaded.

To reduce and/or mitigate the risk from fragments from a PES and from glass fragments clerestory[25] glazing should be used. In occupied explosives buildings, low level glazing should be designed to survive the blast overpressures in order to offer reasonable levels of protection to the occupants.

Glazing materials shall be chosen to reduce injuries to the occupants of inhabited buildings. The materials most suitable for this purpose are:

a) laminated glass. Laminated glass with a minimum thickness of 7.5mm consisting of annealed glass with a 1.5mm thick polyvinylbutyral (PVB) interlayer has a high blast resistance and does not produce such hazardous fragments as annealed or toughened glass. Such glazing should be UV resistant. Deep rebates with polysulphide or silicon sealant should be used when fitting the window frames;

[23] A spring-loaded ball held within a cylinder attached to a flange.

[24] More detailed information on glazing resistance to blast loading is contained within the UK Home Office Scientific Development Branch (HOSDB) Glazing Hazard Guide 1997.

[25] Defined as a high wall with a band of narrow windows along the very top.

b) polycarbonate. Polycarbonate with a minimum thickness of 6mm, fitted into robust frames, is a tough flexible material with a high blast resistance. In comparison with other types of glazing, it is more expensive, less scratch resistant, degrades with time and exposure to solvents such as cleaning materials, and can produce sharp fragments when it fails. It is difficult for X-rays to detect such fragments in the human body and this should be addressed in the risk assessment before it is adopted for use. Such glazing should be UV resistant. It is more useful as a secondary glazing material: and

c) toughened glass (full heat tempered). This glass is 4 to 5 times stronger than annealed glass and can therefore resist higher blast loading if fitted in a strong rigid frame. The fragments produced when it breaks are small, cuboid and less injurious than those from annealed glass.

Untreated plain glass or wired glass shall not be used within IQD. Should these exist in current buildings they should be enhanced with anti-shatter film (ASF) and bomb-blast net curtains (BBNC). Where plain or wired glass is used internally, the side remote from the PES shall be filmed. Where the primary blast can come from either side from multiple PES, both sides shall be filmed. Inside $14.8Q^{1/3}$ only laminated or toughened glass solutions shall be used.

## 11.12 Ventilation and air conditioning (LEVEL 2/3)

Ammunition storage and process buildings should be kept as dry and temperate as possible. To assist in the reduction of condensation they should be provided with natural ventilation and, if required, dehumidification equipment. To optimise the life of explosives, it is desirable to limit the humidity and temperature in a storehouse or process building. The ideal conditions are that:

a) the relative humidity should be maintained between 50 and 60%. Humidity levels higher than this may lead to deterioration of the explosives and lower levels may give rise to problems with static electricity for some types of ammunition; and

b) the temperature should generally be maintained between 5°C and 25°C. Temperatures higher than this could cause damage to propellants and other explosive material.

High- and low-level ventilators should be provided in all buildings and compartments that are not air conditioned. However, in very small compartments, this may not be necessary. If ventilators or air conditioning is not fitted, careful checking for dampness and stock deterioration must take place regularly.[26]

Ventilators may be either controllable from the exterior of the building or be of a permanent open type such as air-brick. They shall comply with all security requirements including the fitting of suitable metal shields to prevent the ingress of rain or snow. Fire shutters with fusible links may be required for certain types of ventilators.

To prevent penetration by fragments, airbricks provided in cavity masonry walls shall be staggered horizontally, and those provided in solid masonry or reinforced concrete walls shall be protected by 6mm thick mild-steel cover-plates giving line-of-sight protection. Overlaps should be provided to ensure secure fitting.

If forced air ventilation is required and exhaust fans are necessary, these should be fitted on the leeward side of the building. Suitable automatic shutter systems fitted with small mesh metal grilles, where necessary, should be provided to ensure that there is no ingress of air when the fans are not running.

[26] See IATG 06.70 *Inspection of explosives facilities.*

In hot climates, special arrangements should be made to keep the contents of a PES as cool as possible by providing an interior ceiling or double roof and extending the width of the roof to protect the walls from the direct rays of the sun. In some PES where the temperature range is critical, it may be necessary to provide insulating materials or air-conditioning. Alternatively, earth covered above ground or semi-underground buildings may be a suitable alternative. It may also be necessary to provide metal grille doors in addition to the normal doors to enable the PES to be adequately ventilated during the night. The grille doors should be fitted with approved locks.

Where it is necessary to provide air conditioning to meet specified restricted humidity conditions, the plant provided shall comply with national requirements and IATG 05.40 *Safety standards for electrical installations*.

Certain processes may have the potential for generating hazardous environments, such as explosives dust, gases or vapours, and, in those cases, ventilation and associated electrical equipment shall be designed to prevent inadvertent initiation of those environments. Such designs should be in accordance with IATG 05.40 *Safety standards for electrical installations*.

### 11.13 Heating and utilities (LEVEL 2)

Suitable protective shields should be provided to prevent explosives, stores containing explosives, or their packages from coming into contact with any heated surface, pipes or radiators. The protective shields should be designed such that items cannot be placed on them, for example with sloping tops.

Utilities to APBs such as compressed air, and any associated plant, water supplies, drainage etc, should have pipelines or conduits carrying services that are colour coded to show the nature of their contents, and bonded at the entry and exit to/from the building or compartment. This colour coding should be shown at the building entrance and at such other points as is necessary to avoid confusion. The colour code should be approved by the national technical authority.

### 11.14 Lifting equipment (LEVEL 2)

Buildings intended to contain heavy or bulk stores should either be provided with an approved overhead hand operated or electric crane, or the construction of the PES should be such that it will allow for the use of mobile handling, lifting and stacking equipment.

### 11.15 Lightning protection

See IATG 05.40 *Safety standards for electrical installations.*

## 12 Electrical requirements (LEVEL 2)

These are covered in depth at IATG 05.40 *Safety standards for electrical installations.*

## 13 Blast design and survivability

The design of buildings to be subjected to blast and shock loadings shall be carried out by competent persons such as chartered civil or structural engineers with appropriate experience in blast design. It is not intended to lay down any firm regulations as these will of necessity be modified by the national technical authority to meet local requirements and laws including design approval. It is suggested that the survivability criteria in this document should be the minimum standard required.

# Annex A
(normative)
# References

The following normative documents contain provisions, which, through reference in this text, constitute provisions of this module. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this module, are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO maintain registers of currently valid ISO or EN:

a) BS 4449:2005[E] and Amendment 2:2009 *Specification for carbon steel bars for the reinforcement of concrete.* BSI. 2009;

b) IATG 01.40 *Glossary of terms, definitions, and abbreviations*. UNODA;

c) IATG 01.50 *UN Explosive hazard classification system and codes*. UNODA;

d) IATG 02.20 *Quantity and separation distances.* UNODA;

e) IATG 02.40 *Safeguarding of explosive facilities*. UNODA;

f) IATG 02.50 *Fire safety*. UNODA;

g) IATG 05.30 *Barricades*. UNODA;

h) IATG 06.70 *Inspection of explosives facilities*. UNODA;

i) IATG 02.40 *Safeguarding of explosive facilities*. UNODA;

j) IATG 09.10 *Security principles and systems*. UNODA;

k) ISO 22965:2007[E] Series *Concrete.* ISO. 2007; and

l) ISO 3766:2003[E] *Construction drawings - Simplified representation of concrete reinforcement.* ISO. 2003.

The latest version/edition of these references should be used. The UN Office for Disarmament Affairs (UNODA) holds copies of all references[27] used in this guideline and these can be found at: www.un.org/disarmament/un-saferguard/references. A register of the latest version/edition of the International Ammunition Technical Guidelines is maintained by UNODA, and can be read on the IATG website: www.un.org/disarmament/ammunition. National authorities, employers and other interested bodies and organisations should obtain copies before commencing conventional ammunition stockpile management programmes.

[27] Where copyright permits.

# Annex B
(informative)
# References

The following informative documents contain provisions, which should also be consulted to provide further background information to the contents of this guideline:[28]

a) AASTP-1, Edition B Version 1. *NATO Guidelines for the Storage of Military Ammunition and Explosives.* NATO Standardization Organization (NSO). December 2015. http://nso.nato.int/nso/nsdd/listpromulg.html;

b) *Handbook of Best Practices on Conventional Ammunition*, Chapter 2. Decision 6/08. OSCE. 2008;

c) DSA03.OME part 2 provides for the safe storage and processing of Ordnance, Munitions and Explosives (OME). UK MOD. November 2020;

d) Technical Paper 15, *Approved Protective Construction*, Revision 3. US Department of Defense Explosives Safety Board (DDESB). May 2010. www.wbdg.org/building-types/ammunition-explosive-magazines; and

e) UFC-3-340-02, *Structures to Resist the Effects of Accidental Explosions*. US Department of Defense. 05 December 2008; Change 2, 01 September 2014. www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-3-340-02.

The latest version/edition of these references should be used. The UN Office for Disarmament Affairs (UNODA) holds copies of all references[29] used in this guideline and these can be found at: www.un.org/disarmament/un-saferguard/references. A register of the latest version/edition of the International Ammunition Technical Guidelines is maintained by UNODA, and can be read on the IATG website: www.un.org/disarmament/ammunition. National authorities, employers and other interested bodies and organisations should obtain copies before commencing conventional ammunition stockpile management programmes.

[28] Data from many of these publications has been used to develop this IATG.

[29] Where copyright permits.

# Annex C
(informative)
# List of ammunition storage building types

This Annex is not intended to provide a definitive list of ammunition storage building types. Rather it is intended to identify the various types of buildings and the functions they carry out to provide information to the national technical authority in order that it can make valued judgements on the type of facility required.

## C.1 ECM (LEVEL 3) and storage buildings (LEVEL 2)

Standard ECM are fully pre-designed structures. They only require the design of their foundations and other elements that depend on individual site conditions. ECM should be designed to a 90% level of confidence that, as an ES, collapse or door failure will not occur when exposed to the blast loading from an explosion at a nearby PES at the appropriate IMD. Significant changes to the design may require complete re-validation of the structure. Drawings of these structures are readily available and in the event of a building programme, expert help should be sought. A source for current '7 Bar' ECM structural designs is the Whole Building Design Guide website at www.wbdg.org/building-types/ammunition-explosive-magazines.

Deflections have been limited to maintain structural integrity. They will not be larger than the width of the air gap around the explosives within, such that the structure will not strike the explosives. The support rotations of all the RC elements and the doors shall be limited to 4° and 12° respectively.

To avoid major spalling, the spall velocities shall be limited to:

a) spall velocities >50 ms and with a kinetic energy ≤2500J; and

b) spall velocities <50 ms and with a momentum ≤100Ns.

Standard ECM construction should prevent major spalling of RC members occurring; however, the limits above may not prevent initiation of sensitive primary explosives.

### C.1.1 Design Loads for ECM as an Exposed Site

The blast parameters that standard ECM have been designed to resist are as follows:

a) 3 Bar ECM. When ECM are constructed with their axes parallel, account shall be taken of the explosion effects from another ECM in a side by side situation. The separation distance (IMD) D3 is given by $0.5Q^{1/3}$. The blast parameters for the dynamic design of the ECM structure are as follows:

| Location on ECM | Peak Positive Overpressure (kPa) | Positive Impulse (kPa.ms) | Positive Duration (ms) |
|---|---|---|---|
| Head Wall, Doors, Rear and Side Walls | 300 | $100Q^{1/3}$ | $1Q^{1/3}$ |
| Roof | 600 | $100Q^{1/3}$ | $1Q^{1/3}$ |

**Table C.1: 3 Bar ECM design parameters**

b) 7 Bar ECM. When ECM have the same longitudinal axis and the head wall and doors of one are exposed face-on to the rear wall of another or vice-versa, the separation distance (IMD) D4, front to back, is given by $0.8Q^{1/3}$. ECM should not be sited with their doors facing each other. The blast parameters for the dynamic design of the ECM structure are as follows:

| Location on ECM | Peak Positive Overpressure (kPa) | Positive Impulse (kPa.ms) | Positive Duration (ms) |
|---|---|---|---|
| Head Wall, Doors and Rear Wall (if the position is reversed) | 700 | $200Q^{1/3}$ | $1Q^{1/3}$ |
| Side Walls | 300 | $100Q^{1/3}$ | $1Q^{1/3}$ |
| Roof | 600 | $100Q^{1/3}$ | $1Q^{1/3}$ |

**Table C.2: 7 Bar ECM design parameters**

c) An ECM that is not a true arch, such as a portal type or "flat arch" structure, should be designed for the likely blast loading on the earth-cover. Each structural element (roof, sidewall or rear-wall) may require consideration depending upon the type and orientation of the structure. Owing to the dearth of data on the loading beneath the earth-cover, it may be necessary to design for the anticipated worst case, similar to the design loads for head-walls and doors. Design authorities should base their work upon applicable blast parameters from test references cited in NATO publication AASTP-1, Part 2, Annex IIB taking into account the maximum NEQ expected for the proposed facility and consulting at the earliest practicable date with national explosives safety authorities.

### C.1.2 Design loads for ECM doors as an Exposed Site

As well as positive phase blast effects, ECM doors should be designed to resist the loads that may occur during the negative phase of the blast loading. An equivalent static pressure of 0.5 Bar over the surface area of the doors should be taken for support restraint design. The doors are not required to remain in position under full rebound loads. Fragment attack on the door and head wall is not of particular significance provided that end-on conditions[30] apply. Typical fragments have less than 1 kg mass and velocity up to 300 m/s. A mild steel door with plate thickness of 20mm will resist the perforation of all fragments within these limits. A 16mm plate thickness will reduce the residual velocity such that sympathetic detonation should not occur.

### C.1.3 Single bay box ECM

Many designs exist but, in essence, this is an RC portal type structure with a minimum of 600mm of earth cover on the roof and earth cover against the side and rear walls. The slope of the earth against the walls is dependent on the material type used but should have a maximum slope of 1:2 (approximately 26°). Access is through a top-hung sliding steel door and a steel personnel door, both located in the headwall. The foundations are RC strip footings with a separate ground-bearing floor slab. The internal dimensions are 16m long, 9.12 m wide and a minimum of 4.6m high. The structure has been dynamically designed to resist the blast effects as an ES from an explosion in a nearby PES.

This particular ECM has been designed at the relevant QDs as a PES and an ES for a nominal maximum NEQ stored of 75,000 kg of HD 1.1 and up to 250,000 kg of HD 1.2 or HD 1.3. Greater NEQ's may be stored, but a design check must be carried out to determine any structural alterations required. An example of this design is illustrated at Annex D.

### C.1.4 Double bay box ECM

Again, different designs are possible. It is an RC structure as described above but the roof slab is supported at midpoint by a longitudinal RC beam spanning on to RC columns at ~4 metre intervals. The internal dimensions are 16m long, 18.64m wide and a minimum of 4.6m high. NEQ limits are as for a single bay ECM. An example of this design is illustrated at Annex D.

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[30] Those scenarios where the ends of each ECM face each other.

### C.1.5 Steel arch ECM

This ECM is formed of corrugated steel sheeting with RC front and rear walls and base slab with earth cover and NEQs as for other forms of ECM. Access is generally through a top-hung sliding steel door, but some designs use double, hinged doors. An example of this design is illustrated at Annex D.

### C.1.6 Steel framed medium wall storehouse

This is a single-storey steel framed building with mono-pitched RC roof and masonry cavity perimeter walls. This structure is not generally designed to resist blast loading. Access is through doors located in the side. An example of this design is illustrated at Annex D.

### C.1.7 Storehouse for HD 1.3 ammunition

This is an RC single storey box structure with a part frangible front wall. Overall dimensions are approximately 37m x 16m x 6.2m. This structure is not generally designed to resist blast loading. Access to the building is through two top-hung sliding steel doors located in the front elevation. An example of this storehouse is illustrated at Annex D.

### C.1.8 Storehouse for unit ammunition holdings

This may be a single storey, compartmentalised and flat roofed building. The roof and floor slab are RC, supported on the external cavity and solid masonry cross-walls. Access into each compartment is through double doors in the front. For security reasons, the inner wall should be constructed of bricks not blocks, unless approval is given by the national technical authority. An example of this storehouse is illustrated at Annex D.

## C.2 Ammunition process buildings (LEVEL 2)

Many different types of APB exist that cover the requirements for ammunition manufacture, maintenance and testing. The design of new buildings should take into account the design principles contained in this IATG. Unfortunately, older buildings of this type were not generally designed to resist blast loading, and protection against high velocity missiles was provided by barricades or heavy walls acting as barricades, together with a protective roof. However, these types of buildings are not satisfactory because the weight of debris from the structure at collapse would cause serious injury to the occupants. An example of these buildings is illustrated at Annex D.

### C.2.1 General purpose ammunition process buildings

This building is used for the assembly and maintenance of explosives. The arrangement of the plant room, changing room, office and so forth should be altered to suit the specific requirements of the individual building. The construction consists of an RC frame and slabs with clerestory glazing and masonry cavity external walls. APBs should be designed to promote flexibility in use. However, a specific process building may be necessary to meet a specific requirement such as large missile surveillance. APBs should always be completely barricaded. As an ES, or where personnel who are not directly involved in the processing activity are exposed to risk of injury, the design shall give them reasonable and practicable protection.

### C.2.2 Special purpose ammunition process buildings

#### C.2.2.1 Integrated weapons complex (LEVEL 3)

These facilities are designed to be used for the assembly, maintenance and testing of missiles, torpedoes and other complex weapons systems.

The example shown at Annex D consists of four Weapon Assembly and Check Rooms (WACR) positioned in a cruciform shape around a central Test Equipment House (TEH) and two independent plant rooms. The actual construction should be determined by the blast parameters from a given amount of explosives in a WACR and should be designed to give reasonable levels of protection to workers in an adjacent WACR and higher levels of protection to personnel in the TEH. This particular design has been verified by trials.

The TEH is a RC box construction, separated from the WACR construction to reduce shock transfer in the event of an explosion. Heavy blast doors, which are mechanically actuated and interlocked, protect the TEH and there are no windows. This design affords protection both to the occupants and test equipment.

Each WACR has three thick reinforced concrete walls, which serve as container barricades. Internal dimensions are approximately 24.5m long x 10.5m wide x 6.6m high. The roof and front wall are designed to be lightweight frangible vents with the front wall additionally provided with a vertical RC barricade. Efflux vent holes are provided in two side walls. A personnel escape door is provided at the rear of each WACR with an external door barricade.

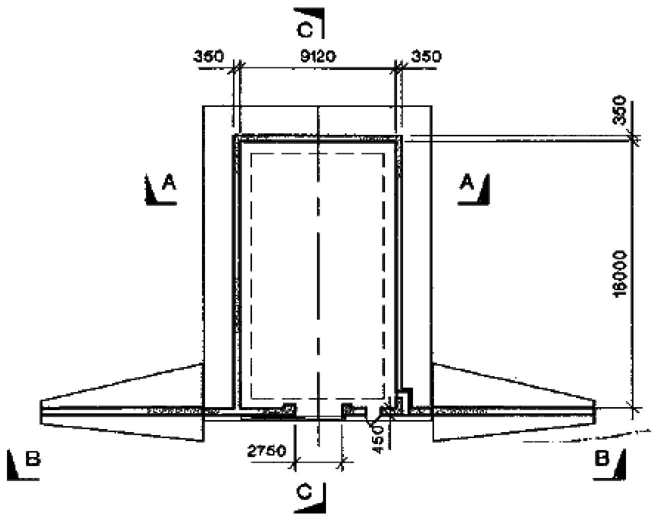
#### C.2.2.2 Guided weapons store and workshop (LEVEL 2)

This is a single storey RC framed building with a flat RC roof slab, cavity masonry panel walls and overall dimensions of 19.0m x 9.7m x 3.7m. It permits the storage and processing of high value guided weapons and their associated test equipment in a building specially designed to process them and negates the need for modifying normal process buildings for a missile task and then re-modifying it to carry out conventional ammunition tasks. This building is illustrated at Annex D.

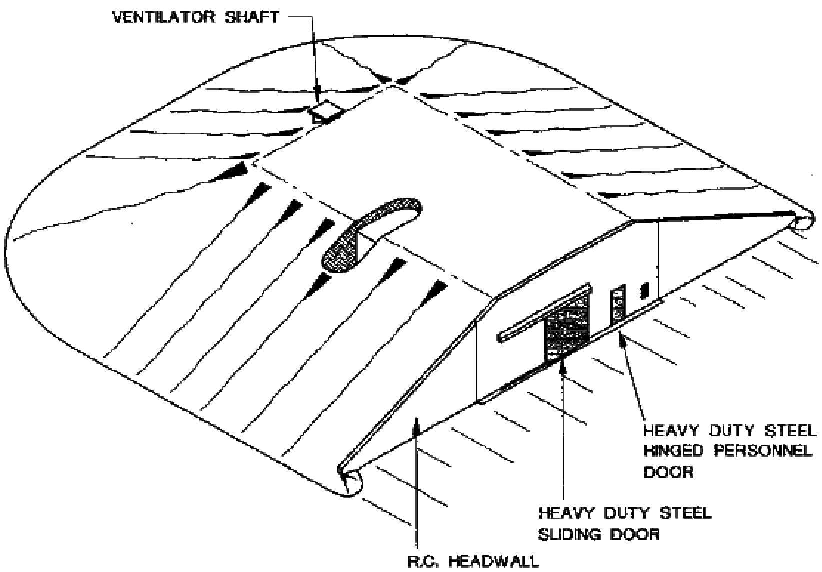
# Annex D
(informative)
# Diagrams of ammunition storage building types

All diagrams are courtesy of the UK Joint Service Publication 482, Chapter 6, *Buildings Associated with Military Explosives*.

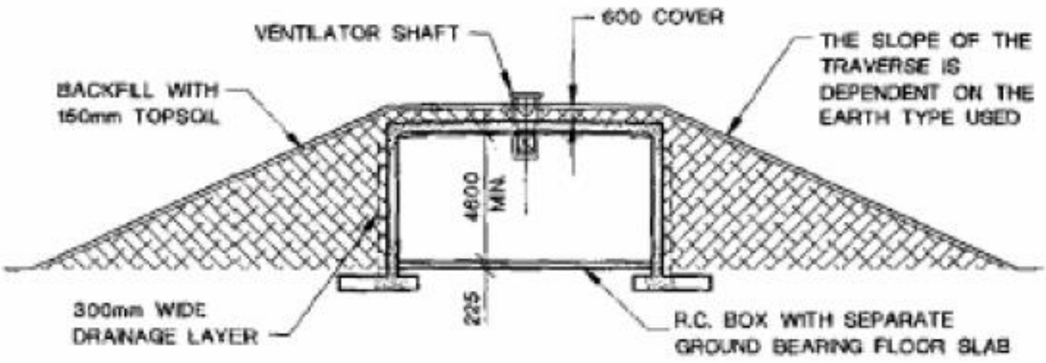
### D.1 Box ECM single bay



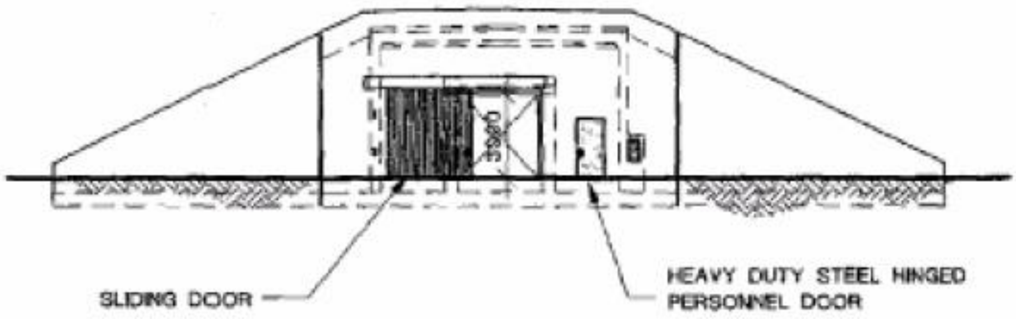

FLOOR PLAN



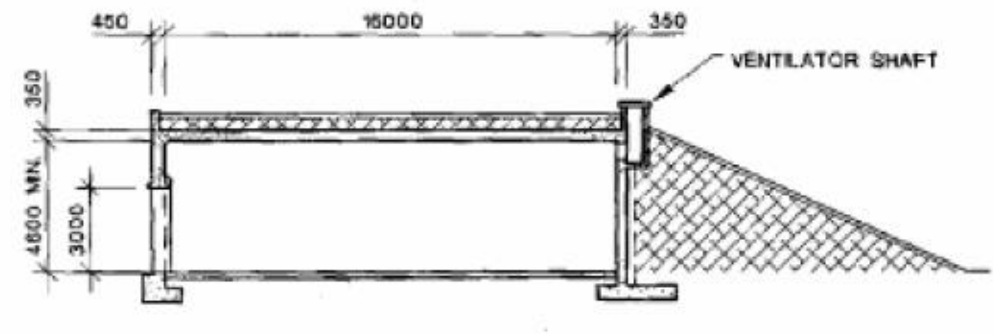

STORAGE CAPACITY: 4 x 10 x 3 HIGH = 120 STANDARD NATO PALLETS
EXPLOSIVE LIMIT: 75,000 kg. TNT EQUIVALENT
INTERNAL DIMENSIONS = 9120x16000x4600 = 6.0 $m^3$ VOLUME




SECTION A-A

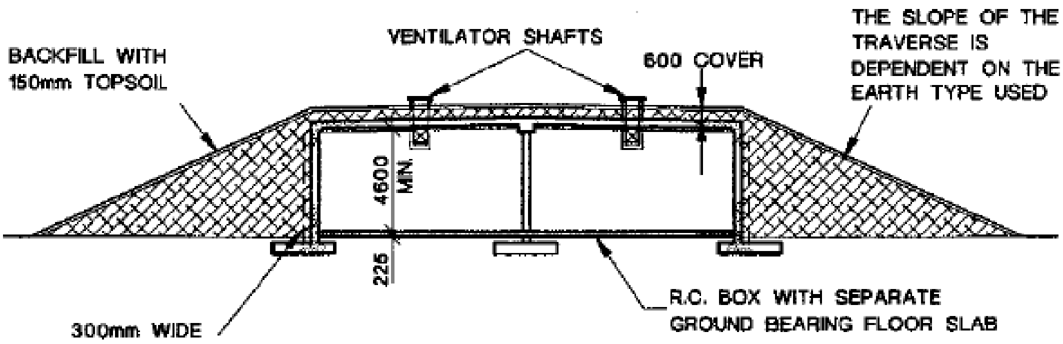



ELEVATION B-B

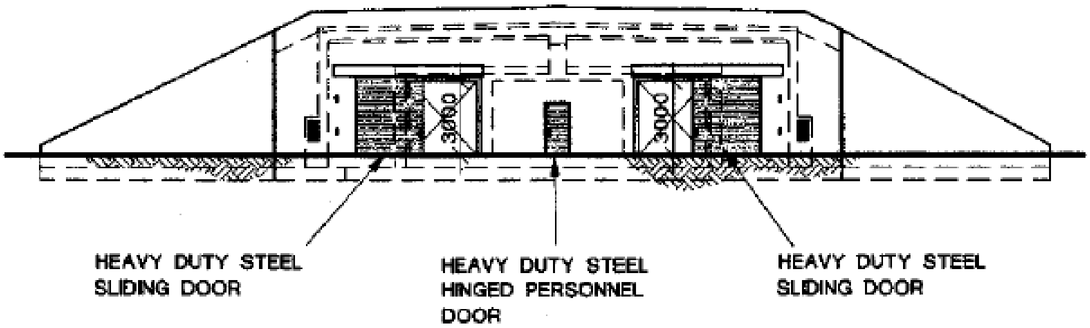



SECTION C-C

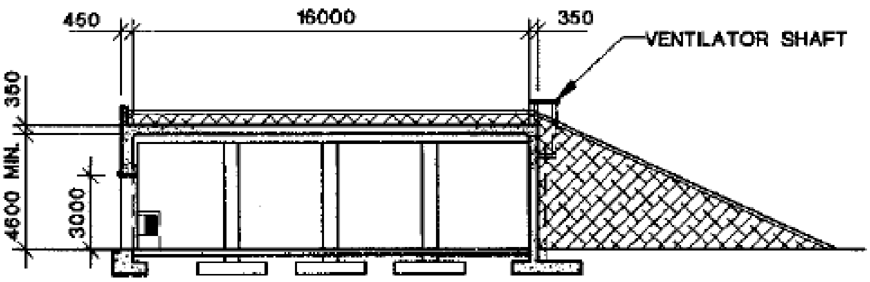
### D.2 Box ECM double bay




SECTION A-A

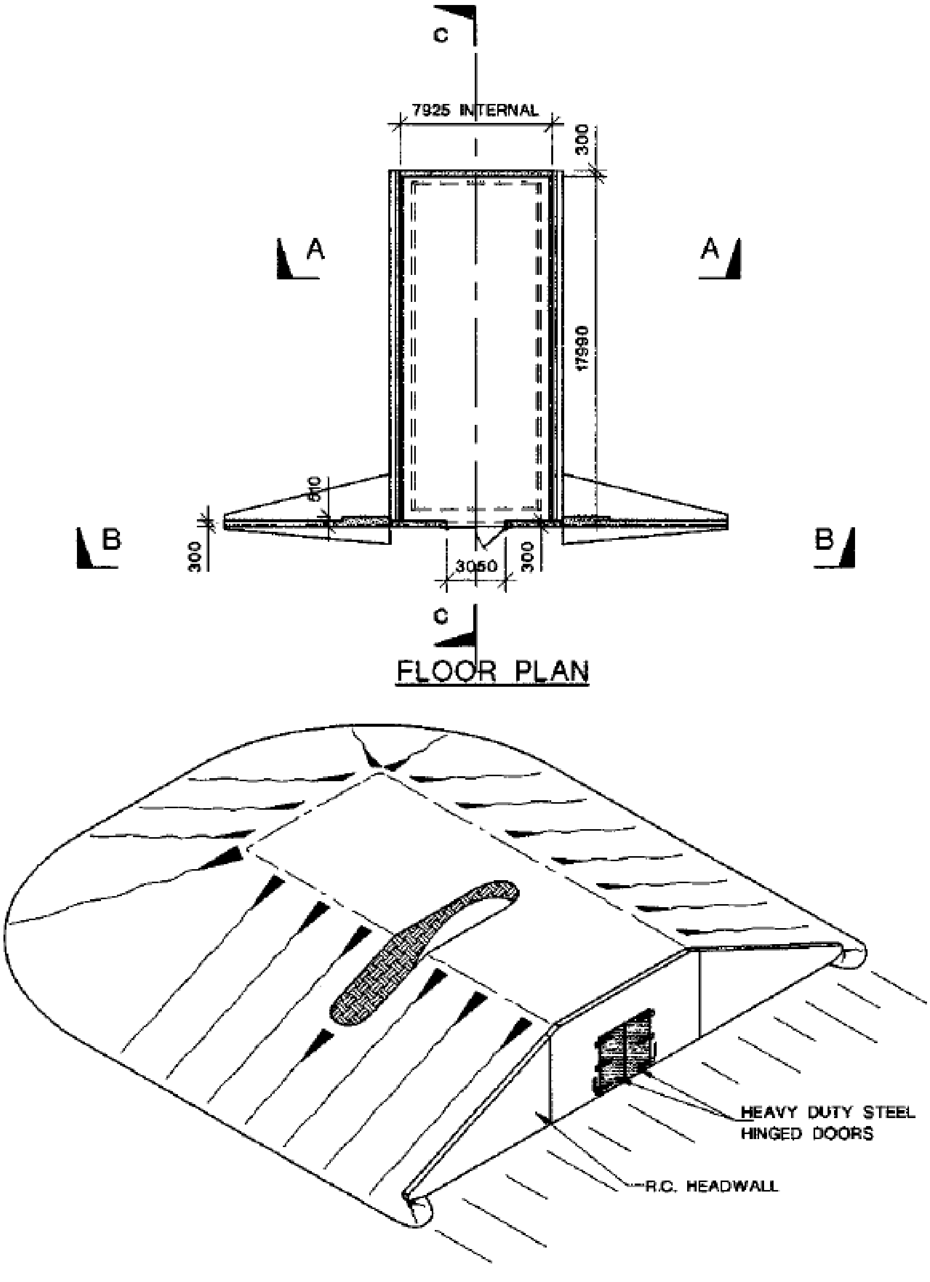



ELEVATION B-B

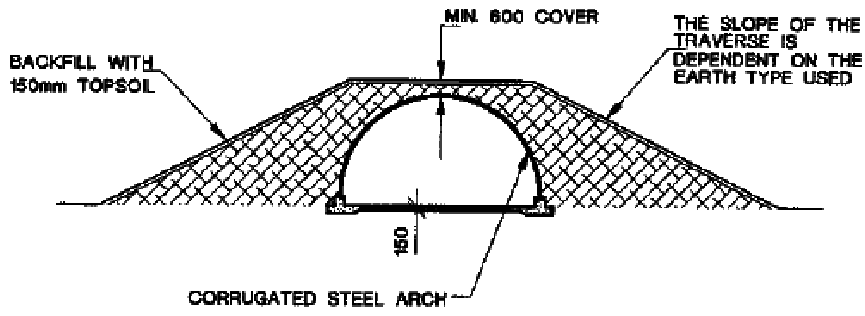



SECTION C-C

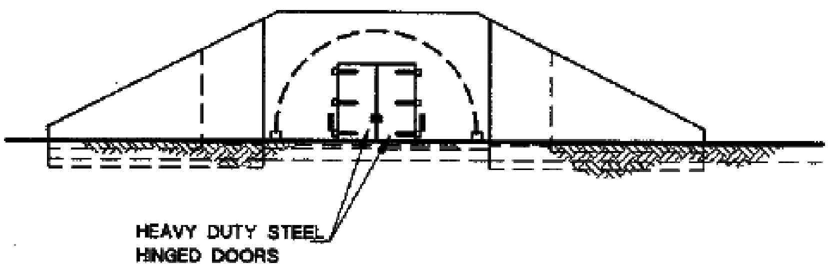
### D.3 Steel arch earth mounded ECM



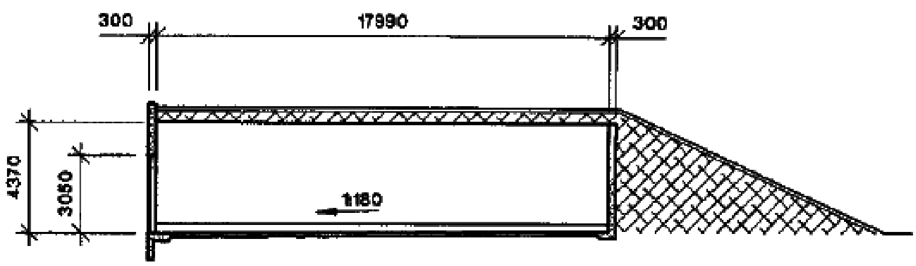

INTERNAL DIMENSIONS = 7925x17990x4370 MAX. = 501 m$^3$ VOLUME




SECTION A-A

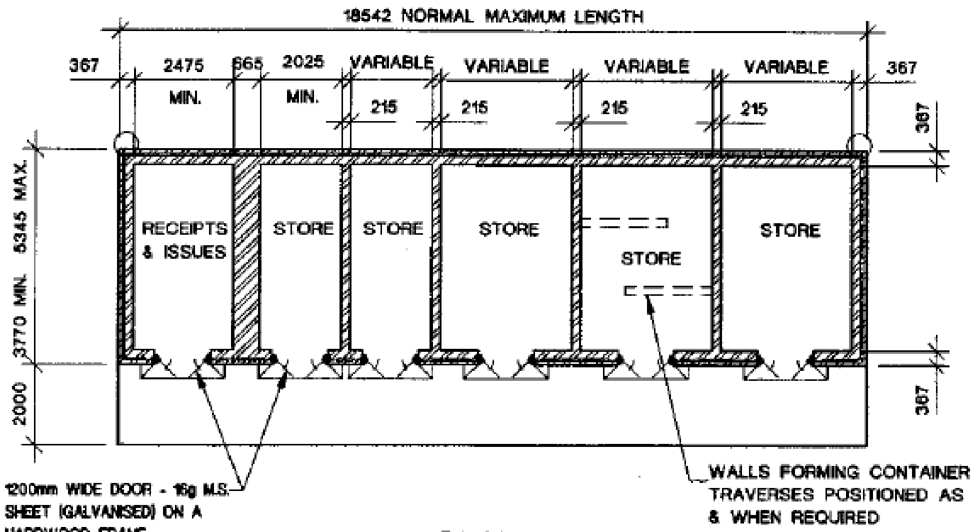



ELEVATION B-B

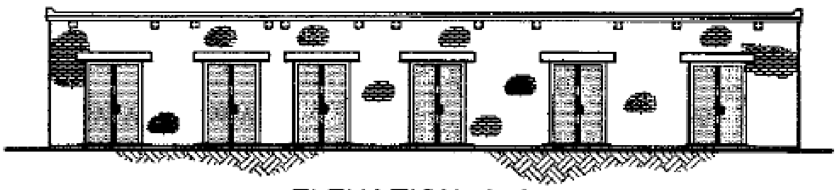



SECTION C-C

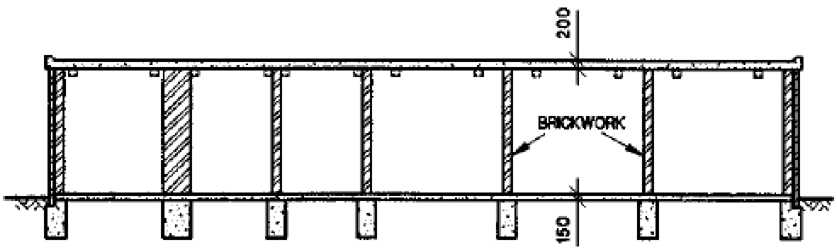
## D.4 Small storehouse for unit holdings



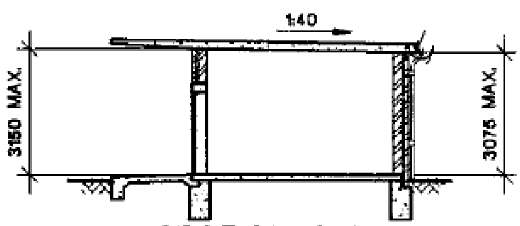

PLAN



ELEVATION A-A

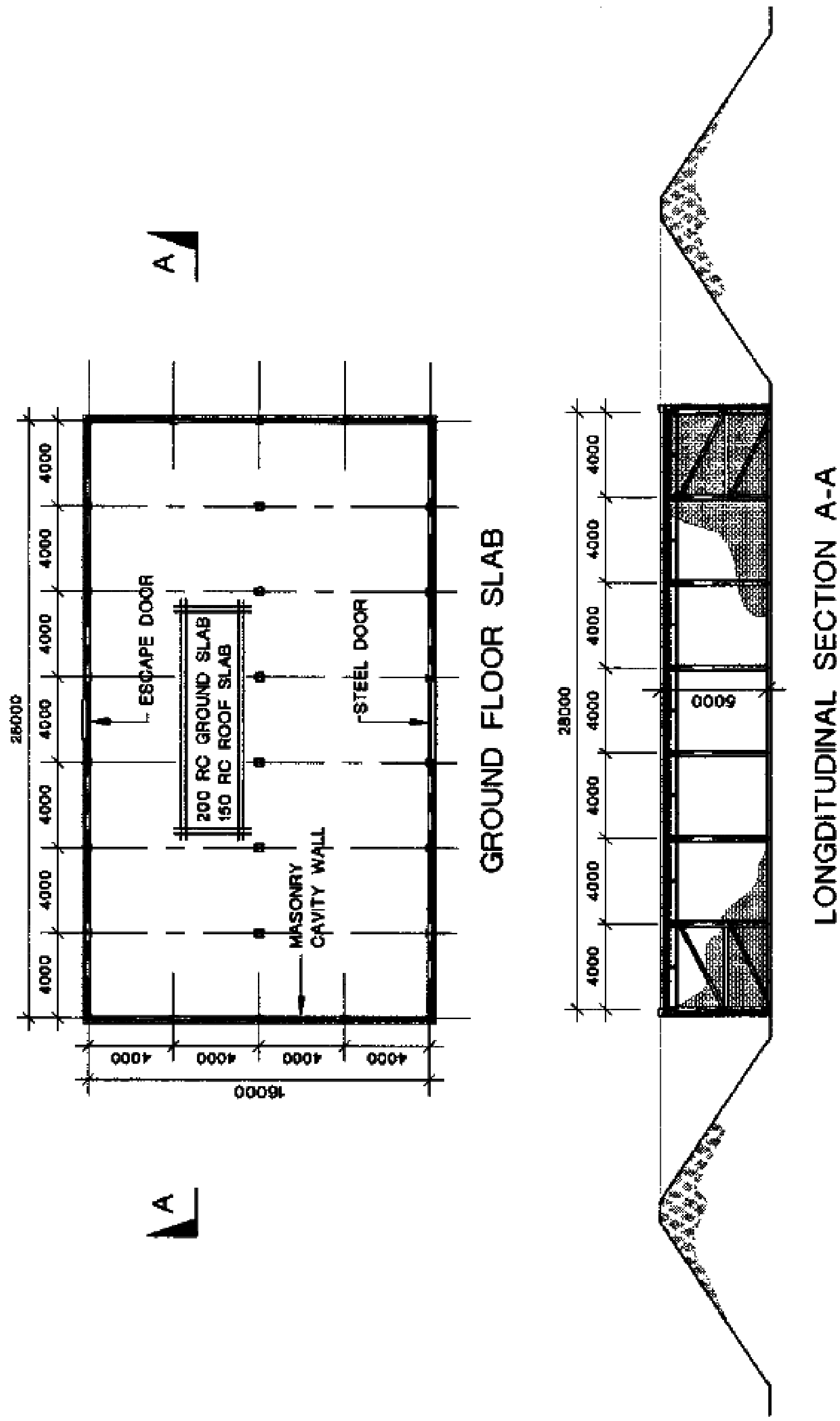


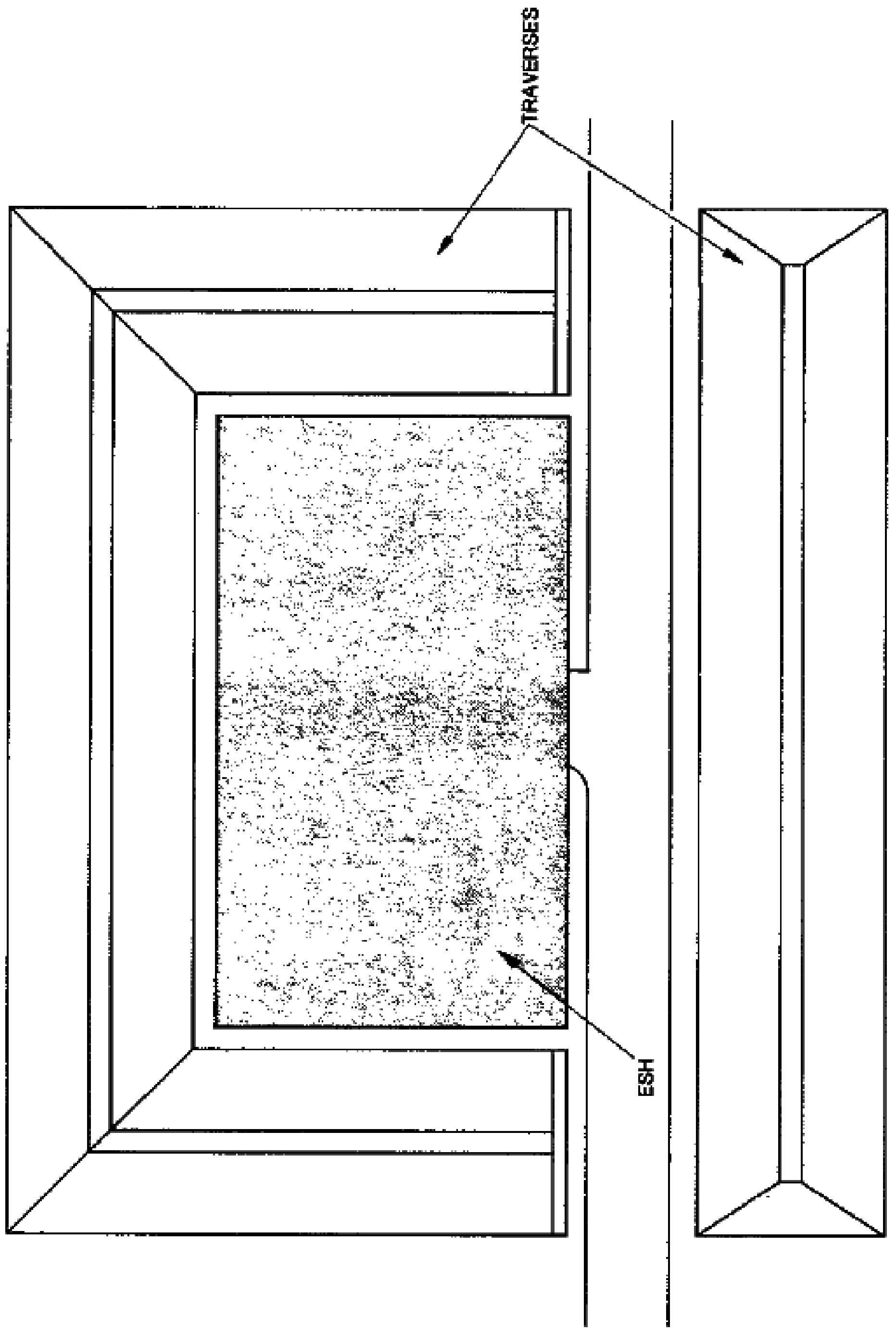

SECTION B-B




SECTION C-C

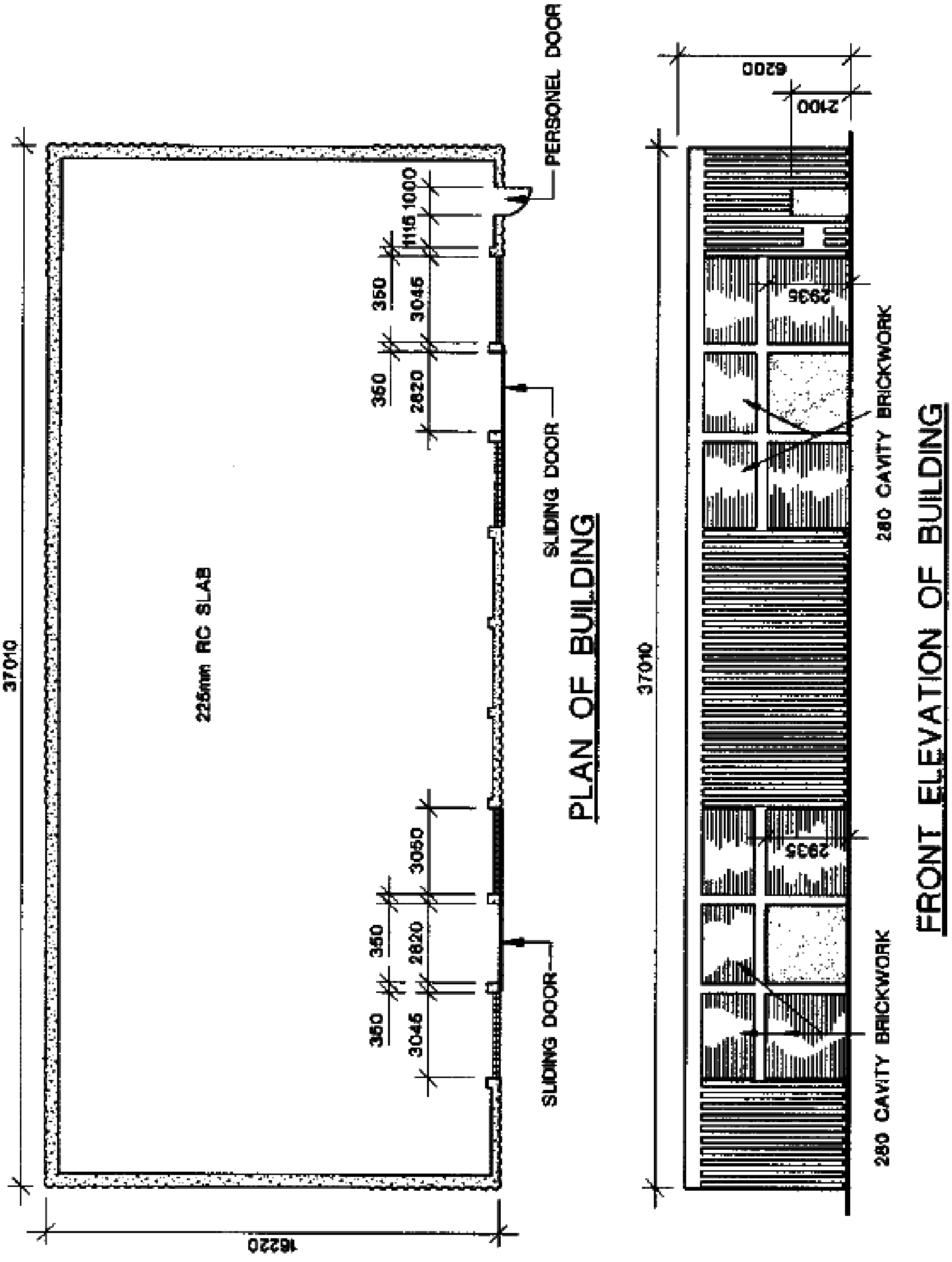
## D.5 Steel framed medium wall storehouse

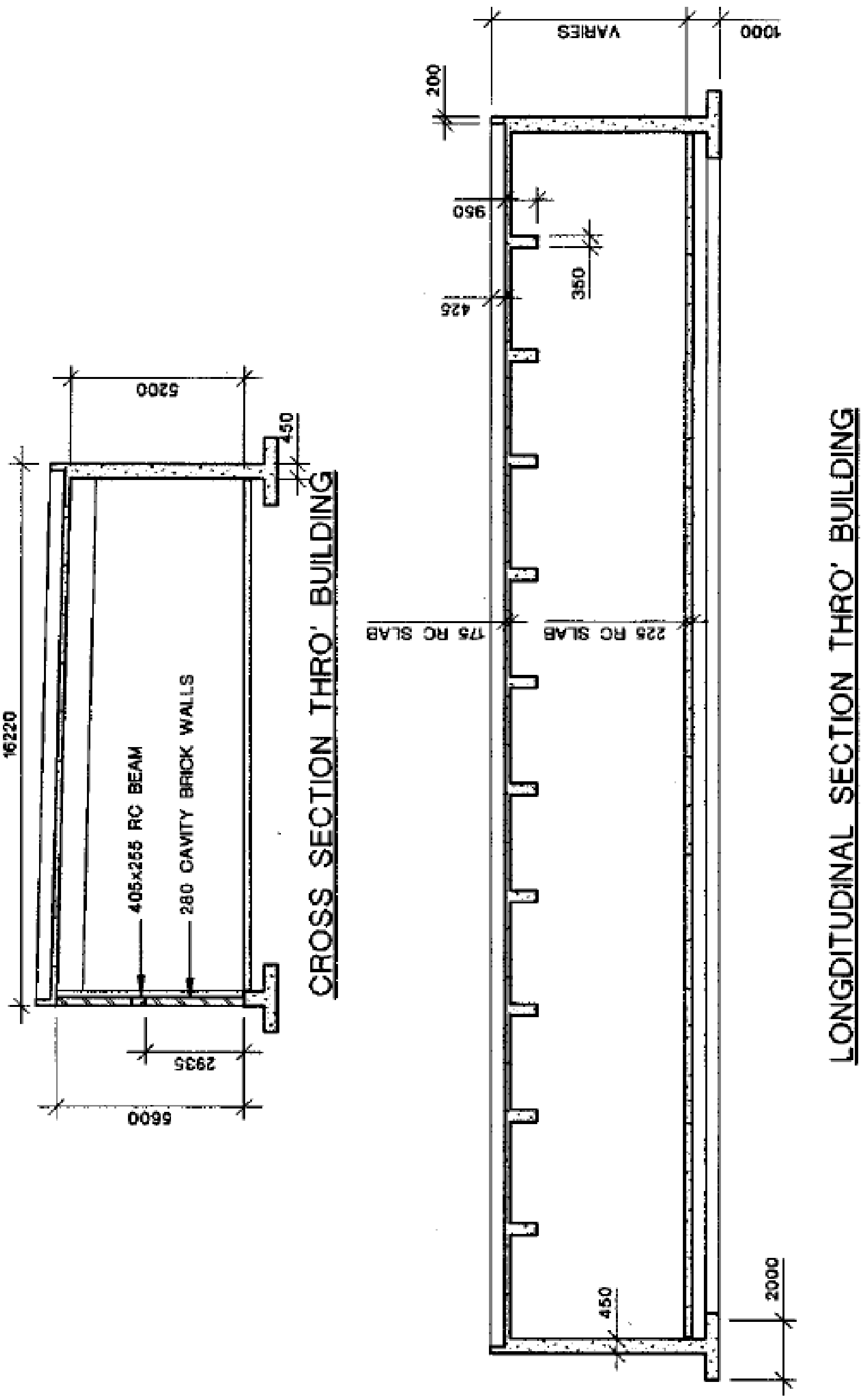




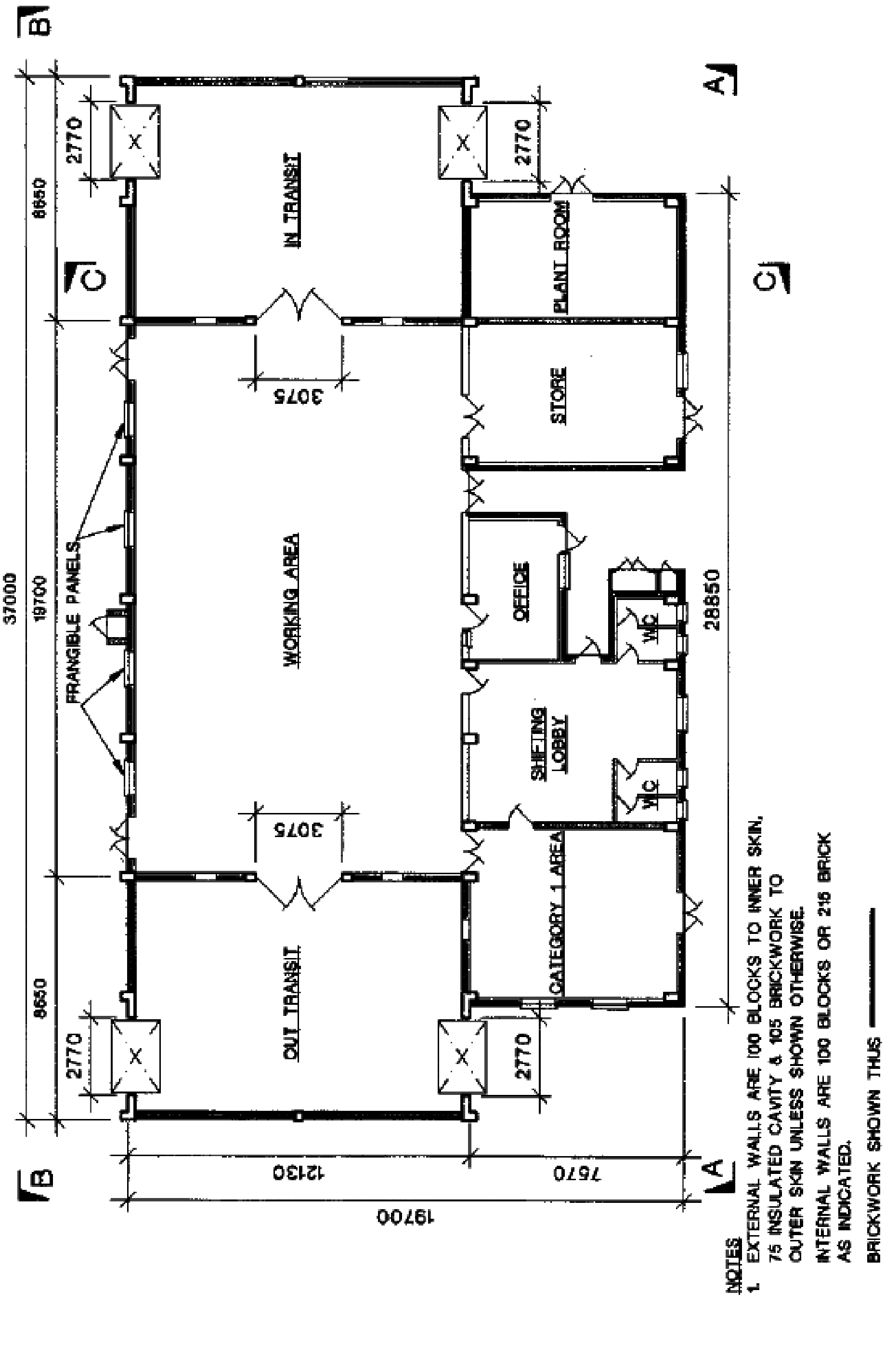

LAYOUT OF STOREHOUSE

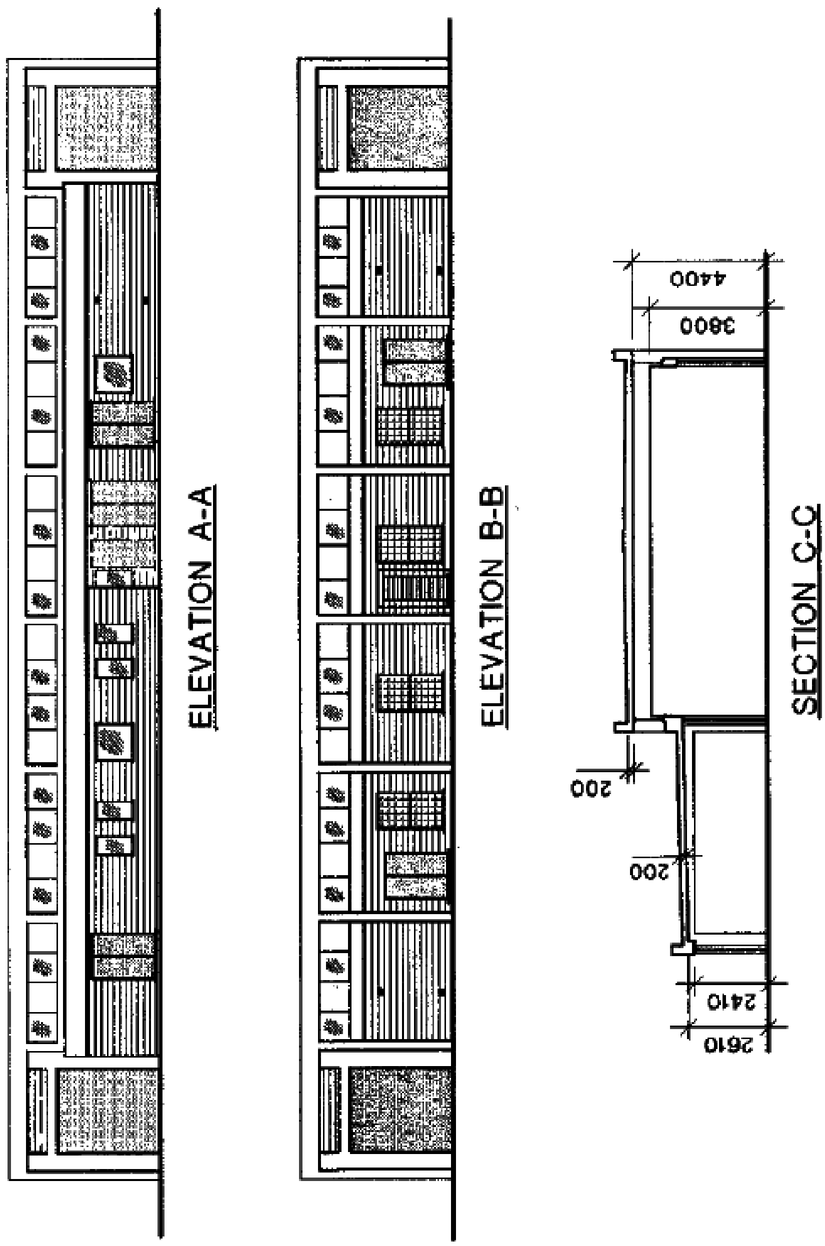
### D.6 Storehouse for HD 1.3 explosives

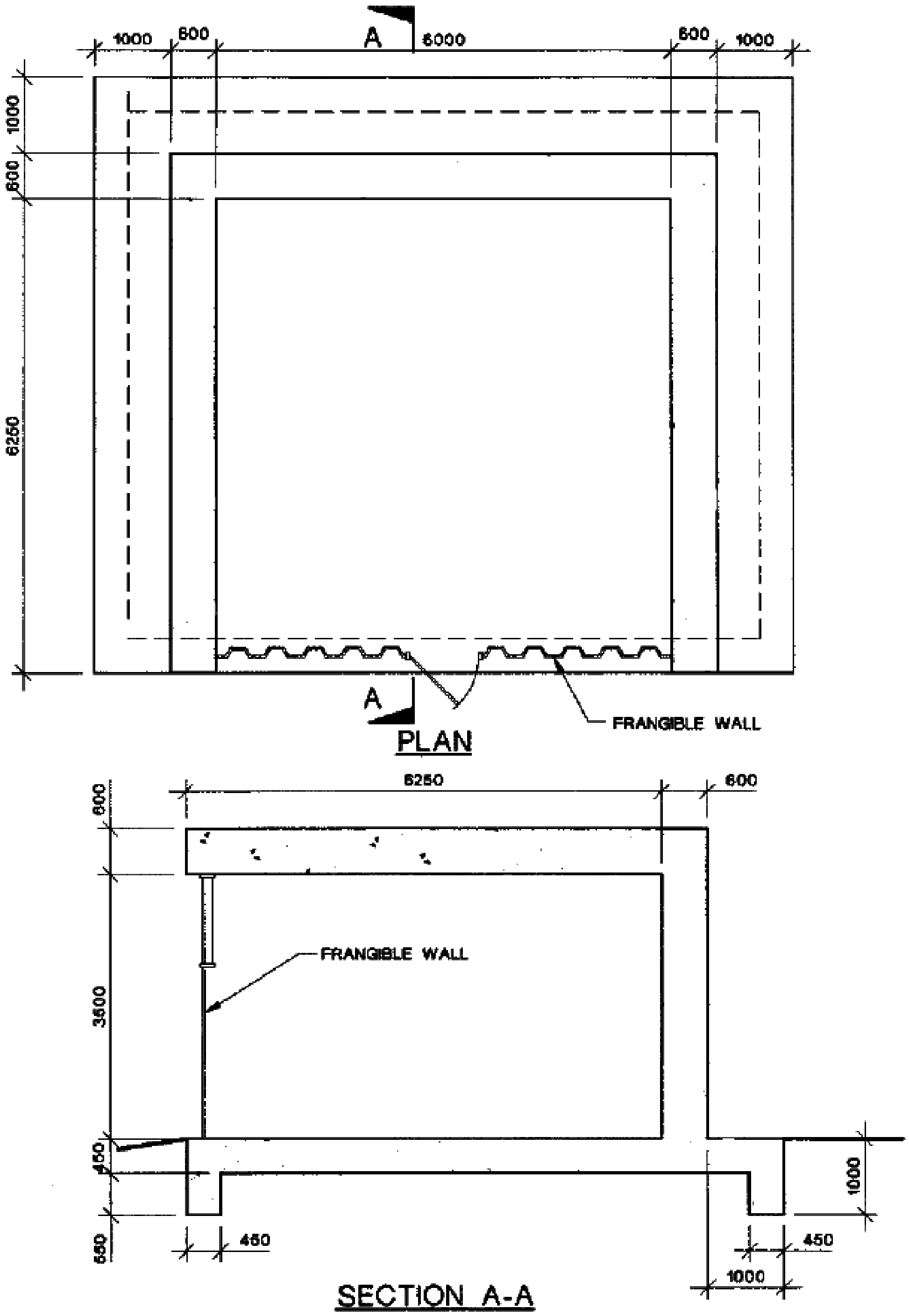



CROSS SECTION THRO' BUILDING
405x255 RC BEAM
280 CAVITY BRICK WALLS
16220
5200
450
2935
6600
LONGDITUDINAL SECTION THRO' BUILDING
VARIES
1000
200
950
350
425
175 RC SLAB
225 RC SLAB
450
2000

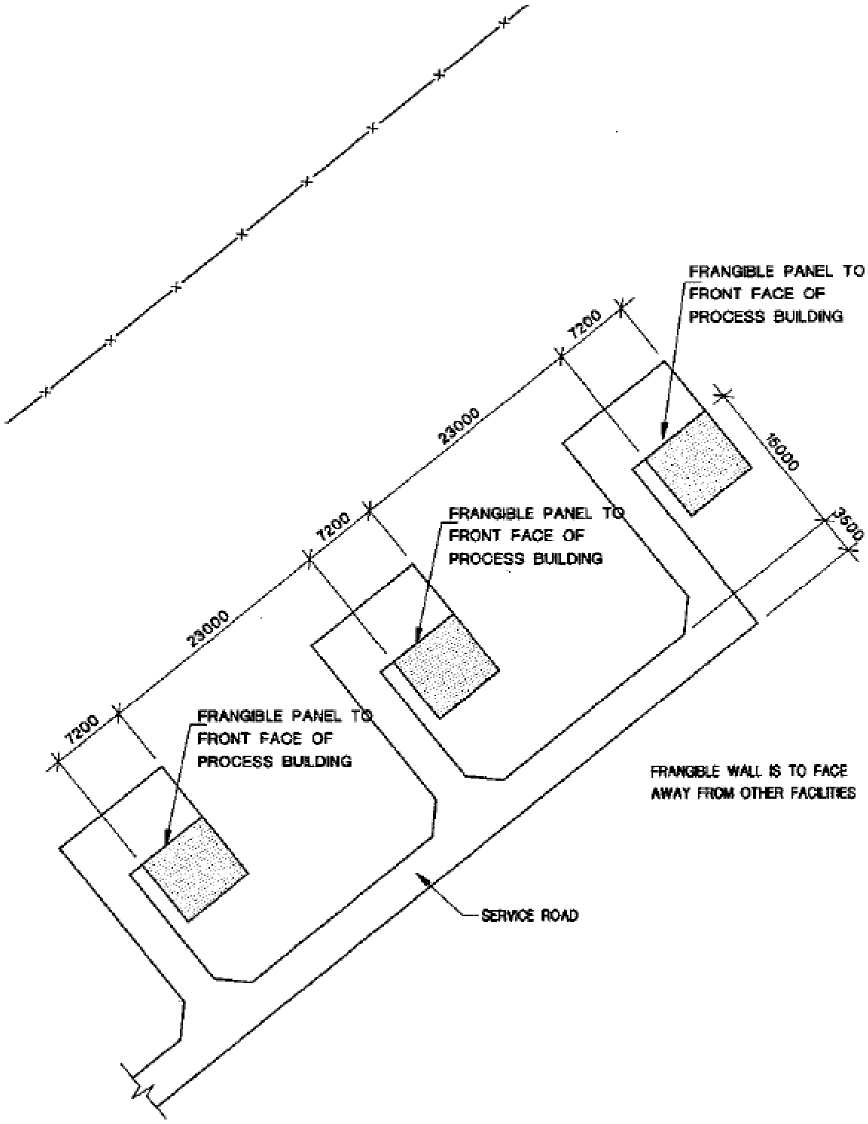
## D.7 Typical ammunition process building




ELEVATION A-A
ELEVATION B-B
SECTION C-C
4400
3800
200
200
2410
2610

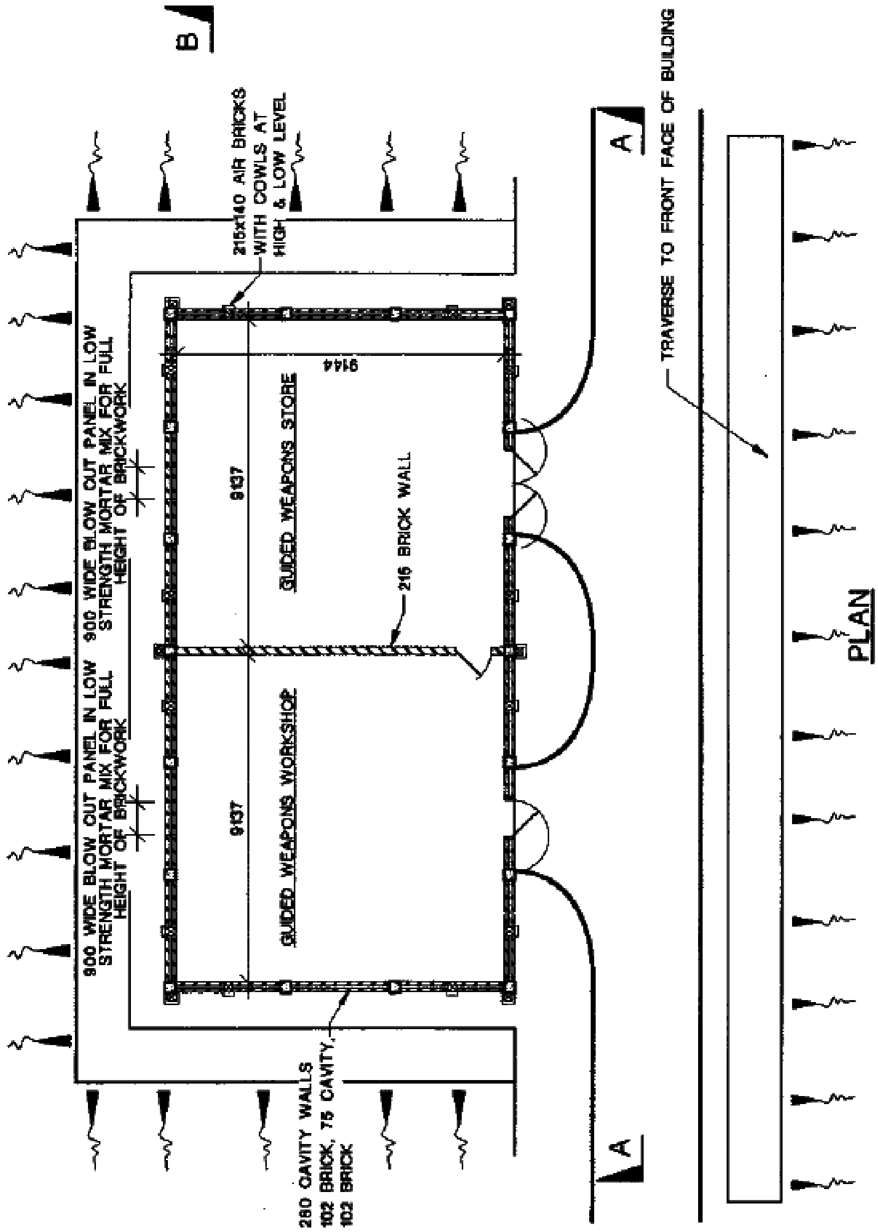

A
A
6000
1000
600
600
1000
1000
600
6250
FRANGIBLE WALL
PLAN
6250
600
600
3500
FRANGIBLE WALL
450
550
450
1000
450
1000
SECTION A-A

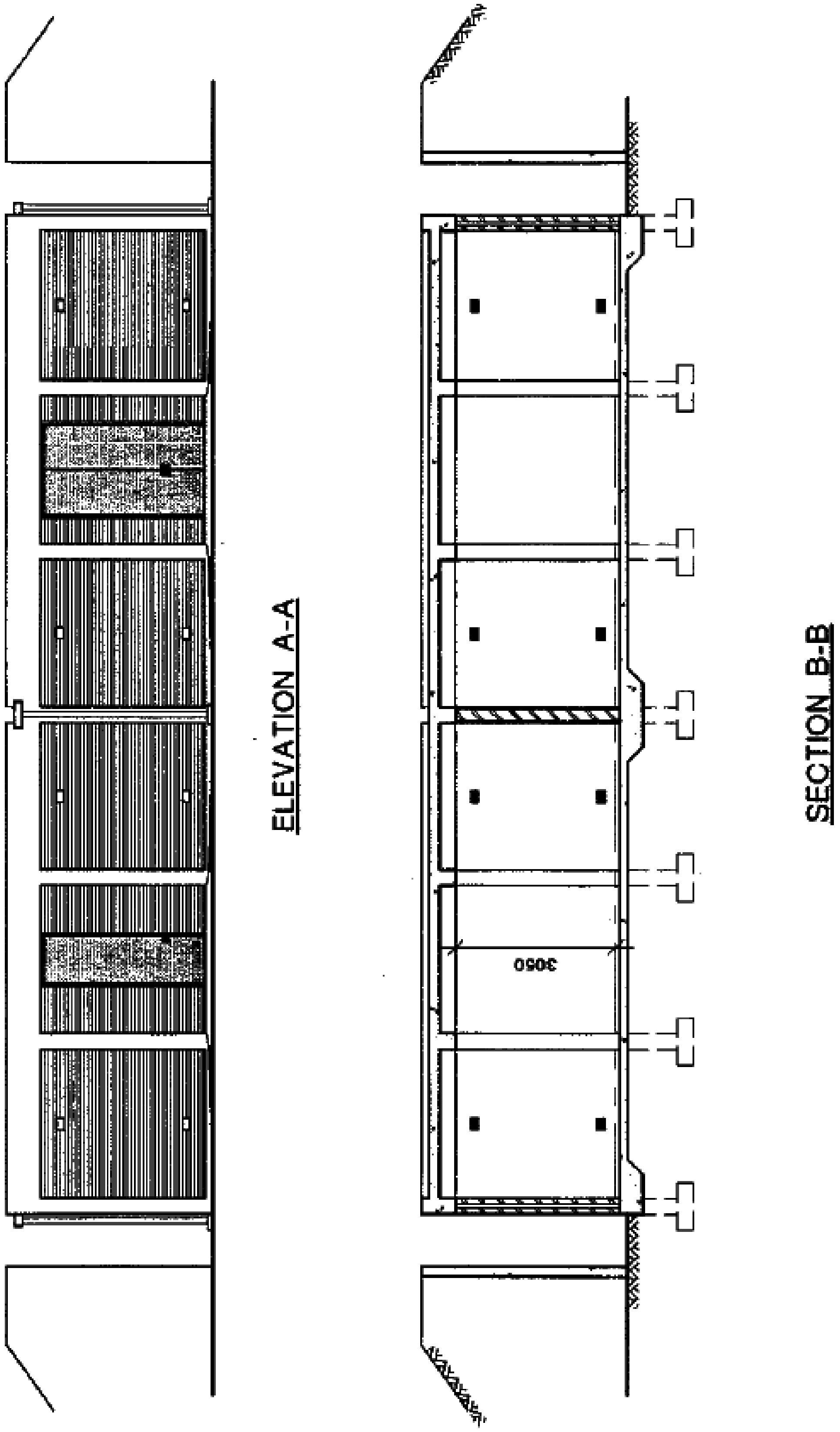
## D.8 Ammunition test building



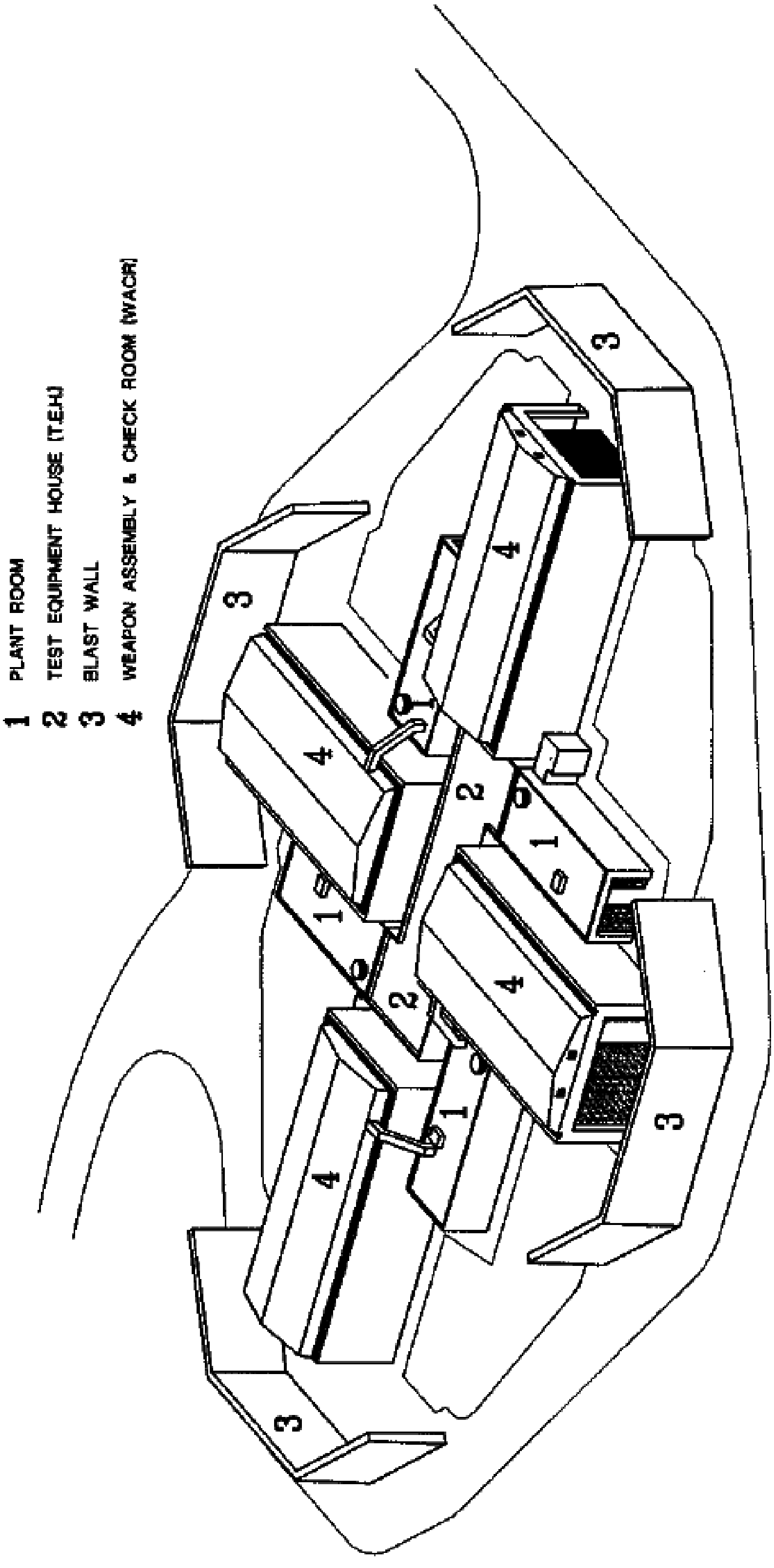

LAYOUT OF A TYPICAL FACILITY

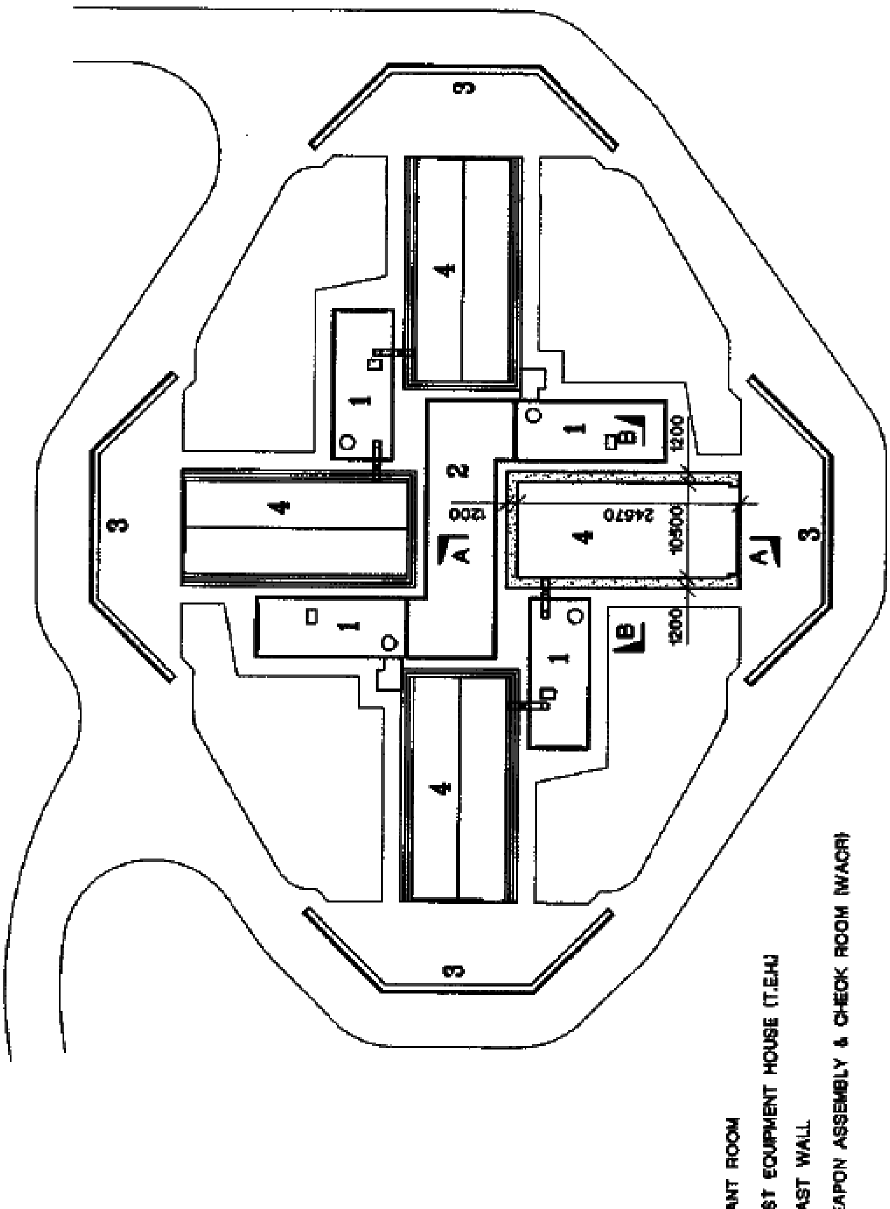
## D.9 Guided weapons store and workshop




ELEVATION A-A
SECTION B-B
3050

## D.10 Integrated weapons complex




1 PLANT ROOM
2 TEST EQUIPMENT HOUSE (T.E.H.)
3 BLAST WALL
4 WEAPON ASSEMBLY & CHECK ROOM (WACR)
1200
24670
10500
1200
1200

# Amendment record

## Management of IATG amendments

The IATG are subject to formal review on a five-yearly basis. This does not preclude amendments being made within these five-year periods for reasons of operational safety, efficacy and efficiency or for editorial purposes.

As amendments are made to this IATG module they will be given a number, and the date and general details of the amendment will be shown in the table below. The amendment will also be shown on the cover page of the IATG by the inclusion of the amendment number and date under the edition number and date of the .

As the formal reviews of each the IATG module is completed, new editions will be issued. Amendments will be incorporated into the new edition and the amendment record table cleared. Recording of amendments will then start again until a further review is carried out.

The most recently amended, and thus extant, IATG module is posted onwww.un.org/disarmament/ammunition~~www.un.org/disarmament/un-saferguard/~~.

| Number | Date | Amendment Details |
|---|---|---|
| 0 | 01 Feb 15 | Release of Edition 2 of IATG. |
| 1 | 31 March 21 | Release of Edition 3 of IATG. |
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