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Highway parapets for bridges and other structures —

Part 4: Specification for parapets of reinforced and unreinforced masonry construction

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Committees responsible for this British Standard

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Association of Safety Fencing Contractors
British Cement Association
British In-situ Concrete Paving Association
British Precast Concrete Federation Ltd
County Surveyors' Society
Department of Transport (Highways Agency)
Institution of Civil Engineers
Motor Industry Research Association
National Fencing Training Authority
Railtrack
Royal Society for the Prevention of Accidents
Transport Research Laboratory
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Contents

Foreword

This part of BS 6779 has been prepared under the direction of Subcommittee B/509/1, Road restraint systems.

Other parts already published in the series are:

— *Part 1: Specification for vehicle containment parapets of metal construction*;

— *Part 2: Specification for vehicle containment parapets of concrete construction*;

— *Part 3: Specification for vehicle containment parapets of combined metal and concrete construction*.

Annex A, Annex B, Annex C, Annex D, Annex F and Annex G are informative. Annex E is normative.

This publication does not purport to include all necessary provisions of a contract. Users are responsible for their correct application.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 48, an inside back cover and a back cover.

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Introduction

Reinforced or unreinforced masonry parapets are often used for economic reasons or where a masonry finish is required on the exposed surfaces of parapets. Reinforced masonry parapets contain steel reinforcement which is adequately anchored into the supporting structure. Unreinforced masonry parapets are built directly onto the supporting structure without any special provision for anchorage.

As masonry parapets are of solid construction they provide effective pedestrian protection without modification, subject to satisfying the minimum height requirements specified in **6.3**.

The requirements in this standard, for both the reinforced and unreinforced masonry parapets, are based on the results of tests. The requirements for unreinforced masonry parapets are additionally based on mathematical modelling of vehicle impacts by computer which has been subsequently verified by full scale vehicle impact tests.

In the case of unreinforced masonry parapets, individual blocks or sections of the masonry may be dislodged and mobilized by a vehicle impact. The tests and computer modelling have shown that most of this masonry will be propelled away from the highway, but some can come to rest on the highway in the immediate vicinity of the parapet. An assessment of the possible injury or damage risk from mobilized masonry can be used to determine the acceptability of the use of an unreinforced masonry parapet at a particular site. A suitable method of risk assessment is described in Annex A.

Vehicle containment levels are related to defined vehicle impacts. Only normal and high containment levels are specified for reinforced masonry parapets. The low containment level described in part 1 of this standard, for the design of metal parapets in certain circumstances, is not considered appropriate for reinforced masonry constructions. For unreinforced masonry parapets only low and normal containment levels are specified since the use of unreinforced masonry at the high risk sites associated with high level containment is not appropriate due to the possibility of masonry becoming detached as a result of an impact. Advice is included for alternative levels of containment where the vehicle speed or angle of impact with the parapet may be restricted (see Annex B).

The main objectives of the types of parapet defined in this part of BS 6779 are:

a) to provide specified levels of containment to limit penetration by errant vehicles;

b) to protect highway users and others in the vicinity by either redirecting vehicles on to a path close to the line of the parapet, or arresting the vehicle motion with acceptable deceleration forces;

c) to reduce the risk of errant vehicles overtopping the parapet or overturning.

It is possible in the case of both reinforced and unreinforced masonry parapets to give design criteria to produce satisfactory designs. In consequence full scale acceptance testing, as required for metal parapets in part 1 of this standard, is not necessary. The criteria for reinforced masonry parapets include equivalent static loads for the design of the parapet. In unreinforced masonry parapets a significant proportion of the kinetic energy of an impacting vehicle is absorbed by momentum transfer into the masonry, in addition to that absorbed by structural deformation. The criteria for unreinforced masonry parapets are, therefore, based on the materials of construction and dimensions of the parapets.

NOTE Composite action with the main structure can be minimized by the sub-division of parapets into panels.

1 Scope

This part of BS 6779 specifies requirements for the design and construction of a specific form of reinforced, and various forms of unreinforced, masonry parapets which are designed to provide specified levels of containment for vehicles on highways. This part of BS 6779 also specifies requirements for the assessment of existing unreinforced masonry parapets.

This part of BS 6779 is applicable to unreinforced masonry parapets of 10 m or greater in length or, if the parapet contains movement joints, with a minimum panel length between joints of 10 m and to reinforced masonry parapets with panels 2 m, or greater, in length.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this British Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS 1449-2:1983, *Specification for stainless and heat-resisting steel plate, sheet and strip*.

BS 3921:1985, *Specification for clay bricks*.

BS 4449:1997, *Specification for carbon steel bars for the reinforcement of concrete*.

BS 5328-2:1997, *Concrete — Part 2: Methods for specifying concrete mixes*.

BS 5328-3:1990, *Concrete — Part 3: Specification for the procedures to be used in producing and transporting concrete*.

BS 5328-4:1990, *Concrete — Part 4: Specification for the procedures to be used in sampling, testing and assessing compliance of concrete*.

BS 5390:1976, *Code of practice for stone masonry*.

BS 5400-2:1978, *Steel, concrete and composite bridges — Part 2: Specification for loads*.

BS 5400-3:1982, *Steel, concrete and composite bridges — Part 3: Code of practice for design of steel bridges*.

BS 5400-4:1990, *Steel, concrete and composite bridges — Part 4: Code of practice for design of concrete bridges*.

BS 5628-1:1992, *Code of practice for use of masonry — Part 1: Structural use of unreinforced masonry*.

BS 5628-2:1995, *Code of practice for use of masonry — Part 2: Structural use of reinforced and prestressed masonry*.

BS 5628-3:1985, *Code of practice for use of masonry — Part 3: Materials and components, design and workmanship*.

BS 6073-1:1981, *Precast concrete masonry units — Part 1: Specification for precast concrete masonry units*.

BS 6073-2:1981, *Precast concrete masonry units — Part 2: Method for specifying precast concrete masonry units*.

BS 6457:1984, *Specification for reconstructed stone masonry units*.

BS 6744:1986, *Specification for austenitic stainless steel bars for the reinforcement of concrete*.

BS 6779-1:1998, *Highway parapets for bridges and other structures — Part 1: Specification for vehicle containment parapets of metal construction*.

BS 8000-3:1989, *Workmanship on building sites — Part 3: Code of practice for masonry*.

BS EN 10088-1:1995, *Stainless steels — Part 1: List of stainless steels*.

BS EN ISO 3506-1:1998, *Mechanical properties of corrosion resistant stainless steel fasteners — Part 1: Bolts, screws and studs*.

BS EN ISO 3506-2:1998, *Mechanical properties of corrosion resistant stainless steel fasteners — Part 2: Nuts*.

3 Terms and definitions

For the purposes of this part of BS 6779, the following terms and definitions apply.

3.1
vehicle restraint system
installation to provide a level of containment for errant vehicles to limit damage or injury to users of the highway

3.2
highway parapet
barrier at the edge of a bridge, or on top of a retaining wall or similar structure, associated with a highway

3.3
safety fence
installation provided for the protection of users of the highway consisting of horizontal beams or wire ropes mounted on posts

3.4
front face
face nearest to the traffic

3.5
outer face
face furthest from traffic

3.6
supporting structure
part of the bridge, retaining wall or other structure on which the parapet is mounted

3.7
adjoining paved surface
paved area on the traffic side of a parapet, immediately adjacent to the base of a parapet

3.8
datum for height considerations
highest level of footway, verge, carriageway or any other part of the road construction, on a horizontal line at right angles to the line of the parapet and within 1.5 m of the front face

NOTE This will normally be the adjoining paved surface.

3.9
datum for design considerations
transverse plane through the parapet, or at the intersection with the main structure, which is critical for design purposes

3.10
top of parapet
top of coping for determining parapet height with respect to the datum for height considerations or top of front face of parapet for determining height for impact considerations

3.11
anchorage
arrangement within the supporting structure to which the parapet is directly fixed by means of the attachment system

NOTE Examples of these are drilled-in or cast-in sockets for bolt attachments or cast in anchorage cradles etc.

3.12
attachment system
system of attachment of the parapet to the anchorage or the continuation of reinforcement from within the core of a reinforced masonry parapet into the supporting structure

3.13
non-effective longitudinal member
additional longitudinal member above the top of the masonry parapet provided to give additional height to the parapet for the protection of pedestrians or animals or to support noise or other environmental barriers

3.14
masonry
assemblage of structural units which are bonded together with mortar so as to act compositely

3.15
reinforced masonry highway parapet
masonry parapet consisting of two parallel single leaf masonry walls, effectively tied together, either side of a cavity containing steel reinforcement which attaches the parapet to an integral base or continues as attachment to the main structure

NOTE The cavity is infilled with concrete so as to result in composite action with the masonry under load.

3.16
unreinforced masonry highway parapet
parapet constructed of masonry structural units bonded together with mortar with no reinforcement incorporated into the construction other than bed joint reinforcement

NOTE 1 Bed joint reinforcement may be incorporated to control cracking arising from longitudinal thermal or shrinkage movement.

NOTE 2 Specific types of unreinforced masonry parapets are defined in **3.17**, **3.18**, **3.19** and **3.20**.

3.17
brick masonry highway parapet
parapet consisting of brick units with mortared joints

3.18
ashlar stone masonry highway parapet
stone parapet of finely dressed stone blocks, laid in courses with mortared joints

NOTE 1 The stone blocks are solid between the faces of the parapet, i.e. there is no mortared core.

NOTE 2 The facing may be plain or tooled.

3.19
coursed/uncoursed rubble stone masonry highway parapet
parapet consisting of multi-sized natural stone blocks of random rubble, squared rubble or miscellaneous rubble as defined in BS 5390 which have been coursed, brought to courses or are uncoursed and which have thick mortared joints

NOTE The parapet shall have a well filled mortared core and may have through stones passing through the core.

3.20
drystone highway parapet
parapet without mortar consisting of multi-sized natural stone blocks, which may be coursed or uncoursed, with or without through stones (stones extending through to both faces)

NOTE Drystone construction is not included in the definition of masonry (see **3.14**) but it is nevertheless covered by the scope and requirements of this standard.

3.21
masonry structural unit
bricks or blocks of fired clay, concrete, natural, or reconstructed stones

3.22
road speed limit
statutory speed limit applicable to the length of highway at the site of the highway parapet

3.23
impact speed
vehicle speed at impact corresponding with a particular level of containment which, for the purposes of assessing the adequacy of existing parapets, may be a site specific level of containment

3.24
hazard zone
area of highway or adjacent land where occupiers could be at risk of injury following a vehicle impact with a parapet

3.25
divergent width
distance, measured at right angles to the direction of travel, through which a vehicle could diverge on an errant course, prior to striking the parapet

4 Symbols

H is the vertical distance from the top of the front face of the parapet to the datum for design considerations (m).

γ_{m} is the partial factor for material strength.

γ_{mb} is the partial safety factor for bond strength between concrete infill and steel.

γ_{mm} is the partial safety factor for compressive strength of masonry.

γ_{ms} is the partial safety factor for strength of steel.

γ_{mv} is the partial safety factor for shear strength of masonry.

f_{k} is the characteristic compressive strength of masonry.

f_{cu} is the characteristic compressive strength of concrete.

f_{y} is the characteristic tensile strength of steel reinforcement.

L is the length of parapet panel in metres (m).

Q^* is the applied design load in kilonewtons (kN).

Q_{k} is the nominal load in kilonewtons (kN).

γ_{fl} is the partial safety factor for load.

S^* is the applied design load effects (kN).

γ_{f3} is the partial safety factor for load effect.

R^* is the member design load resistance (kN).

5 Designation of masonry vehicle parapets

For the purpose of an abbreviated description, masonry parapets shall be designated, in accordance with Table 1, by three characters indicating:

a) level of containment;

b) height of parapet above the adjoining paved surface;

c) type of parapet.

Table 1 — Designation of masonry vehicle parapets

Item	Designation	Clause reference number
a)	*Level of containment* L = Low N = Normal H = High	**6.1**
b)	*Height above datum* 1.00 = 1 m height 1.25 = 1.25 m height etc.	**6.3**
c)	*Type* RMB = reinforced brick masonry RMS = reinforced stone masonry UMA = unreinforced ashlar stone masonry UMB = unreinforced brick masonry UMR = unreinforced random rubble stone masonry UMD = unreinforced drystone	**3**
NOTE Examples of designation. N/1.00/RMB indicates a parapet of 1 m height above the datum of normal containment in reinforced brick masonry construction. L/1.2/UMD indicates a parapet of 1.2 m height above the datum of low containment in unreinforced drystone construction.		

6 Design

6.1 Levels of containment

6.1.1 *Low and normal levels of containment*

The low and normal levels of containment shall be those required to resist penetration from the following vehicle impact characteristics.

Vehicle	Saloon car
Mass	1 500 kg
Height of centre of gravity	480 mm to 580 mm
Angle of impact	20°
Speed	80 km/h (50 mile/h) for low level of containment
	113 km/h (70 mile/h) for normal level of containment

NOTE For the assessment of the adequacy of existing parapets, a site specific level of containment may be adopted. The vehicle impact characteristics for the site specific containment should be the same as those for the low and normal levels, except that the speed should be the lowest value from the following:

a) the statutory road speed limit appropriate to the class of road;

b) the maximum speed attained by 85 % of vehicles using that section of highway within any 16 hour week day period;

c) the theoretical speed based on highway geometrical constraints determined in accordance with the method suggested in Annex B.

6.1.2 *High level of containment*

A high level of containment shall be that required to resist penetration from the following vehicle impact characteristics.

Vehicle	Four axle rigid tanker or equivalent
Mass	30 000 kg
Height of centre of gravity	1.65 m
Angle of impact	20°
Speed	64 km/h (40 mile/h)

NOTE 1 The high level of containment is for use only in extremely high risk situations.

NOTE 2 Some authorities, notably Railtrack and other bodies undertaking railway operations authorized by the Railway Inspectorate, have specific requirements which should be determined for parapets on structures over their property. For applications over or adjacent to railways, reference should be made to Railtrack or other appropriate railway authority.

6.2 Wind loading

Wind loading shall be in accordance with BS 5400-2. Wind loading and vehicle impact shall not be considered coexistent.

6.3 Parapet heights

The minimum height of parapets shall be measured above the datum for height considerations and for particular applications shall be as listed below:

1.00 m	— for vehicle and vehicle pedestrian parapets except as otherwise specified below;
1.25 m	— with agreement, for bridges carrying motorways over railways, or other situations where pedestrians are excluded;
1.50 m	— for all other bridges over railways;
	— for high containment applications;
	— for protection of animals.

NOTE 1 The minimum heights are to be provided in masonry construction. If additional height is required only for the protection of animals this may be provided by the addition of a non-effective longitudinal member, excepting that for applications over railways or in other high risk situations non-effective members may not be used where such members may become detached if struck by an errant vehicle.

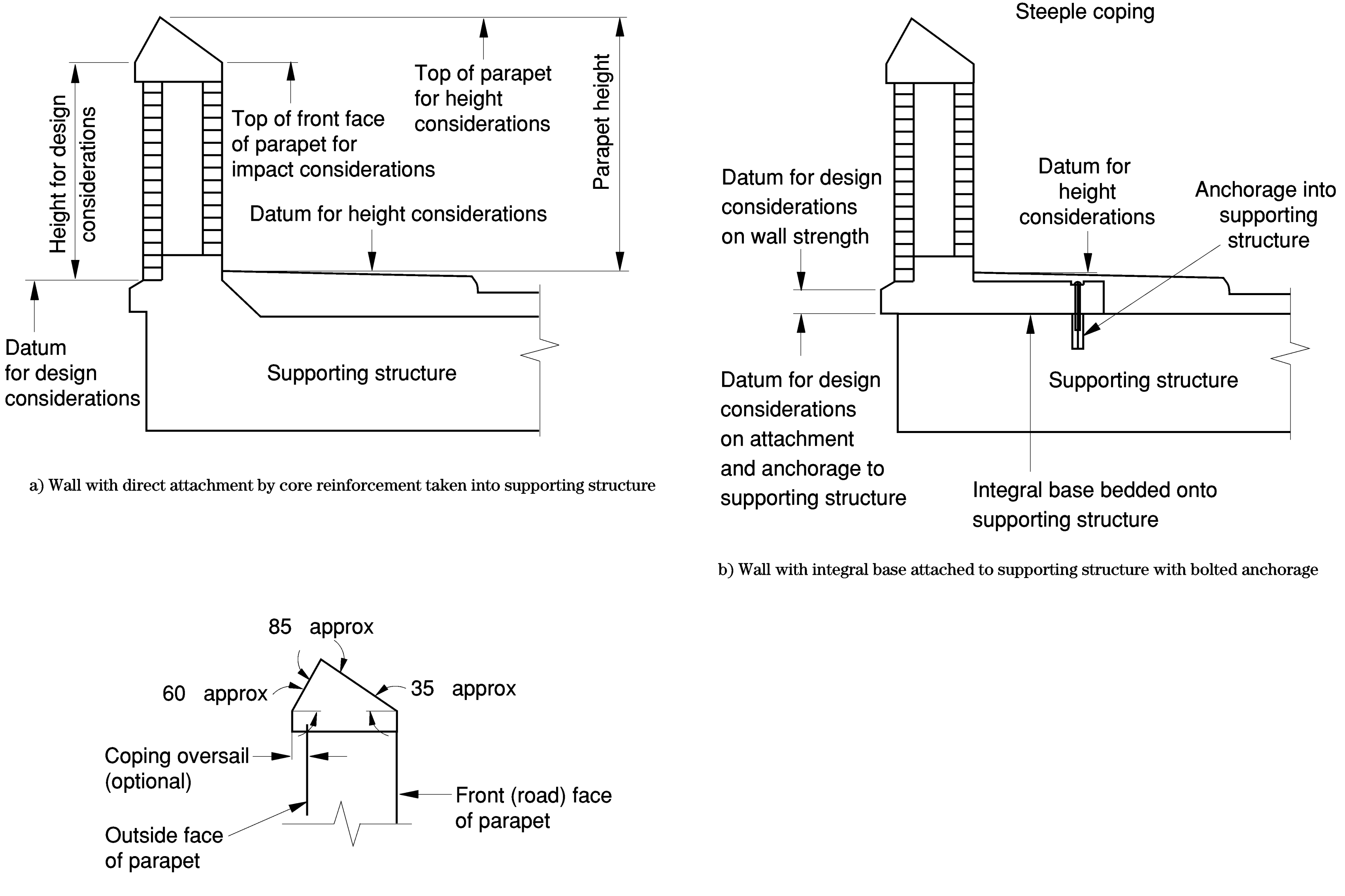
NOTE 2 Many existing unreinforced masonry parapets may be less than 1.00 m high hence for assessment purposes containment charts (see Figure 2, Figure 3, Figure 4 and Figure 5) are provided for parapets down to 0.8 m high. The 0.8 m lower limit has been chosen to restrict the risk of cars riding over the top of the parapet. This risk is increased where kerbs are present on the approach to the parapet which could give an upward momentum to the impacting vehicle.

6.4 Front face and top face profile

The front face profile shall be either vertical or uniformly inclined away from the traffic, from the base to the top of the parapet at an angle not exceeding 5°.

Where the masonry on the front face of the parapet has an irregular surface finish, the maximum amplitude of the steps and undulations in the surface shall be not more than 30 mm when measured with respect to a plane taken through the peaks. This plane shall be flat for straight parapets and curved to follow the nominal parapet curvature for parapets which are curved on plan.

Where pedestrians have access adjacent to the parapet, and there is a significant risk of injury due to people climbing on the parapet, a steeple coping [see Figure 1c)], or other suitably shaped coping, shall be provided on the top face. Steeple copings shall be provided on bridges over railways where there is access to pedestrians. (See also **6.6.14**).



a) Wall with direct attachment by core reinforcement taken into supporting structure

b) Wall with integral base attached to supporting structure with bolted anchorage

c) Profile of steeple coping

Figure 1 — Reinforced masonry parapets, dimensions and profiles

6.5 Pilasters

To minimize the risk of hook-up of a vehicle, the front face of the pilaster shall be flush with the front face of the parapet. However, where a projection of the pilaster to the front face of the parapet is essential, the projection shall be limited to a depth of 75 mm and be splayed at an angle of 45° or flatter relative to the front face.

Where a recessed panel is required to the front face of a pilaster it shall be limited to 75 mm and the edges be splayed as required for projections.

Where a pilaster is located at a curved end on a parapet (see Figure 7) it shall not project or be recessed.

For unreinforced parapets if the interlocking bond pattern in the masonry units of the parapet is discontinued at the junction with the pilaster then shear connections shall be provided in accordance with **6.7.4**.

6.6 Reinforced masonry parapets

6.6.1 *General*

Reinforced masonry parapets shall be designed generally in accordance with BS 5628-2, to resist loading appropriate to the designated level of containment using the equivalent static nominal loading from Table 2 for panel lengths up to and including 3.5 m. For parapets of greater panel length than 3.5 m, the forces and moments given in **6.6.3** shall apply. In all cases the design shall be checked against punching shear in accordance with **6.6.4**.

NOTE 1 The difference between height for structural design considerations and parapet height is illustrated in Figure 1a) together with potential difference between top of parapet for height considerations and top of front face of parapet for impact considerations.

The parapet shall be attached to the supporting structure by appropriate attachments/anchorage such that all of the sustained loading is resisted by cantilever action. The attachment/anchorage system shall satisfy the design requirements of **6.6.9** with the partial safety factors of Table 3 and Table 4.

NOTE 2 Partial safety factors for attachments/anchorages are enhanced with respect to those for parapet design to prevent failure occurring within the attachment/anchorage system with consequential damage to the supporting structure.

NOTE 3 The equivalent static nominal loads for the design of reinforced masonry parapets to high containment level are derived from strain measurements on the vertical reinforcement. From the strain values and observations of damage caused under test, a reinforced masonry parapet designed to the specific requirements of this part of BS 6779 should not require emergency replacement. Different levels of damage may be sustained by parapet systems designed to the specified requirements of other parts of this standard.

NOTE 4 Details of a reinforced masonry parapet design developed from a test carried out to a high level containment for British Rail by MIRA (Motor Industry Research Association) are given in Annex C. This design performed very satisfactorily under test and the values from the instrumentation attached to the wall have been incorporated in this standard.

NOTE 5 A typical strain graph of a high level containment test showing the recorded values in the vertical reinforcement is shown in Annex D. This serves well to illustrate the time scale of peak strains and the way the impact force is impacted in particular stages.

NOTE 6 The profile of the coping for the parapet tested at MIRA as illustrated in Annex C has been subsequently revised in agreement with the Railway Inspectorate, see Figure 1c) for the revised profile.

6.6.2 *Design loading for panel lengths (L) 2.0 m to 3.5 m*

For parapet or panel lengths of 2.0 m to 3.5 m, the bending moments and shear forces to be resisted per unit length of parapet shall be in accordance with Table 2.

Table 2 — Equivalent static nominal loads (Q_k) for panel lengths (L) 2.0 m to 3.5 m inclusive

Parapet containment level	Q_k for deriving nominal bending moment[a]	Q_k for deriving nominal shear forces[b]
Normal	77 kN over 1 m length	$110L$ kN/panel
High	$(124 + 104L)$ kN/panel	$(110 + 85H)L$ kN/panel
NOTE It is not considered practicable to provide for shear transfer between panels without inducing a concentrated load at the panel joints such that severe local damage may occur.		
[a] The bending moment to be resisted at the datum for design considerations by applying the stipulated load as a transverse horizontal uniformly distributed load to the top of the front face of the parapet for impact considerations. [b] The shear force to be resisted by any transverse section at distance H below top of front face of parapet for impact considerations. Also as the applied force to design copings and their attachment to the parapet wall.		

6.6.3 ***Parapet lengths greater than 3.5 m***

For parapet lengths greater than 3.5 m the bending moments and shear forces to be resisted per unit length of parapet shall be derived from Table 2 assuming a panel length of 3.5 m.

NOTE The requirement to resist a minimum force of 110 kN/m for shear considerations for normal as well as high containment is to ensure that wall elements, such as coping units, are not detached under a severe impact at top of parapet level.

6.6.4 ***Punching shear***

In order to prevent masonry becoming displaced from the outer face under punching shear, the shear on a defined perimeter throughout the wall thickness shall not exceed the allowable characteristic shear strength of masonry in accordance with BS 5628-2:1978, providing that f_v is not taken to be greater than 0.7 N/mm^2.

For high containment the nominal punching shear force shall be a patch load of 255 kN applied over a circular area of 0.6 m diameter at any position on the front face of the wall.

For normal containment the nominal punching shear force shall be a patch load of 150 kN applied over a circular area of 0.6 m diameter at any position on the front face of the wall.

NOTE It may be assumed that the plane in which punching shear acts will be the circumference of the patch load spreading at 45° to the wall face for the thickness of the wall.

6.6.5 ***Design method***

The parapet and attachments/anchorages shall be designed by the application of limit state principles, as specified in **6.6.6**, **6.6.7**, **6.6.8** and **6.6.9**, using appropriate partial safety factors, γ_{fl}, in accordance with Table 3.

Table 3 — Values of γ_{fl}

Element	Loading	Partial safety factor, γ_{fl}	
		Normal containment	High containment
Parapet	Vehicle impact	1	1
	Wind loading	1.4	1.4
Attachment reinforcement	Displacement of coping	1.25	1.25
	Parapet collapse with reinforcement bonded to supporting structure	1.3	1.2
Bolts	Parapet collapse with parapet bolted to supporting structure	1.4	1.25
Anchorage	Parapet collapse	1.5	1.3

NOTE The partial safety factors specified are intended to control damage at the designated level of containment such that displacement of material from the parapet is not a hazard to highway users or to the space usage beyond the outer face of the parapet.

Characteristic (or nominal) material strengths, f, and partial factors on material strength, γ_m, shall be used in accordance with Table 4.

Table 4 — Values of f_{cu}, f_y, f_k and γ_m, ultimate limit state

Component	Material	Characteristic material strengths	γ_m
Parapet and coping	concrete	f_{cu} in accordance with BS 5400-4	1.0
	reinforcement	f_y in accordance with BS 5400-4	0.8
	masonry	f_k in accordance with BS 5628-2	1.0
Parapet integral base	concrete	f_{cu} in accordance with BS 5400-4	1.2
	reinforcement	f_y in accordance with BS 5400-4	1.0
Anchorage	steel	f_y in accordance with BS 5400-3	1.2
	stainless steel nuts bolts and washers	f_y in accordance with BS EN ISO 3506-1 and -2 or BS 1499-2 as appropriate	1.2
NOTE γ_m may be read as γ_{mm}, γ_{mv} and γ_{ms} as appropriate (see clause **4**).			

6.6.6 *Applied design load values*

The design loads Q^* in kilonewtons (kN) shall be determined from the following:

$$Q^* = \gamma_{fl}\, Q_k$$

where

γ_{fl} is the partial safety factor for load, as specified in Table 3;

Q_k is the nominal load in kilonewtons (kN).

6.6.7 *Applied design load effects*

The design load effects S^* in kilonewtons (kN) shall be obtained from the following:

$$S^* = \gamma_{f3}\, Q^*$$

where

γ_{f3} is the partial load factor for load effect. This shall be taken as:

1.0 for impact loading and parapet collapse;

1.1 for wind loading;

Q^* is the design load (in kN).

6.6.8 *Design load resistance values*

The design load resistance R^* in kilonewtons (kN) shall be obtained from the equation:

$$R^* = \frac{f}{\gamma_m}\ ;\ \frac{f_y}{\gamma_{ms}}\ ;\ \frac{f_{cu}}{\gamma_m}\ ;\ \frac{f_v}{\gamma_{mv}} \text{ as appropriate}$$

NOTE $R^* \geqslant S^*$ for all aspects of design.

6.6.9 *Attachment systems and anchorages*

Attachment systems and anchorages shall be designed to resist the loadings given in **6.6.2** and **6.6.3** as appropriate.

In addition, attachment systems and anchorages for high containment parapets shall be designed to withstand the following coexistent nominal loads, Q_k:

a) a nominal horizontal longitudinal load of 72 kN applied at the top of the front face of the parapet uniformly distributed over a length of 3.0 m, or for panel lengths less than 3.0 m, distributed over the length of the panel;

b) a nominal downwards vertical load of 175 kN uniformly distributed over a horizontal length of 3.0 m at the top of front face of the parapet or, for panel lengths less than 3.0 m, distributed over the length of the panel.

6.6.10 *Design detail: reinforcement*

NOTE 1 Where attachment is achieved by vertical reinforcement bars within the wall core bonded into the supporting structure, couplers may be used to facilitate construction or any subsequent repair work.

Couplers shall be designed to transfer the full design loads, Q^*, with the stipulated limit state factors, γ, into the attachment bars in the supporting structure and shall be of a type which permits the replacement of the vertical reinforcement within the wall core.

Reinforcement shall be of Type II high bond type in accordance with BS 4449.

NOTE 2 For durability requirements see **7.2.7**.

All vertical reinforcement bars shall continue for the full height of the parapet up to coping level.

Horizontal distribution reinforcement bars shall be provided, at not less than 25 % of the area of vertical reinforcement, positioned on the outer face side of the vertical reinforcement.

Stainless steel bed joint reinforcement shall be provided in alternate courses of the masonry face work where this is brickwork and shall continue across the full thickness of the parapet to 20 mm from the external faces of the wall.

Where the masonry face is in stonework of a vertical depth of stone greater than 150 mm, bed joint reinforcement shall be provided at each course level.

The bed joint reinforcement shall provide an area of transverse reinforcement in each layer across the wall core of not less than 88 mm^2 per metre length of wall. Across core reinforcement shall be structurally attached to longitudinal reinforcement secured within the bed joints of the masonry. The longitudinal reinforcement shall be so positioned that at least one bar is located in the outer third area of the bed joint, and shall have a minimum cross-sectional area of 19 mm^2 per bar.

Bed joint reinforcement, where required to be accommodated within a 10 mm bed joint thickness, shall have an overall thickness of not more than 6 mm.

NOTE 3 As well as bonding the composite construction of the wall together, bed joint reinforcement is required to provide link reinforcement resisting horizontal shear. The specified minimum area is for a cross wire or bar at right angles to the wall face. Where the reinforcement is of the inclined lattice type an appropriate adjustment in sectional area is required.

6.6.11 *Design detail: concrete*

The concrete infilling to the wall core shall be a design mix of minimum grade C 45 in accordance with BS 5328-2, -3 and -4.

The maximum size of aggregate shall not exceed the minimum cover to the vertical or horizontal reinforcement specified in **6.6.10**, less 5 mm.

A concrete mix containing an admixture to improve workability shall be used to improve emplacement and compaction.

The concrete cover to the vertical or horizontal reinforcement in the wall core shall be not less than 30 mm with respect to the inner face of the masonry.

NOTE 1 Increased cover to 60 mm may be required where the front face of masonry facework is subjected to road spray containing de-icing salts (see **7.2.7**).

NOTE 2 The minimum thickness of core may be determined by the practical requirements for compacting concrete and for access to the bottom of the core to remove mortar droppings. Aggregate size may have to be reduced to 14 mm to ensure full compaction in narrow core widths.

6.6.12 *Design detail: anchorage for walls constructed with integral base*

Bases shall be bonded to the supporting structure or cast with provision for separation from the supporting structure to facilitate replacement in the event of unacceptable damage.

NOTE Bases with separation provision should be cast to suit the panel length construction.

Where separation is provided for, all of the design forces at the interface of the base with the supporting structure shall be taken by the attachment/anchorage provision.

Where bases are cast with separation provision from the supporting structure, and the attachment system is of bolted form, stainless steel holding down bolts in accordance with BS EN ISO 3506-1 and -2 shall be provided to connect the base with the anchorage in the supporting structure. Stainless steel washers or plates in accordance with BS 1449-2 shall be used to transfer bolt tension to the top of the base.

Holding down bolts shall have a length of engagement in millimetres (mm) into the anchorage of not less than

$$0.7 \times \frac{\sigma_{vb}}{\sigma_{ya}} \times D$$

where

σ_{vb} is the minimum ultimate tensile strength of the bolt material in newtons per square millimetre (N/mm^2);

σ_{ya} is the minimum yield strength of the anchorage material in newtons per square millimetre (N/mm^2);

D is the nominal bolt diameter in millimetres (mm).

Anchorage for a bolted attachment to the supporting structure shall be by cast-in or drilled-in individual bolt anchors. Local reinforcement with partial safety factors in accordance with Table 3 shall be provided to resist the forces transmitted from the parapet.

NOTE 1 It is recommended that internal threads are coated with grease having a high resistance to flow/creep and bolts are sealed in with a passive filler to protect and assist with any need for renewal.

NOTE 2 The strength of the supporting structure will be a major consideration where a high containment parapet is to be provided on an existing structure. Load testing may be required where analysis is indeterminate and also for attachments generally where a verified strength for the attachment is not available.

6.6.13 *Design detail: separation joints between panels*

Where parapets are divided into panel lengths, to prevent composite action between the parapet and supporting structure the separation joint between panels shall extend from the top of the parapet to a level not below the adjoining pavement.

The joint width shall be not less than 20 mm and filled with a durable soft joint filler of the closed cell flexible foamed plastic type.

NOTE 1 Surface sealant to the joint should comply in general with the recommendations of BS 6213. Extreme movement of the joint may require the sealant to be debonded from the joint filler.

NOTE 2 Stopping off the joint at or above the level of any waterproofing to the supporting structure is advised to restrict the passage into the supporting structure of any water which penetrates the joint.

NOTE 3 Separation joints coinciding with movement joints in the supporting structure may require special treatment extending to a joggled joint or inclusion of a surface coverplate to prevent a gap forming when the supporting structure expansion joint is in the open position.

NOTE 4 Where joint width does not decrease under movement and an open joint is acceptable a joint filler may not be required.

NOTE 5 Where it is considered desirable to provide dowel bars across joints, to minimize shear transfer, they should be of light section and of stainless steel with one end de-bonded, preferably with a plastic sleeve.

6.6.14 *Design detail: coping units*

For railway applications to which pedestrians have access, a coping unit with a profile which detracts from the coping forming an access ledge shall be present.

NOTE 1 Such a profile (approved by the Railway Inspectorate) is illustrated in Figure 1c) and could also be used for parapets not intended for railway applications.

Designs for copings for high containment parapets shall include a means of reducing weight and provision for mechanical handling as well as the method of securing the coping unit to the parapet.

NOTE 2 A satisfactory method of handling and bedding the substantial coping units for a high containment situation is to lift by a horizontal hair pin hook lifting device, one leg of which is inserted through a void aligned longitudinally in the centre of the unit and the other leg of which has a lifting eye. Units are placed consecutively, working from one end of the parapet, on a mortar bed set on the masonry face work. A gap should be left between the concrete core and coping bed position of an amount sufficient to accommodate reinforcement projecting from the underside of the coping unit. Concrete is then compacted into this area from the leading end of the coping as each unit is bedded onto the face work using a stiff mix to reduce shrinkage in the core concrete.

Reinforcement detailing shall be designed to provide for crack control and resistance to spalling of significant lumps of concrete under impact.

6.6.15 ***Masonry facework: construction and workmanship***

Joints in brickwork shall be of nominal 10 mm thickness. Joints in stonework shall be as close to 10 mm as is practicable with regard to the evenness of the unit bed and tolerance on unit dimensions. Joints on the inner face of the facework shall be struck clean and those on the outer face shall be pointed as the work progresses. The facework shall be built so as to exclude mortar droppings from the core cavity. For this purpose cavity battens shall be used to catch any mortar which falls into the cavity, and at frequent intervals any mortar which is not caught on the batten, or adheres to the reinforcement, shall be broken away before it hardens. On completion of the masonry facework, the core cavity shall be blown out with sufficient pressure to remove any arisings which have collected in the cavity.

The concrete core shall not be cast until the masonry facework has achieved sufficient strength to resist displacement. Just prior to concreting, the inner face of the masonry facework shall be in a saturated, but surface dry, condition.

Where the facework units are of natural or artificial stone, they shall preferably be of such dimensions that the ratio of height to length of unit is approximately 1:3.

NOTE 1 Where special feature facework requires a radical departure from a 1:3 ratio, the characteristic compressive strength of the masonry could be affected.

NOTE 2 Particular facework units such as concrete bricks or artificial stonework may require wetting to achieve the saturated surface dry condition.

6.6.16 ***Protection to end parapets***

For low or normal containment parapets where a safety fence is present the front face of the fence shall be flush with the front face of the parapet and shall allow for any irregular surface finish of the parapet and projection allowances of **6.5**.

The termination of the safety fence at the parapet end shall have an anchorage system of the full height anchorage form or be made continuous with the parapet by a connection capable of resisting an ultimate longitudinal tensile force of not less than 330 kN.

For high containment parapets where a safety fence is present a transition system shall be provided between the safety fence and the parapet.

NOTE Details of transition systems for high containment parapets may be obtained from BSI (see BS 6779-1:1998, Appendix F).

Where a safety fence is not present at the end of a parapet, the parapet shall conform to **6.7.3** in respect of curved ends to parapets.

6.7 Unreinforced masonry parapets

6.7.1 ***General***

A risk assessment shall be carried out to determine the risk of damage to property, or injury to people in the vicinity of the parapet. This assessment shall be used to justify or advise against the use of this type of parapet at a particular site.

NOTE 1 The risk assessment is necessary because unreinforced masonry parapets are only suitable for low or normal levels of containment, or in the case of the assessment of existing parapets, site specific levels of containment (see Annex C). As a result of a vehicle impact, individual pieces or sections of masonry may become dislodged and mobilized.

NOTE 2 A suitable method of carrying out a risk assessment is described in Annex A.

NOTE 3 In resisting the forces generated by a vehicle impact, longitudinal arching action occurs in unreinforced masonry parapets but not in those of drystone construction. In drystone parapets it is assumed that the open joints between the stones will prevent the arching action. Where parapets are curved on plan the arching resistance of the parapet will be increased by the curvature for impacts occurring on the convex side and decreased for impacts occurring on the concave side. Studies have shown that the decrease in containment for concave parapets is negligible providing the radius of curvature of the parapet is not less than 15 m, which is probably the minimum radius likely to be used on highways. The increase in containment for small radius convex parapets allows curves to be introduced at the ends of parapets, without loss of containment capacity, to minimize the risk of an end-on collision (see **6.7.3**).

6.7.2 *Containment charts*

6.7.2.1 *General*

6.7.2.1.1 The parapets shall be designed in accordance with the containment charts set out in Figure 2, Figure 3, Figure 4 and Figure 5, which are applicable to:

a) parapets having a minimum length of 10 m, or in the case of parapets with movement joints a minimum panel length of 10 m;

b) parapets which are straight or curved on plan, subject to a minimum radius on the traffic face of 15 m;

c) impacts from vehicles, as specified in clause **6.1.1**, occurring not less than 1 m from the end of the parapet.

6.7.2.1.2 Adjustments to the containment values shown in the charts Figure 2, Figure 3, Figure 4 and Figure 5 shall be applied where the minimum assumed material properties are unlikely to be achieved.

NOTE 1 This is to allow for assumptions that have been made regarding the properties of the materials in the parapets when deriving the charts.

NOTE 2 Requirements are specified in this clause for some of the adjustments to be made.

6.7.2.1.3 Where parapets are being rebuilt the bedding joints shall provide a shear resistance at least equal to that which would be provided by friction, assuming a coefficient of friction of 0.7, to a minimum depth of 0.7h below the adjoining paved surface (where h = the parapet height).

NOTE 1 The bedding mortar in masonry parapets is sometimes subject to a loss of strength due to weathering at the level of the adjoining paved surface. The containment charts are, therefore, based on the assumption that only frictional resistance is present in the parapet at the level of the adjoining paved surface, with a coefficient of friction of 0.7.

NOTE 2 In the derivation of the containment charts the friction due to the self weight of the masonry has been ignored. Only that friction which results from the stresses due to vertical arching action in the parapet is taken into account. Thus hairline cracks in the bedding joints, such as might be present at the base of a parapet due to the deflection of a bridge deck, should close up as a result of the arching action and not significantly affect the containment capacity. Where a damp proof course is considered to be necessary, and it is to be provided in the form of a membrane at the base of a parapet, the manufacturer's advice should be sought on the frictional characteristics of the material. Integral damp proof courses are recommended.

NOTE 3 The containment charts have been derived assuming the perpend joints in the masonry are continuous throughout the thickness of the parapet, for example, as in ashlar stone masonry construction. Improved containment capacities, giving higher margins of safety, will be provided where bond patterns are used, in which the perpend joints are not continuous throughout the parapet thickness and are also staggered between courses.

6.7.2.1.4 The containment charts in Figure 2, Figure 3 and Figure 4 have graphs for two assumed densities of masonry and for different heights of parapet; the densities refer to the masonry structural units taken in combination with the jointing mortar and shall be calculated on the gross volume. The containment capacity for parapets with masonry of different density from those shown in the charts shall be obtained by linear interpolation or extrapolation from the plotted values.

NOTE For parapets less than the minimum height of 800 mm or greater than the maximum height of 1.25 m covered by Figure 2, Figure 3, Figure 4 and Figure 5, the containment capacity may be obtained by extrapolation from the values plotted. It should be recognized, however, that where parapets are significantly lower than 800 mm there is a risk of overtopping, particularly for large wheeled vehicles where there are kerbs in front of the parapet. This has not been considered in the derivation of the charts. For parapets significantly higher than 1.25 m there is a risk of masonry from the top of the parapet falling towards the highway and onto an impacting vehicle, again not considered in the derivation of the charts.

6.7.2.1.5 Where data are not available on the characteristic shear strengths between particular masonry units and mortar, conservative values shall be assumed or appropriate values shall be determined from tests.

NOTE 1 Conservative values for brickwork with some mortar mixes are given in clause **25** of BS 5628-1.

NOTE 2 Containment charts are provided for a range of characteristic initial shear strengths between the mortar and the masonry units, different dimensions of parapets and densities of masonry. The tensile strength between the mortar and the masonry units is assumed to be directly related to the initial shear strength.

Where tests are carried out these shall cover the ranges of moisture contents of the masonry and the initial surface suction values and the curing regime specified for the construction. The tests shall be carried out on masonry triplets as detailed in Annex D. For masonry units with perforations or voids in the mortared face, the results shall be reported based on the gross area of the face.

NOTE 3 The containment provided by unreinforced masonry parapets primarily arises from one or more of the following:

a) arching action within the masonry;

b) momentum transfer from the impacting vehicle to the masonry which is mobilized by the impact;

c) energy absorbed by the deformation or fracture of the joints. Compliance with the requirements in this standard should ensure that any fractures mainly occur at joints and not in the masonry units.

NOTE 4 Testing has revealed large variations in shear and tensile strengths between masonry units (particularly stone units) and mortar, which is not directly related to the strength of the mortar. Such variations seem to be related to the moisture content of the masonry unit, the initial rate of suction, the surface roughness, size and distribution of pores and the curing regime. Strong mortar mixes have sometimes resulted in very poor adhesion.

NOTE 5 The containment charts are based on computer modelling, which was verified by full scale tests. Brief details of the background to the derivation of the charts are described in Annex F.

6.7.2.2 *Containment chart: high mortar adhesion*

The containment chart shown in Figure 2 shall be used for the design of unreinforced masonry parapets, and in exceptional circumstances for the assessment of existing parapets, (where there are no significant defects in the parapet and the construction details are known), in accordance with Table 5.

Table 5 — Criteria for unreinforced masonry parapets designed in accordance with Figure 2

Property	Value
Minimum characteristic compressive strength of masonry to BS 5628	10.0 N/mm^2
Minimum characteristic initial shear strength between mortar and masonry unit	1.2 N/mm^2
Minimum co-efficient of friction mortar to masonry unit	0.7

NOTE Tests have shown that the criteria in Table 5 were satisfied using a class (i) mortar (1:¼:3) in accordance with BS 5628-3, in conjunction with one type of class B engineering clay brick. The moisture contents for the class B engineering bricks and the initial rates of suction were not measured. However, similar tests using one lightweight type of class FL clay brick conforming to BS 3921, which had a relatively high initial rate of suction of approximately 2.0 kg (m^2·min), when used with the same 1:¼:3 mortar, showed much lower adhesion, somewhat lower than the appropriate to the use of the containment chart in Figure 2. These low values were probably as a result of water being absorbed by the bricks from the mortar leading to incomplete hydration of the cement at the mortar to brick interface.

6.7.2.3 *Containment chart: medium mortar adhesion*

The containment chart shown in Figure 3 shall be used for the design of unreinforced masonry parapets and in exceptional circumstances for the assessment of the existing parapets (where there are no significant defects in the parapet and the construction details are known) in accordance with Table 6.

Table 6 — Criteria for unreinforced masonry parapets designed in accordance with Figure 3

Property	Value
Minimum characteristic compressive strength of masonry to BS 5628	5.0 N/mm^2
Minimum characteristic initial shear strength between mortar and masonry unit	0.6 N/mm^2
Minimum co-efficient of friction mortar to masonry unit	0.7

NOTE A series of tests showed that the above criteria were satisfied using a class (iii) mortar (1:1:6) in accordance with BS 5628-3 in conjunction with two types of class B engineering clay bricks conforming to BS 3921. The specified moisture contents were in the range 0 % to 2.5 % and the initial rates of suction in the range 0.13 kg/(m^2·min) to 0.19 kg/(m^2·min). The mixing water to cement ratio was 1.4:1.

6.7.2.4 *Containment chart: low mortar adhesion*

The containment chart shown in Figure 4 shall be used for the design of parapets, except those with slate or other similar impervious structural units, where the mortar is hard and durable but the characteristic initial shear strength between the mortar and the masonry unit is not known.

NOTE 1 The containment chart is based on conservative values for the characteristic initial shear strength.

The containment chart shown in Figure 4 shall also be used for the assessment of existing unreinforced masonry parapets, except for those with slate or similar smooth impervious structural units, where there are no significant defects in the parapet, and the mortar is uncracked and hard such that it cannot easily be removed by manual scraping.

NOTE 2 The chart is based on the very low characteristic mortar adhesion strengths obtained by testing a 1:20 cement/sand mortar used in conjunction with a class B engineering brick. The 1:20 mortar was intended to represent a very weathered mortar and could be easily removed from the masonry joints by scraping even when fully cured.

6.7.2.5 *Containment chart: design of drystone parapets, and unreinforced masonry parapets with masonry units of slate or similar smooth or impervious material*

The parapets shall be designed or assessed using the containment chart in Figure 5.

NOTE The chart is based on an assumed effective density of the parapet of 1 920 kg/m^3 which is equivalent to the parapet being constructed of stone with a density of 2 250 kg/m^3 and having a 15 % void ratio (i.e. 15 % voids 85 % stone). The sketch shown in Figure 6 shows the basis of the determination of the void ratio.

Drystone parapets, mortared slate parapets and other mortared stone parapets constructed of impervious smooth stones shall be assumed to provide containment by mass alone. Consequently, when designing parapets using the containment chart, adjustments shall be made to the parapet thickness determined from the chart, to take into account any variations in effective density of the stone, i.e. parapet thickness required

$$= \text{thickness determined from the chart} \times \frac{1920}{\text{effective density of masonry to be used}}.$$

6.7.3 *Protection to ends of parapets*

Where there is a safety fence which terminates at a parapet the safety fence shall be provided with a connection or anchorage system capable of resisting an ultimate longitudinal tensile force of not less than 330 kN. The safety fence shall extend along the parapet for not less than 1 m from the end of the parapet. The connection to the parapet shall be so recessed, or the section of the parapet to the rear of an anchorage system shall be set back, such that the front face of the safety fence is flush with the front face of the parapet, with due regard to any irregular surface finish and the projection allowances of clause **6.5**.

NOTE 1 Unreinforced masonry parapets conforming to this standard resist impact forces applied to the parapet at not less than 1 m from the parapet end. Impacts within 1 m of the end of the parapet may lead to excessive penetration and “hook up”, which may cause the vehicle to spin. Hence the requirement for safety fence protection where present over the first metre length of the parapet with suitable stiffening to the fence on the approaches, which can be achieved by providing post spacings at reduced centres.

An alternative to terminating and providing an anchorage to the safety fence, which may be particularly suitable for short span structures, is to attach the beam element of the safety fence direct to the front face of the parapet throughout its length so that it is in close contact with the face. Stand-off brackets should not be used in order to avoid point loading. Connections should be provided in the safety fence beam, if necessary at expansion joints, which are capable of transmitting a longitudinal tensile force of at least 330 kN.

Where there is no safety fence at the end of the parapet, such precautions as are practicable under the circumstances shall be taken to prevent errant vehicles colliding with the end of the parapet.

NOTE 2 One method of reducing the risk of an end on collision and to increase the containment performance of the end section is to curve the ends of the parapet away from the edge of the highway as shown in Figure 7.

NOTE 3 Curving the ends of the parapet increases the containment capacity on the curved portion due to the increased strength arising from the curvature, but could increase the angle of impact of an errant vehicle. It has been demonstrated by computer modelling that the increased containment provided by the curvature more than offsets the increased potential angle of impact providing the radius of the curvature on the inside face of the parapet is not less than 3 m and the angle subtended by a parapet so curved does not exceed 40° approximately (i.e. length of curve for a 3 m radius not greater than 2 m approximately), giving a maximum offset of about 0.67 m to the end of the parapet. A larger radius curve with a smaller angle subtended will provide adequate containment but it is recommended that the end parapet is offset a minimum of 0.5 m by the curvature.

6.7.4 *Movement joints in unreinforced masonry parapets*

Vertical movement joints shall be provided in the parapets where appropriate (see Annex G). The joint width shall be a minimum of 20 mm. If necessary, to prevent the ingress of material, the joint shall be filled with a durable soft joint filler of the closed cell flexible foamed plastic type.

Where bed joint reinforcement is incorporated in the parapet to permit an increased spacing of the movement joints, the reinforcement shall consist of stainless steel bars conforming to BS 6744, grade 316 S 33, and shall have a minimum of four longitudinal bars in each layer. The reinforcement shall have a minimum cover of 25 mm. Where necessary to accommodate lapping the reinforcement shall be of the flattened wire type.

NOTE 1 The containment charts in Figure 2, Figure 3, Figure 4 and Figure 5 have been devised for parapets without any movement joints and are applicable for impacts occurring a minimum distance of 1 m from the end of the parapet. The charts are applicable for parapets with movement joints, and panel lengths not less than 10 m, providing there is a provision for shear transfer across the joints.

The shear transfer requirements which are related to the ductility of the shear transfer devices shall conform to Table 7. Intermediate values may be determined by linear interpolation.

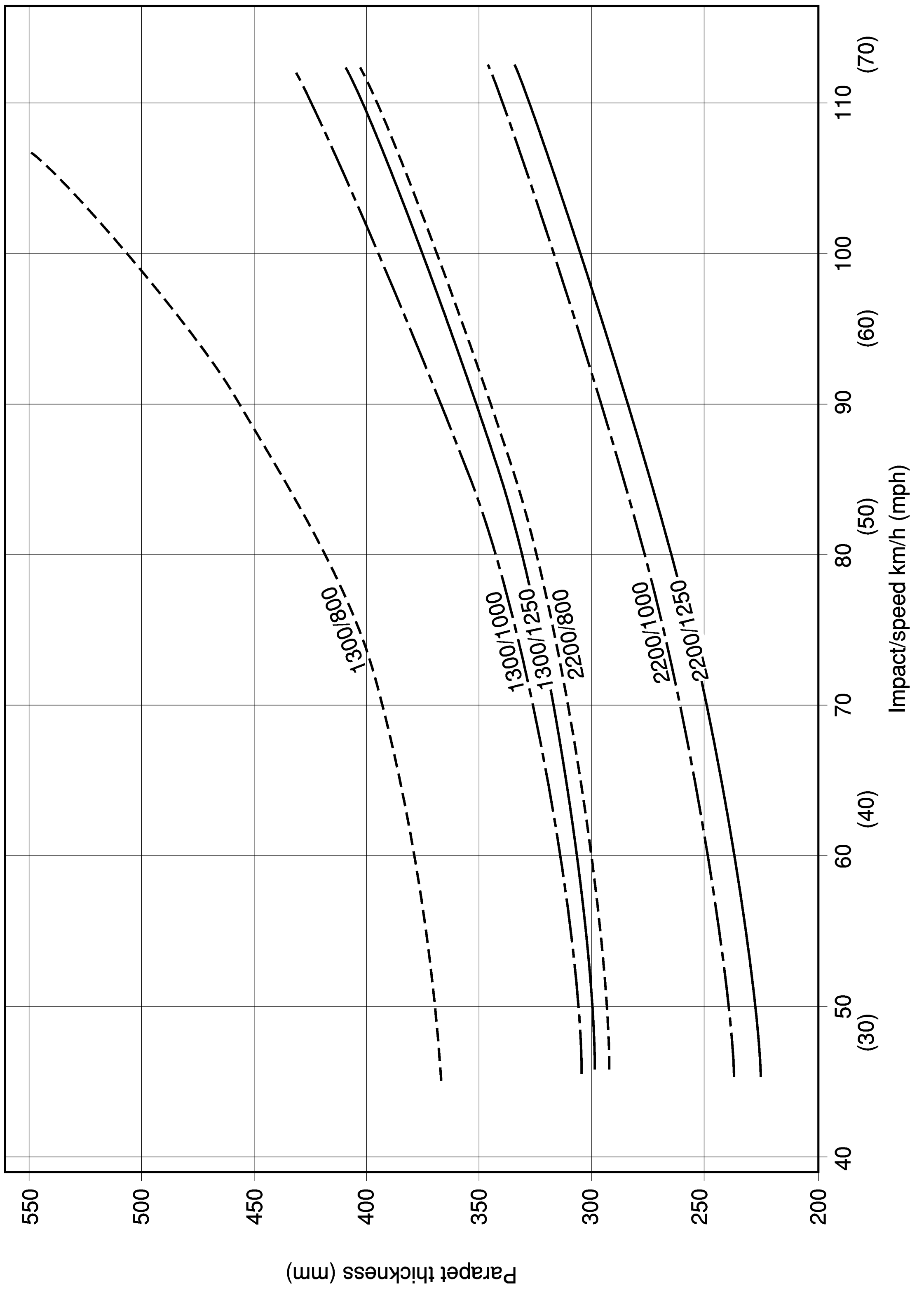
Table 7 — Shear transfer at movement joints

Average shear force sustained prior to failure kN	Defection across movement joint at failure mm
110	0
45	20
22	50

The shear transfer arrangement shall consist of grade 316 S 33 stainless steel plates or dowel bars, or similar, crossing the joint and suitably debonded on one side of the joint to permit expansion and contraction of the parapet. Tests shall be carried out if necessary to determine the strength of the shear transfer devices with the particular masonry to be used for construction. A partial safety factor $\gamma_m = 2$ shall be applied to the average of the test results for design purposes.

NOTE 2 Tests using a class (iii) mortar (1:1:6) in accordance with BS 5628-3 in conjunction with class B engineering clay bricks in accordance with BS 3921 showed that 10 mm diameter stainless steel dowel bars in 12 mm thick bed joints had an average shear resistance of 4.2 kN per dowel over a deflection in excess of 50 mm prior to failure. There were a pair of dowels in a bed joint projecting 150 mm each side of the joint. Stainless steel dowel bars 16 mm diameter in 20 mm thick bed joints had a similar average shear resistance. Failure in each case was in the adhesion between the mortar and bricks of the bed joints in the masonry. The specified moisture contents of the bricks were in the range 0 % to 2.5 % and the initial rates of suction were in the range 0.13 kg/m^2·min to 0.19 kg/m^2·min.

These tests show that, taking into account the partial safety factor, two dowel bars in each bed joint in the brick masonry in a 1 m high parapet would provide adequate shear connection.



Notation - Density (kg/m^3) / parapet height (mm)

Figure 2 — Containment chart, high mortar adhesion

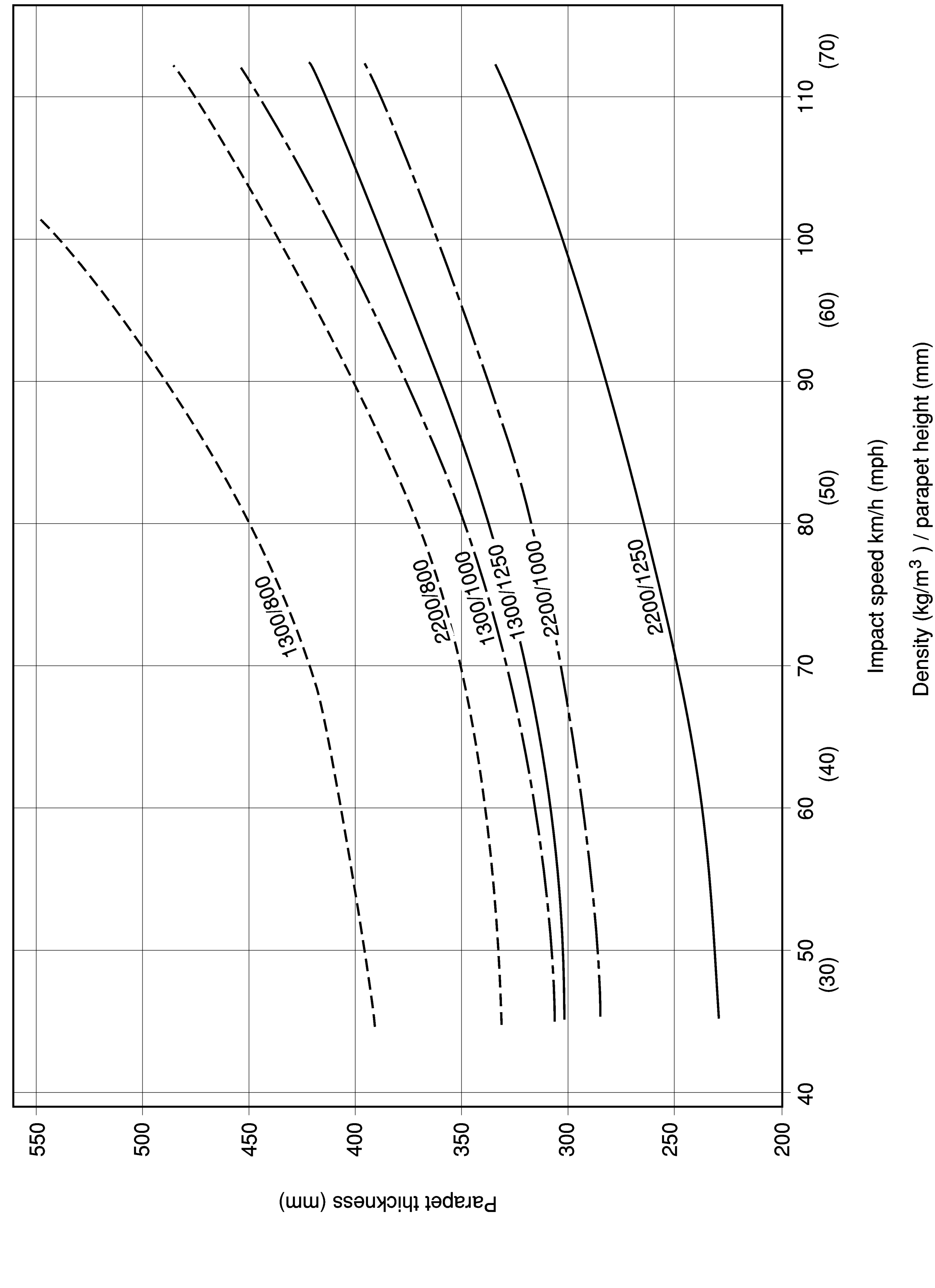


Figure 3 — Containment chart, medium mortar adhesion

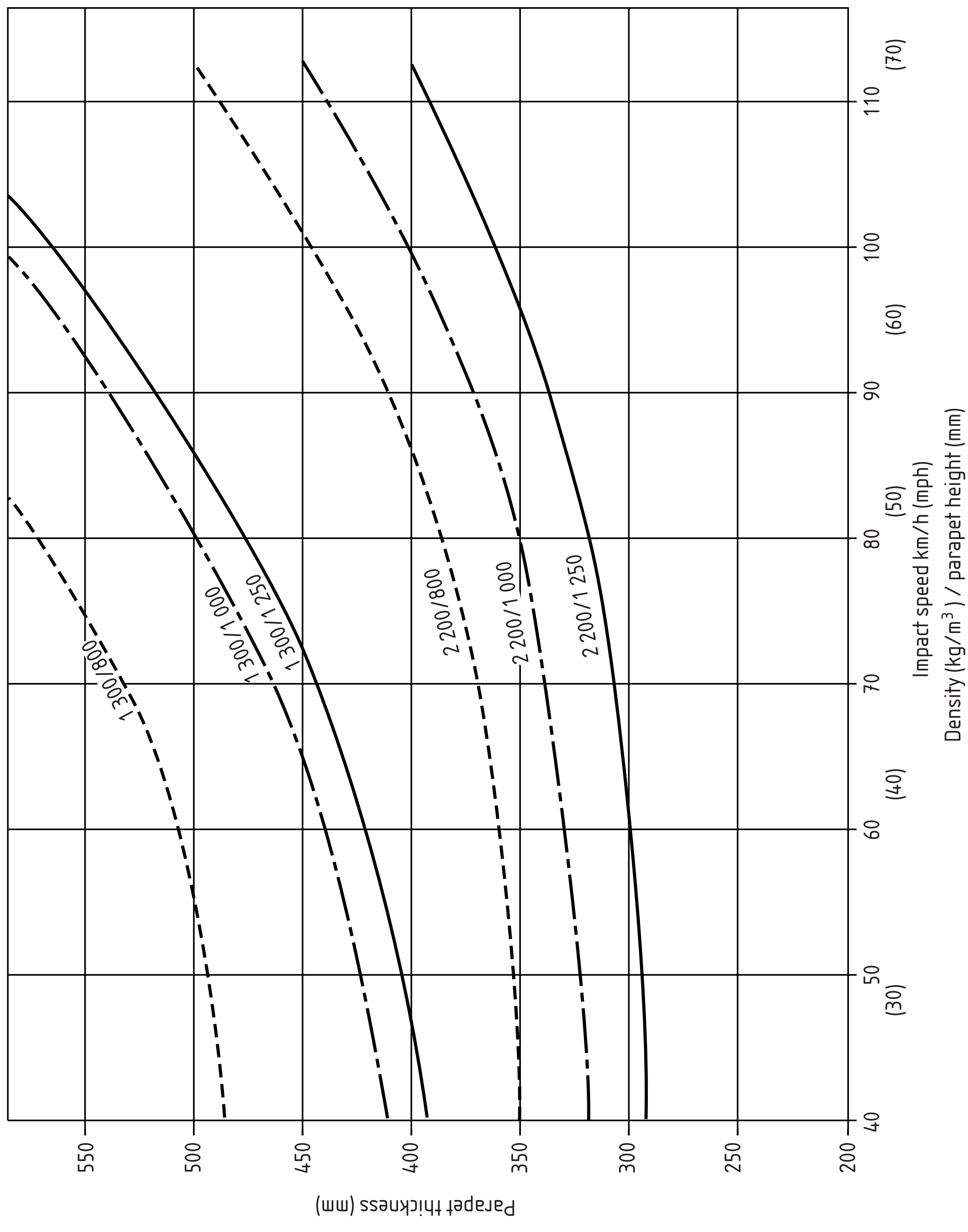


Figure 4 — Containment chart, low mortar adhesion

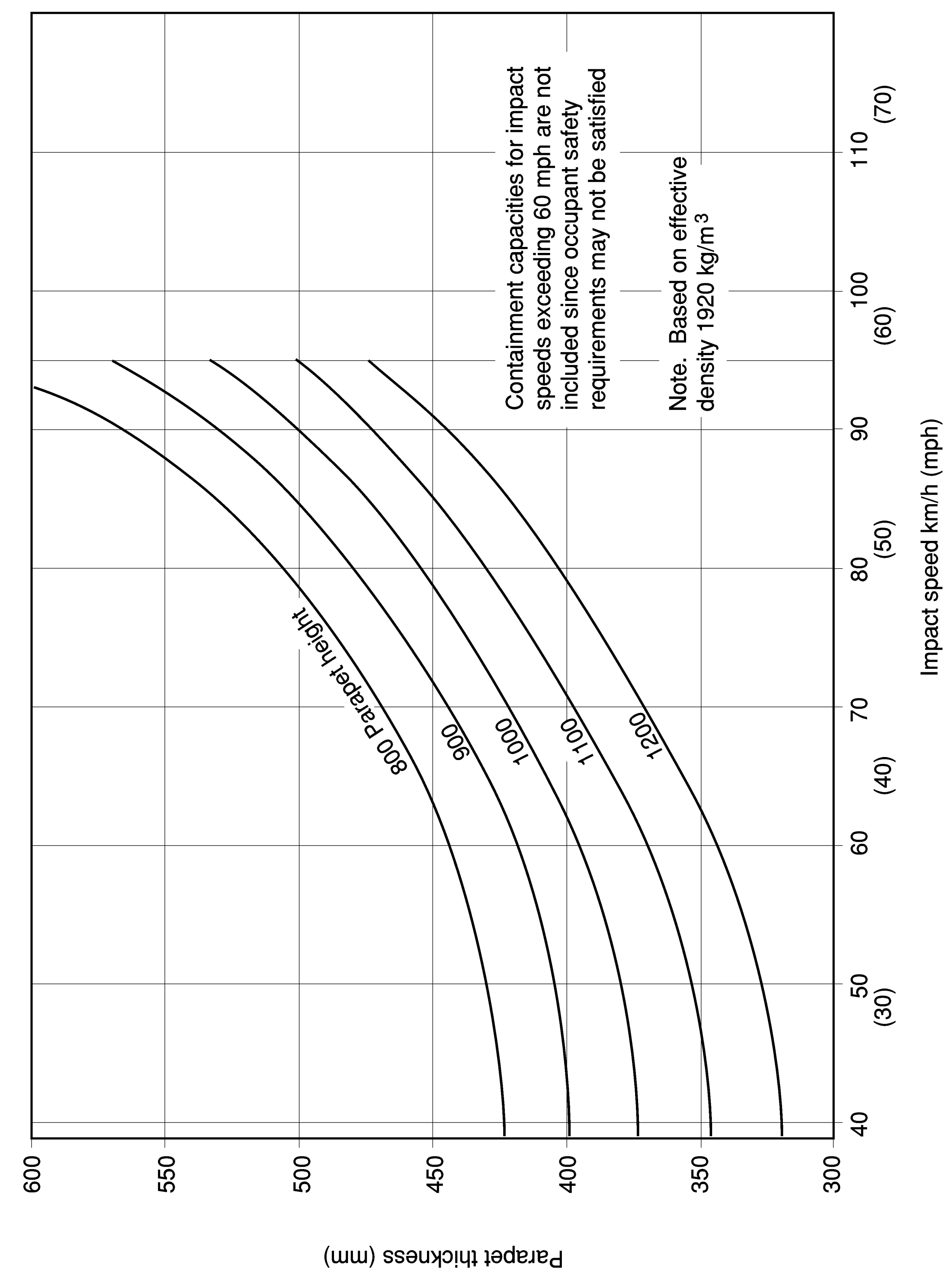
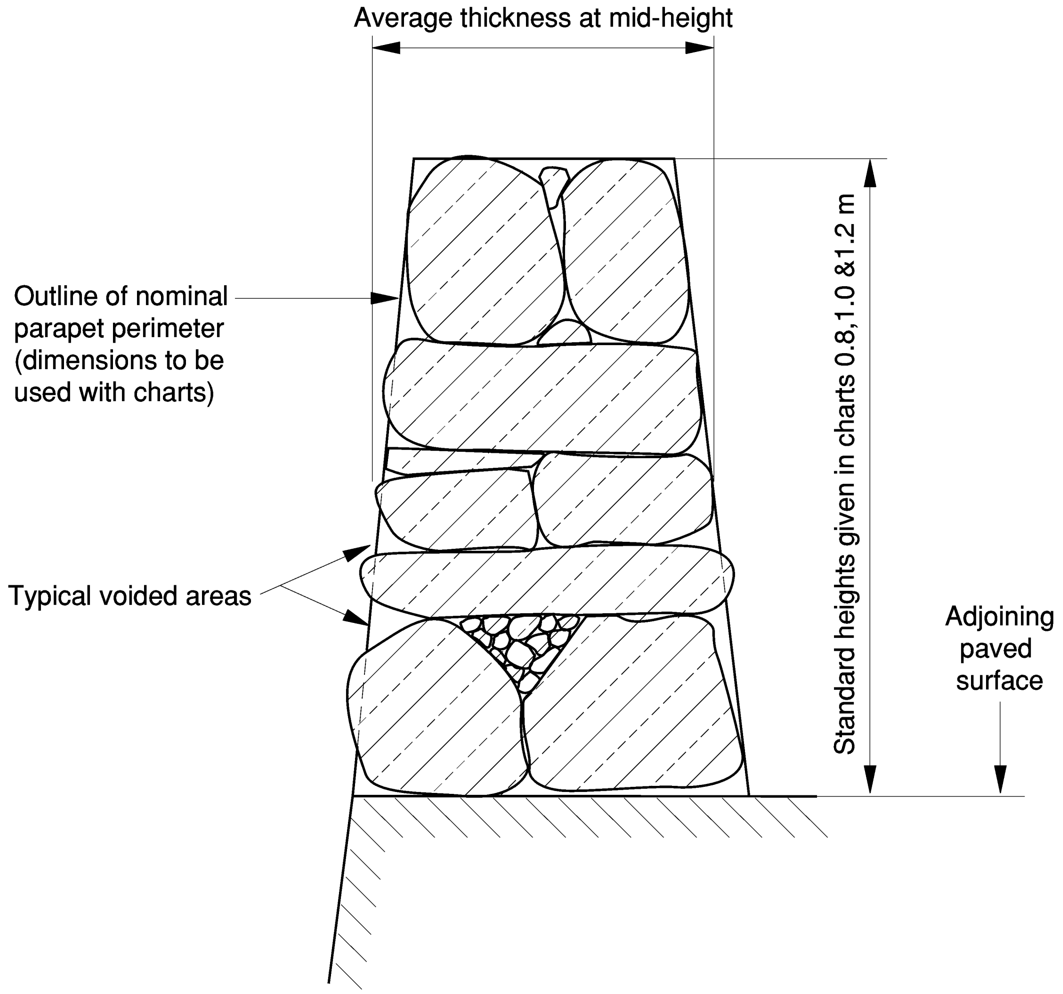


Figure 5 — Containment chart, drystone or mortared slate or similar parapets



Note: Drystone wall construction will vary from region to region and this diagram should be considered diagrammatic only.

Figure 6 — Drystone construction showing the basis for determining voids percentage

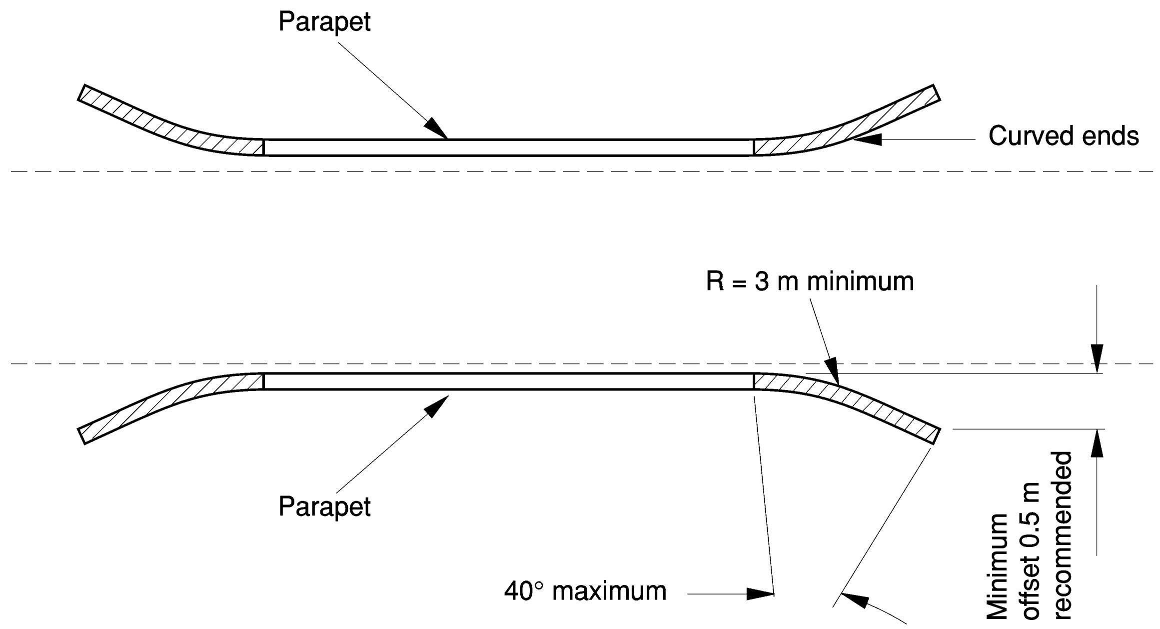


Figure 7 — Curved ends to parapet to prevent end on impact

7 Materials and workmanship

7.1 General

This clause shall not apply to the assessment of existing parapets.

Manufacturing and construction control for masonry units shall be in accordance with BS 5628-1, -2 and -3. Clay brick masonry units and pre-cast concrete masonry units together with workmanship for reinforced masonry parapets shall be to special category as described in BS 5628.

Unless otherwise stated the materials components and workmanship clauses of BS 5628-1, -2 and -3 and BS 8000-3 shall apply.

The compressive strength of the masonry, as required by the design, shall either be established by test in accordance with BS 5628-1 or be established by reference to the tables and charts in BS 5628-1:1992, clause **23**.

7.2 Materials

7.2.1 *Brick masonry*

Brick masonry units shall be clay bricks complying with BS 3921 and shall unless otherwise specified have a minimum unit compressive strength of 30 N/mm^2 and an initial rate of suction not exceeding 1.5 $kg/(m^2 \cdot min)$ measured in accordance with BS 3921.

Where brick units with a frog depression are used this shall be in one face only and shall not exceed 20 % of the gross volume of the unit. The frog shall be laid uppermost and solidly filled with mortar. The quoted density for brick units with perforations shall be calculated on the gross volume of the brick unit.

Brick masonry units shall be FL designation for durability and soluble salt content.

NOTE FL designation is described in BS 3921.

7.2.2 ***Precast concrete masonry***

Precast concrete masonry units shall conform to BS 6073-1 and be specified in accordance with BS 6073-2, except that the average crushing of the bricks or blocks referred to in BS 6073- 2:1981, clause **10**, shall be not less than 14 N/mm².

Pre-cast concrete masonry units where specified as solid shall not have holes, cavities or depressions. Where specified as permitting a frog depression this shall be in one face only, shall not exceed 20 % of the gross volume of the unit, and shall be laid uppermost and solidly filled with mortar.

NOTE 1 Where a minimum crushing strength is required and not the average crushing strength allowed in BS 6073-1 this should be stated and the unit described as a special purpose unit for manufacturing/ordering purposes.

NOTE 2 Where the units are to be used in a reinforced parapet consideration should be given to the exclusion of calcium chloride which is permitted generally as an admixture in BS 6073-1.

7.2.3 ***Natural stone masonry***

Natural stone masonry units shall conform to BS 5390 and shall have proven satisfactory durability in the exposure conditions applying to highway parapets.

Stone shall be selected from quarry beds without marked thickness or geological variations, and supplied against an approved sample.

NOTE 1 For reinforced masonry parapet walls the requirement for bed joint reinforcement will restrict walling type to ashlar or squared rubble coursed masonry units.

NOTE 2 It is advisable to allow masonry units to stand after cutting from the quarry bed so that quarry sap (moisture saturated with soluble minerals) can dry out before units are transported and built into walling. Incipient defects are then more readily detectable and the stone is in a stronger condition when so dried out.

7.2.4 ***Reconstructed stone masonry***

Reconstructed stone masonry units shall conform to BS 6457 and shall have proven satisfactory durability in the exposure conditions applying to highway parapets.

NOTE 1 The average crushing strength of units is likely to be limited to the value of 20 N/mm² stated in BS 6457.

Units of greater minimum crushing strength which may be required for reinforced masonry parapet design may therefore have to be specified and special arrangements made for the manufacture.

NOTE 2 Where the units are to be used in a reinforced parapet, consideration should be given to the exclusion of calcium chloride which is permitted generally as an admixture in BS 6457.

NOTE 3 BS 6457 does not cover masonry units consisting of a facing material and a backing concrete. Should such units be considered for special aesthetic considerations then the facing material should have sufficient strength to prevent spalling under impact such that large size lumps of material are discharged onto the highway.

7.2.5 ***Mortar***

Mortar shall conform to BS 5628-3.

NOTE For reinforced masonry construction and durability generally a mortar strength of not less than designate (ii) of BS 5628-1 and -2, is required. In particular for protected environments, where special facing masonry is required, mortar strengths of less than that achieved with designate (ii) may be more compatible with the strength of the masonry unit.

7.2.6 ***Reinforcement steel***

All stainless steel reinforcement fixings shall conform to BS EN 10088-1, designation 1.4436. The required mechanical properties for fasteners shall be specified in accordance with BS EN ISO 3506-1 and -2.

Carbon steel reinforcement shall conform to BS 4449 grade 460.

7.2.7 ***Durability***

Masonry units shall have proven durability against weathering, de-icing salts and frost damage. Natural stone shall be provided from an approved source, not from top rock strata, geologically faulted strata, or from material damaged by blasting operations such that it contains incipient fractures.

Reinforcement within the concrete core of the wall shall be selected for durability purposes in accordance with BS 5628- 2:1995, Tables 13 and 14, and restricted to stainless steel or uncoated carbon steel. Where stainless steel reinforcement is specified the minimum cover shall be 30 mm. Where carbon steel reinforcement is specified the minimum cover shall be 60 mm.

Annex A (informative)
Risk assessment related to vehicle impacts on unreinforced masonry parapets

A.1 General

A.1.1 In some instances the effects of a vehicle impact on an unreinforced masonry parapet will result in masonry becoming detached, most of which will fall from the supporting structure into the hazard zone outside the highway. The level of the risk of injury to any occupants of the hazard zone should determine whether such an occurrence is acceptable.

A.1.2 The risk of injury can be assessed on a quantitative basis using a risk evaluation process to determine whether it is within acceptable limits. Factors which will affect the risk evaluation include:

a) the estimated frequency of parapet impacts which result in detached masonry;

b) the use and frequency of occupation of the hazard zone.

A.1.3 The use of a risk evaluation procedure based on a method described in a paper by Hambly and Hambly [1] is suggested. The method is based on the calculation of the fatality accident rate (FAR), which is the risk of death per 100 million hours of exposure to the activity. The paper includes a list showing the approximate FAR values some of which are reproduced in the Table A.1 (the higher the number the greater the risk).

Table A.1 — Risk evaluation

Activity	FAR
Travel by bus	1
Travel by car or by air	15
Walking beside a road	20
Travel by motorcycle	300
Travel by helicopter	500

It should be noted that the paper is written in general terms and is not specifically aimed at parapet impacts.

A.1.4 Examples of the use of the method applied to parapet impacts are given in **A.4**. The following conservative assumptions have been made in the examples:

a) that any person in the hazard zone will suffer a fatal injury in the event of an impact;

b) that the parapet impacts being considered all result in detached masonry;

c) that each impact affects all of the potential hazard zone; this would clearly be excessively conservative for a long bridge where only part of the bridge passed over a public area (e.g. public footpath);

d) that the parapet impacts occur at a uniform rate throughout a 24 h day, whereas it is thought that most will occur during the hours of darkness when the hazard zones are less likely to be occupied.

A.2 Frequency of parapet impacts

In the examples, the frequency of parapet impacts has, arbitrarily, been assumed to be once every 10 years. When estimating the frequency at a particular site historical records should, if available, be used. However, in the absence of such records an estimate will need to be made taking into account the particular features appertaining at each site.

NOTE From records of one local Highway Authority, which is responsible for the maintenance of approximately 2 000 highway bridges, there were approximately 60 reported accident damages to bridge parapets (all types) over a 12 month period. About 40 of these reported accident damages involved unreinforced masonry parapets, but only about one-third of these resulted in detached masonry. The frequency of parapet impacts resulting in detached masonry could, at many bridge sites, be very much lower than the once every 10 years assumed in the examples in **A.7**.

A.3 Falling masonry and length of hazard

Figure A.1 shows the theoretical trajectory of a masonry block detached from a 1 m high parapet for a range of bridge clearances and an impact velocity of 60 mph.

The chart has been determined from the principles of simple kinematics and has been verified from the slow motion videotape recording of vehicle impact tests. The chart shows only the trajectory of the block before impact and does not allow for post-impact rolling, bouncing or shattering on impact. The user may wish to consider an additional length beyond the hazard zone shown by the chart to form a safety clearance or buffer zone.

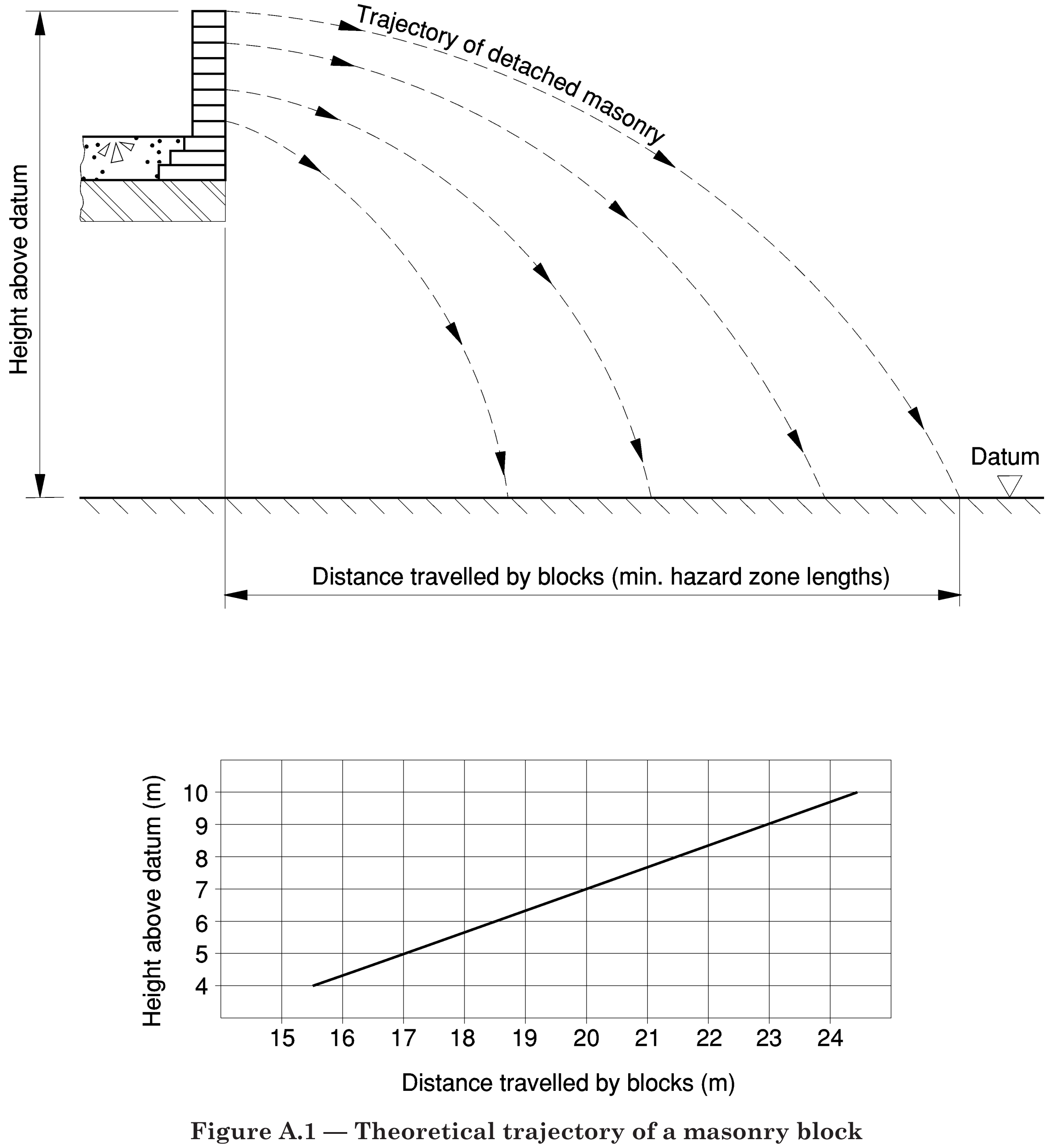


Figure A.1 — Theoretical trajectory of a masonry block

A.4 Examples of risk evaluation

EXAMPLE 1

Masonry parapet over a canal

A bridge spans a canal which conveys eight barge movements per 8 h day. The barges travel at 8 km/h. The bridge has an unreinforced masonry parapet the top of which is 5 m above the water level. From records it is estimated that the parapet is struck by an errant vehicle once every ten years.

From Figure A.1:

a) length of hazard zone = 17.1 m;

b) time taken for block to fall = 1.00 s.

Time taken for barge to traverse hazard zone is:

$$\frac{17.1}{8\ 000} = 2.14 \times 10^{-3}\ \text{h} = 7.7\ \text{s}$$

NOTE Only one occupant of the barge is assumed and the time to traverse the hazard zone calculated accordingly, i.e. independent of the barge length.

Assuming that the barge is unable to manoeuvre to avoid the falling blocks then,

barge exposure period = 2.14×10^{-3} h

Total daily barge exposure period, in exposure hours per hour:

$$= 2.14 \times 10^{-3} \times 8 \times \frac{8}{24} = 5.71 \times 10^{-3}$$

Frequency of errant vehicle incident per hour

$$= \frac{1}{10\ \text{years}} = \frac{1}{87\ 600}$$

Therefore probability of simultaneous occurrence of errant vehicle and barge

$$= \frac{1}{87\ 600} \times 5.71 \times 10^{-3} = 6.5 \times 10^{-8}$$

Therefore FAR = 6.5 which is relatively low on Hamblys' League table and is probably acceptable.

EXAMPLE 2

Masonry parapet over footpath

Assume a similar bridge structure over a footpath having five pedestrian movements every hour per 16 h day. Pedestrians are assumed to walk at a pace of 5 km/h. The errant vehicle is similar to example 1.

From Figure A.1:

a) length of hazard zone = 17.1 m;

b) time taken for block to fall = 1.00 s.

Time taken for pedestrian to traverse the hazard zone

$$= \frac{17.1}{5\ 000} = 0.0034\ \text{h} = 12.3\ \text{s}$$

A pedestrian would be unlikely to react within 1 s and therefore the exposure period = 12.3 s

Therefore daily pedestrian exposure period, in exposure hours per hour

$$= \frac{12.3}{3\ 600} \times 5 \times \frac{16}{24} = 0.0114$$

Frequency of errant vehicle incident per hour

$$= \frac{1}{10\ \text{years}} = \frac{1}{87\ 000}$$

Therefore probability of simultaneous occurrence of errant vehicle and pedestrian

$$= \frac{1}{87\ 600} \times 0.0114 = 13 \times 10^{-8}$$

Therefore FAR = 13.

This value of FAR is equivalent to the risk of travel by car from Hambly's chart and may be considered acceptable.

EXAMPLE 3

Masonry parapet over an all-purpose road

A bridge spans a two lane dual carriageway trunk road which carries 20 000 vehicles per day in a 24 h period. The vehicles travel at 80 km/h on average. The bridge has an unreinforced masonry parapet, the top of which is 7 m above the trunk road carriageway level.

The errant vehicle is similar to example 1.

Assume that:

a) there is one fatality in each vehicle on the lower road (the subject vehicle) which is either hit by or runs into the falling masonry;

and, from Figure A.1:

b) detached masonry would be projected 20.2 m;

c) time taken for block to fall = 1.19 s to carriageway level.

The period of exposure (in hours) will either be the time taken for the subject vehicle to traverse the hazard zone, or the time that a driver, having seen the blocks, would need in order to react and brake to avoid the blocks.

Time taken to traverse hazard zone

$$= \frac{20.2}{80\ 000} = 2.53 \times 10^{-4}\ \text{h} = 0.91\ \text{s}$$

Assuming that the driver spots the block as it just appears below the soffit of the deck, then the time that he has in order to react is:

total time taken for block to fall to ground less time taken to fall below soffit

total time = 1.19 s

$$\text{time to fall to soffit} = \sqrt{\frac{2 \times 1.5}{9.81}} = 0.553\ \text{s}$$

available reaction time = 0.64 s

The Highway Code allows a reaction time of 0.68 s at this stopping distance which is slightly greater than that theoretically available. There is therefore some risk of drivers running into the blocks which have fallen into the road. This is ignored in the ensuing calculation for simplicity.

Therefore subject vehicle exposure period, in hours

$$= \frac{1.19}{60 \times 60} = 3.306 \times 10^{-4}$$

Total subject vehicle exposure period = subject vehicle exposure period × number of vehicles per hour

$= 3.306 \times 10^{-4} \times 20\ 000$

= 6.612 exposure hours in 24 h period

= 0.276 exposure hours per hour.

Frequency of parapet incident, per hour

$$= \frac{1}{10\ \text{years}} = \frac{1}{86\ 600}$$

Therefore probability of errant vehicle and subject vehicle simultaneous occurrence

$$= \frac{1}{87\ 600} \times 0.276 = 3.15 \times 10^{-6}$$

Using FAR units of $10^{-8,}$ FAR = 315 (assuming one occupant per vehicle). This is relatively high on Hamblys' League table and should be considered unacceptable.

NOTE These are numerical examples only to demonstrate the approach. The assessing engineer or authority should use available statistical values wherever possible. The FAR levels of acceptability should be decided by the highway authority or bridge owner.

Annex B (informative) Site specific levels of containment, assessment of existing parapets

B.1 General

B.1.1 The low and normal levels of containment assume an angle of impact of 20° with the parapet. On some minor roads, using the same logic from which the low and normal containment criteria were derived, it may not be theoretically possible to achieve a 20° angle of impact at the standard impact speeds due to the restricted width of the road. In such situations it may be appropriate, for the assessment of existing parapets, to adopt a site specific level of containment based on the theoretical speed consistent with an angle of impact of 20°.

B.1.2 Before adopting a site specific level of containment, which it is assumed would be less onerous than the standard level of containment appropriate to the class of road, due consideration should be given to the horizontal alignment of the road at a particular site, in addition to its width. In the example shown in Figure B.1, due to the alignment of the road and parapet it would be possible to achieve an angle of impact greater than 20° with an errant vehicle continuing on a straight path. However for masonry parapets, as for other types of parapet, angles of impact greater than 20° are not usually taken into account in design or assessment.

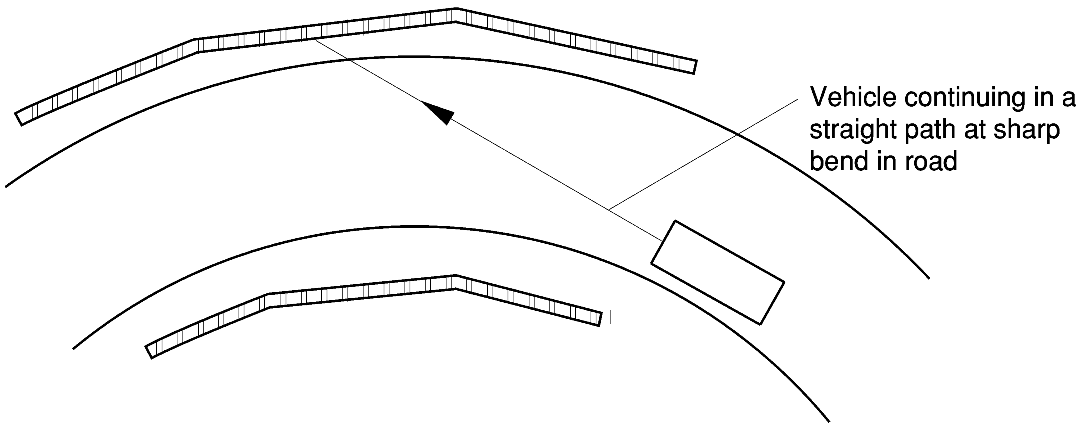


Figure B.1 — Impacts with curved parapets

B.2 Background to the low and normal levels of containment

The theoretical relationship between vehicle speed and the maximum angles of impact with roadside barriers was investigated by the Transport and Road Research Laboratory and the results published in TRRL Report No. 801 [2]. An errant vehicle was assumed to diverge from the road on a curved path and the maximum theoretical speed was determined, for a given radius of curvature, such that the vehicle would not slide or overturn due to centrifugal force. The relationship is shown diagrammatically in Figure B.2. The speeds of 80 km/h (50 mph) and 113 km/h (70 mph) and an angle of impact of 20° are compatible with the divergent widths for two lane and three lane carriageways having 1 m wide verges in front of roadside barriers. These therefore provide reasonable design speeds and impact angles for trunk road and motorway parapets which correspond with the low and normal levels of containment.

In Figure B.2:

- w is the divergent width in metres (m);
- m is the mass of vehicle in kilograms (kg);
- r is the radius of curvature in metres (m);
- α is the angle of incidence in degrees (°);
- g_n is the acceleration due to gravity (g_n = 9.81 m/s^2);
- μ is the coefficient of friction between vehicle tyres and road surface (assumed to be 0.7);
- v is the vehicle speed in metres per second (m/s).

The minimum angle of turn of the vehicle in degrees (°) is determined by equitorium of the lateral forces, using the following equations:

$$mg\mu = \frac{mv^2}{r}$$

From Figure B.2:

$$\cos\alpha = \frac{r-w}{r} = 1-\frac{w}{r}$$

$$\therefore \cos\alpha = 1-\frac{gw\mu}{v^2}$$

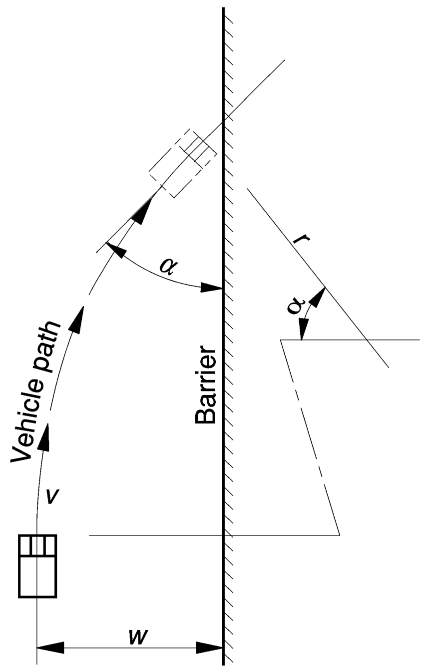


Figure B.2 — Relationship between divergent width and impact speed for impact angle of 20° (from TRRL Report No. 801)

B.3 Theoretical impact speed, straight road

Where the horizontal alignment of the road and parapet are substantially straight on plan, the speed for an impact angle of 20° to be used for the site specific level of containment should be determined by reference to Figure B.3.

NOTE The containment capacity requirement for a speed associated with a 20° angle of impact will always be greater than that required for a higher speed and shallower angle of impact determined in accordance with the method described.

B.4 Theoretical impact speed, effects of road curvature

The theoretical speed at which a vehicle can strike a parapet with an angle of impact of 20° will be increased for parapets on the outside edge of curved roads. In such situations the speed to be used for the site specific level of containment should be determined by reference to Figure B.4.

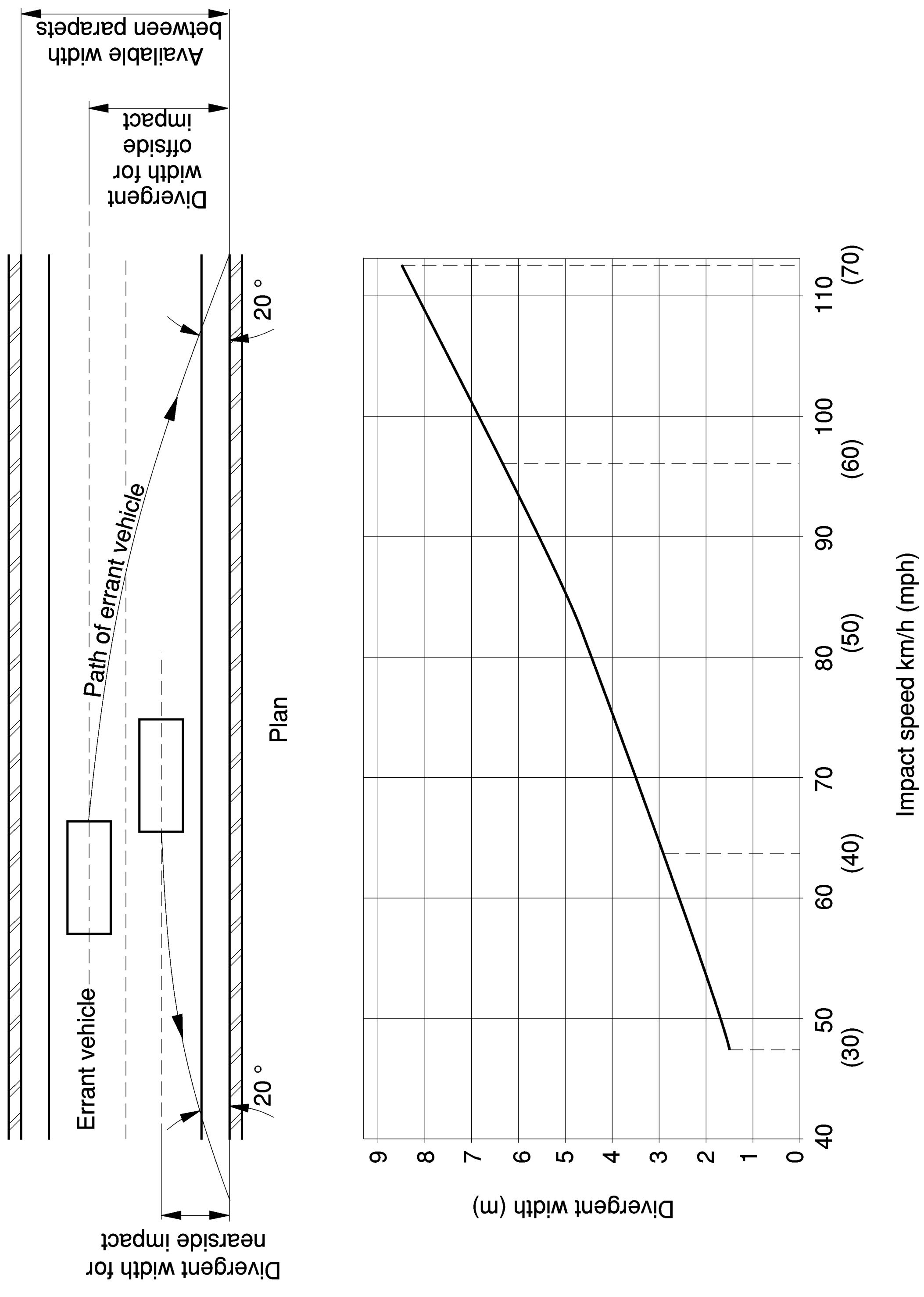


Figure B.3 — Chart relating divergent width and impact speed of errant vehicle

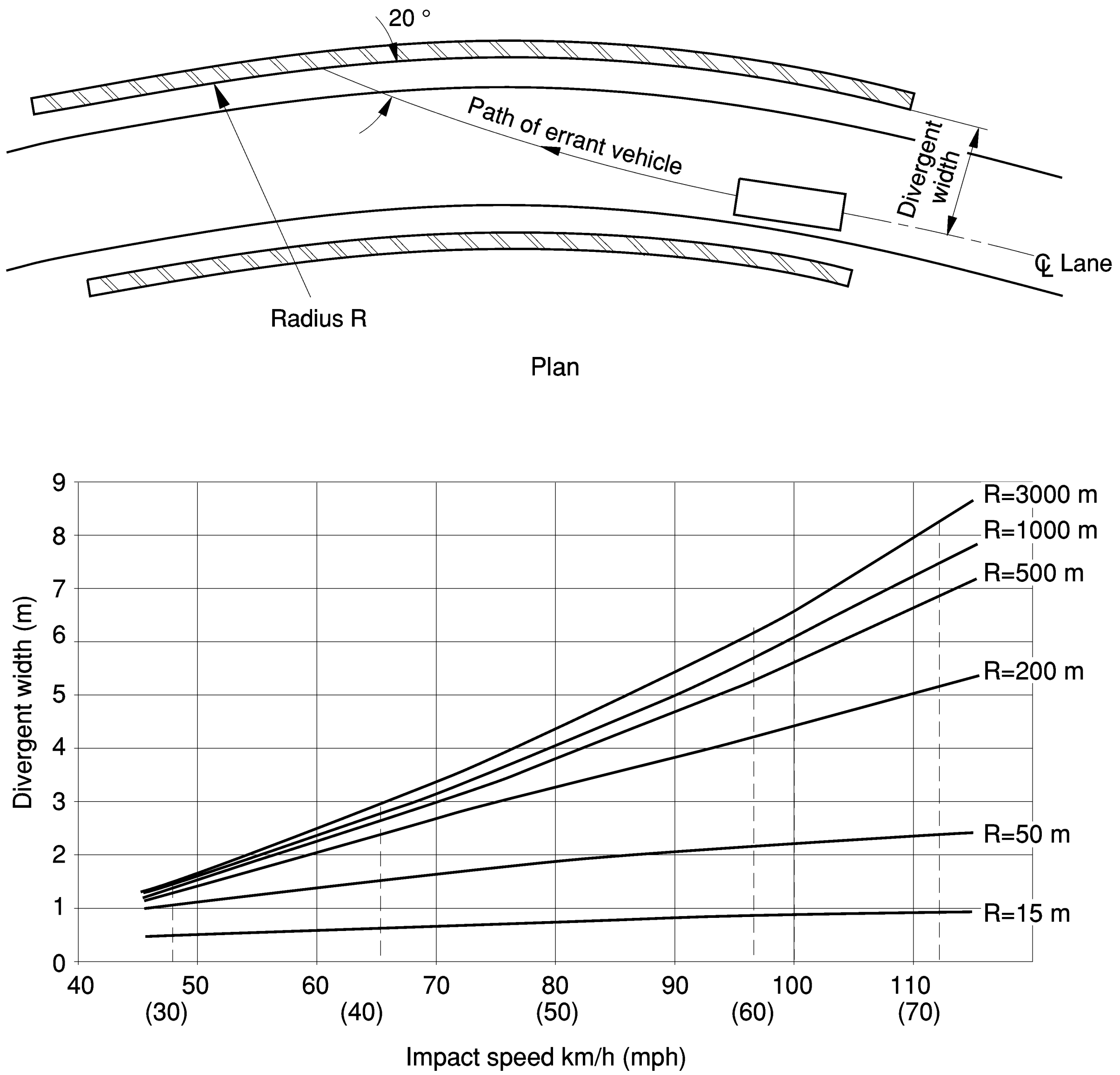


Figure B.4 — Chart relating divergent width and impact speed of errant vehicle for a curved layout

Annex C (informative)
Reinforced masonry parapets — Dimensions and reinforcement of prototype

Figure C.1 and Figure C.2 show details of a British Rail design for a high containment reinforced masonry parapet successfully tested at MIRA.

Annex D (informative)
Reinforced masonry parapets — Strain in vertical reinforcement

Figure D.1 shows a graph derived from results of a high level containment test on a reinforced masonry parapet by MIRA for British Rail depicting the strain in vertical reinforcement during impact of a vehicle.

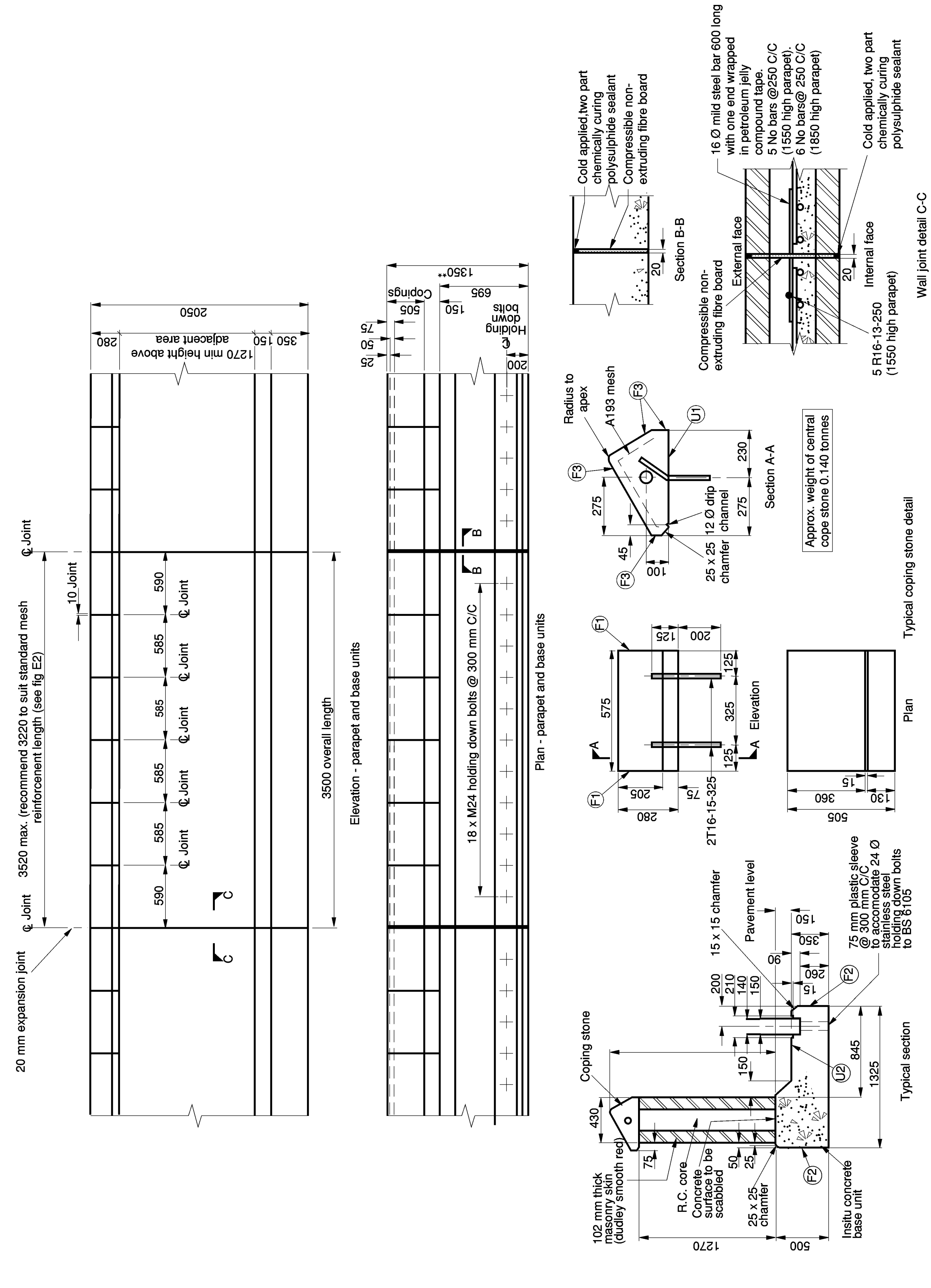
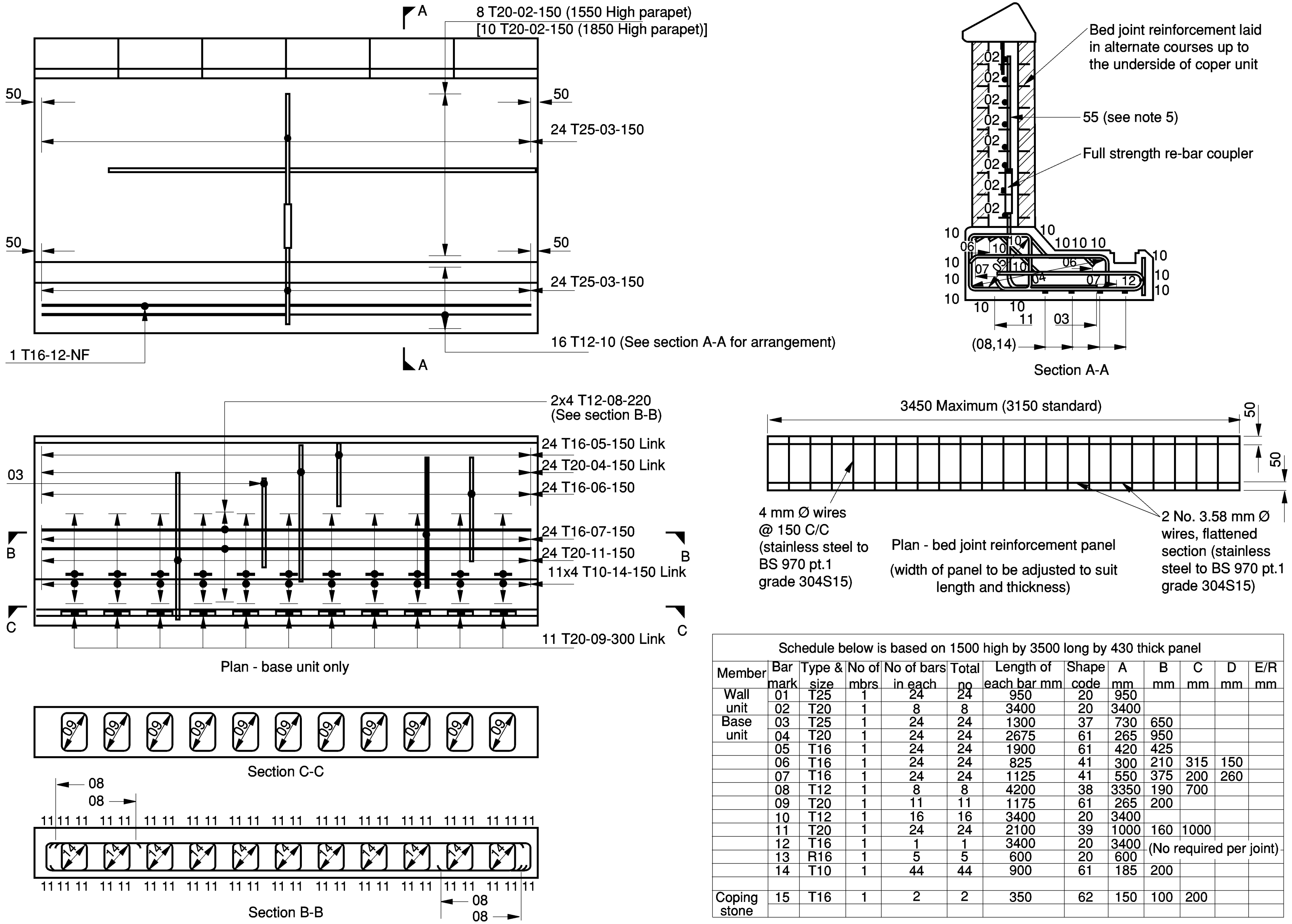


Figure C.1 — High containment bridge parapet



Schedule below is based on 1500 high by 3500 long by 430 thick panel

Member	Bar mark	Type & size	No of mbrs	No of bars in each	Total no	Length of each bar mm	Shape code	A mm	B mm	C mm	D mm	E/R mm
Wall unit	01	T25	1	24	24	950	20	950				
	02	T20	1	8	8	3400	20	3400				
Base unit	03	T25	1	24	24	1300	37	730	650			
	04	T20	1	24	24	2675	61	265	950			
	05	T16	1	24	24	1900	61	420	425			
	06	T16	1	24	24	825	41	300	210	315	150	
	07	T16	1	24	24	1125	41	550	375	200	260	
	08	T12	1	8	8	4200	38	3350	190	700		
	09	T20	1	11	11	1175	61	265	200			
	10	T12	1	16	16	3400	20	3400				
	11	T20	1	24	24	2100	39	1000	160	1000		
	12	T16	1	1	1	3400	20	3400	(No required per joint)			
	13	R16	1	5	5	600	20	600				
	14	T10	1	44	44	900	61	185	200			
Coping stone	15	T16	1	2	2	350	62	150	100	200		

Figure C.2 — High containment bridge parapet (reinforcement)

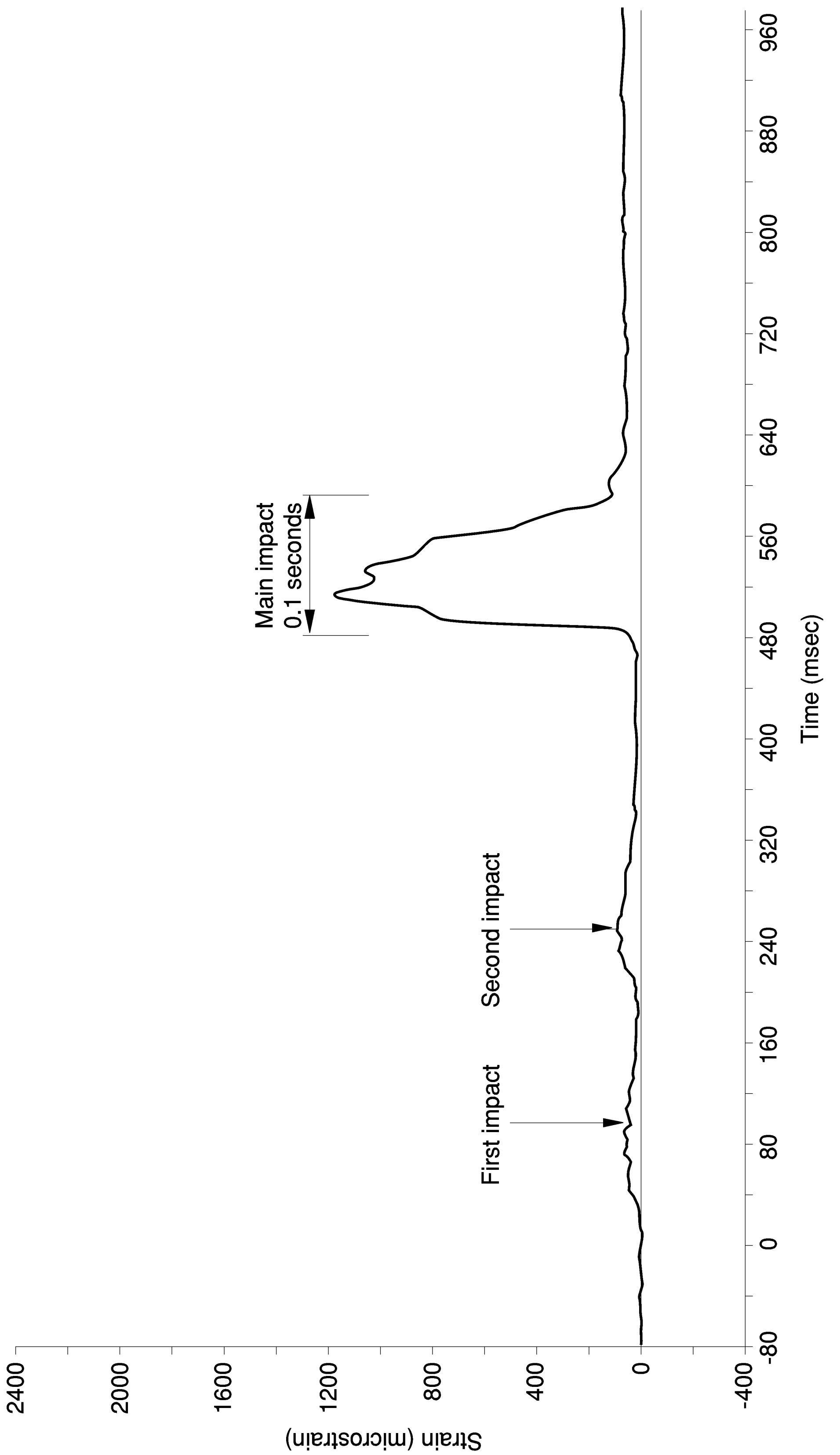


Figure D.1 — Strain versus time in vertical reinforcement

Annex E (normative) Determination of the characteristic initial shear strength of masonry

E.1 Principle

The initial shear strength of masonry is derived from the strength of small masonry specimens tested to destruction. The specimens are tested in shear under four-point load, with precompression perpendicular to the bed joints.

Four different failure modes are considered to give valid results. The initial shear strength is defined by the linear regression curve to zero normal stress.

E.2 Symbols

l_u	is the length of the masonry units, in mm.
l_s	is the length of the masonry specimen, in mm.
h_u	is the height of the masonry units, in mm.
h_1 and h_2	are the heights of cut units, in mm.
t_{bj}	is the thickness of the bed joint, in mm.
t_s	is the thickness of the steel loading places, in mm.
A_i	is the cross-sectional area of a specimen parallel to the bed joints, in mm^2.
F	is the representation of the force applied to the specimen.
$F_{i,max}$	is the maximum shear load, in N.
F_{pi}	is the precompressive force, in N.
e	is the distance between centre lines of the mortar bed and the loading roller.
f_{voi}	is the shear strength of an individual sample, in N/mm^2.
f_{pi}	is the compressive stress of an individual sample, in N/mm^2.
f_{vo}	is the mean initial shear strength, in N/mm^2.
f_{vok}	is the characteristic initial shear strength, in N/mm^2.
α	is the angle of internal friction, in degrees.
α_k	is the characteristic angle of internal friction, in degrees.

E.3 Materials

E.3.1 *Conditioning of the masonry units*

Masonry units shall be in the condition specified for the test.

The initial surface suction and moisture content by mass of representative samples of the units, at the time of constructing the specimens, shall be determined in accordance with BS 3921 and reported in the test report.

E.3.2 *Mortar*

The constituents of the mortar and the mixing of the mortar shall be as specified for the test and these shall be reported in the test report.

E.4 Apparatus

E.4.1 *Testing machines*, used to apply the shear loads and precompression, in accordance with the following requirements:

— maximum permissible repeatability of forces as percentage of indicated force = 2.0;

— maximum permissible mean error of forces as percentage of indicated force = ±2.0;

— maximum permissible error of zero force as percentage of maximum force of range = ±0.4.

The testing machine to apply the shear loads shall have adequate capacity but the scale used shall be such that the ultimate load on the specimen exceeds one-fifth of the full scale reading. The machine shall be provided with a load pacer or equivalent means to enable the load to be applied at the rate specified.

The apparatus shall be capable of measuring the cross-sectional area of the specimens to an accuracy of 1 %.

E.5 Preparation and curing of specimens

E.5.1 ***Preparation of masonry specimens***

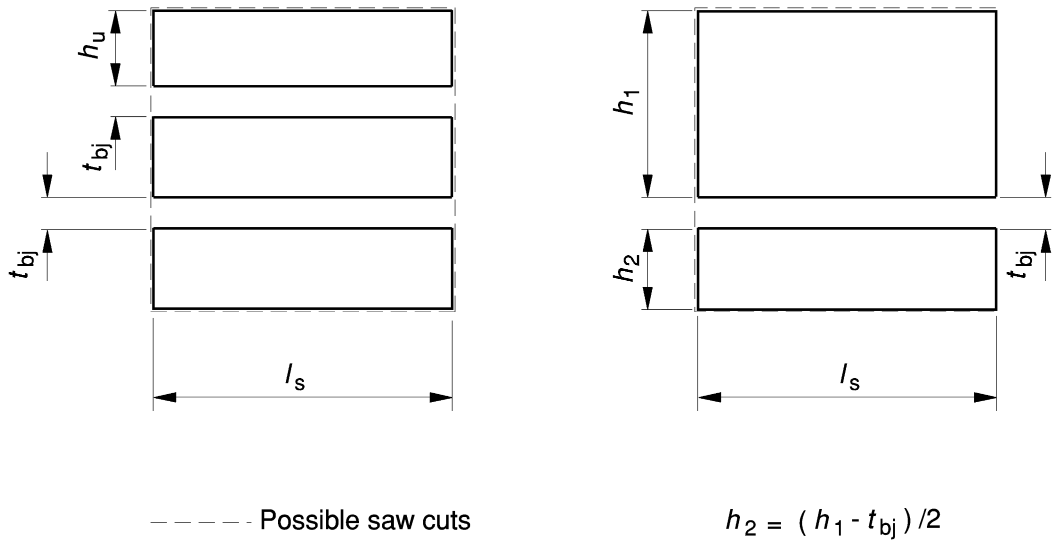
Prepare at least nine specimens with dimensions in accordance with Table E.1 and in accordance with Figure E.1 type A if $h_u \leq 200$ mm or with Figure E.1 type B if $h_u > 200$ mm.

Build the specimens within 30 min after completion of the conditioning of the units, using mortar mixed not more than 1 h beforehand unless the mortar is designed to be used over a more prolonged period.

The bearing surfaces of the masonry units shall be wiped clean of any adherent dust. The lower unit shall be laid on a clean level surface. The next unit should be laid such that a final mortar joint thickness of (10 ± 1) mm, or other thickness representative of the specified masonry, is attained. The masonry unit shall be checked for linear alignment and level using a set-square and spirit level. Excess mortar shall be struck off with a trowel. In the case of specimens according to Figure E.1 type A, the procedure for the second unit shall be repeated for the top unit.

Table E.1 — Dimensions and type of shear test specimens

Unit size		Specimen type and dimensions	
l_u mm	h_u mm	Type according to Figure E.1	Dimensions mm
≤300	≤200	A	$l_s = l_u$
>300	≤200	A	$l_s = 300$
≤300	>200	B	$h_1 = 200$ $l_s = l_u$
>300	>200	B	$h_1 = 200$ $l_s = 300$



Type A — $h_u \leq 200$ mm

Type B — $h_u > 200$ mm

Figure E.1 — Dimensions of shear test specimen

E.5.2 ***Curing and conditioning of the specimens***

Immediately after building, pre-compress each specimen, using a testing machine (**E.4.1**), by a uniformly distributed mass to give a vertical stress between 2.0×10^{-3} N/mm^2 and 5.0×10^{-3} N/mm^2 then cure the specimens and maintain them undisturbed until testing. For other than lime based mortars, prevent the test specimens from drying out during the curing period by close covering with polyethylene sheet and maintain the specimens undisturbed until testing unless otherwise specified. Test each specimen at an age of (28 ± 1) days, unless otherwise specified for lime based mortars.

E.6 Procedure

E.6.1 ***Placing the specimens in the testing machine***

Support the end units of each specimen in the test apparatus in accordance with Figure E.2 on pieces of steel at least 12 mm thick, using an appropriate capping, if necessary, to ensure good contact. The diameter of the roller bearings shall be 12 mm.

Apply the load through a ball hinge placed in the centre of the top central steel plate.

E.6.2 ***Loading***

Test at least three specimens at each of three precompression loads. Use precompression loads F_{pi} that give precompression stresses of approximately 0.2 N/mm^2, 0.6 N/mm^2 and 1.0 N/mm^2. The precompression load shall be kept within ±2 % of the initial value. The precompression shall be applied using a testing machine (**E.4.1**) in accordance with Figure E.3.

The stiffness of the loading beams that are used for the precompression shall be sufficient to ensure an equally distributed stress. If the plattens of the machine are shorter than the length of the specimen l_u, loading beams shall have a length equal to the length of the specimen l_u and a depth greater than or equal to the length beyond the edge of the platten.

Increase the shear stress at a rate between 0.1 N/(mm^2·min) and 0.4 N/(mm^2·min) until the sample fails.

E.6.3 ***Measurements and observations***

Record the following:

a) the age of the non-autoclaved concrete units;

b) the cross-sectional area A_i of the specimens parallel to the shear force with an accuracy of 1 %;

c) the maximum load $F_{i,max}$ applied before the sample failed;

d) the precompression load F_{pi};

e) the type of failure (see Figure E.4).

E.6.4 ***Replications***

If failure is by shear failure in the unit parallel with the bed joint (see type 3 in Figure E.4), or crushing or splitting of the units (see type 4 in Figure E.4), then either further specimens shall be tested until three shear failures of the type 1 or 2 (see Figure E.4) for each precompression level have been achieved or alternatively the result shall be used as a lower bound to the shear strength for each precompression level. Lower bound results should not be used in the evaluation of results in **E.8**. If necessary, an alternative precompression shall be applied so that sufficient failures are achieved.

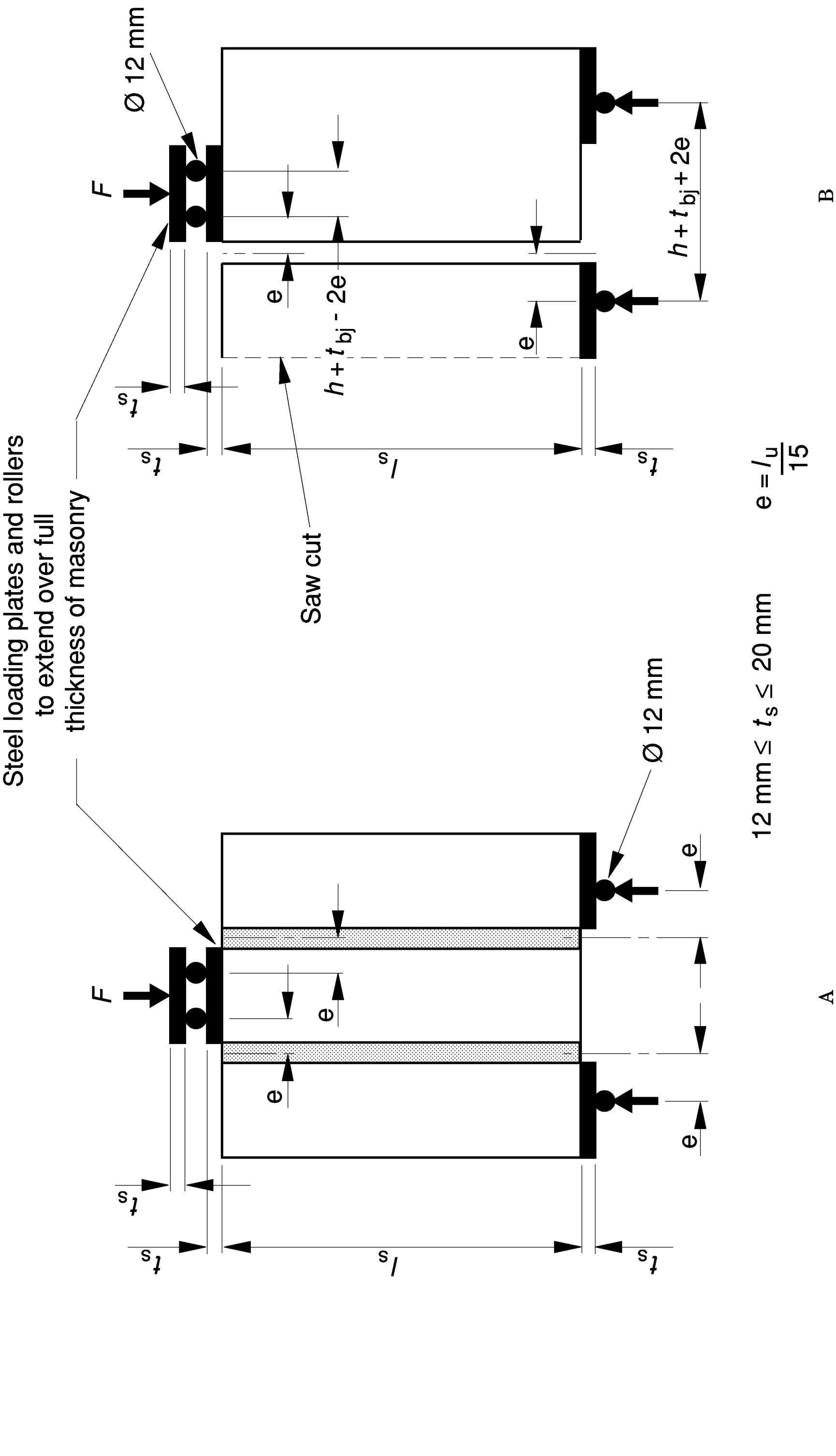


Figure E.2 — Loading of shear test specimen

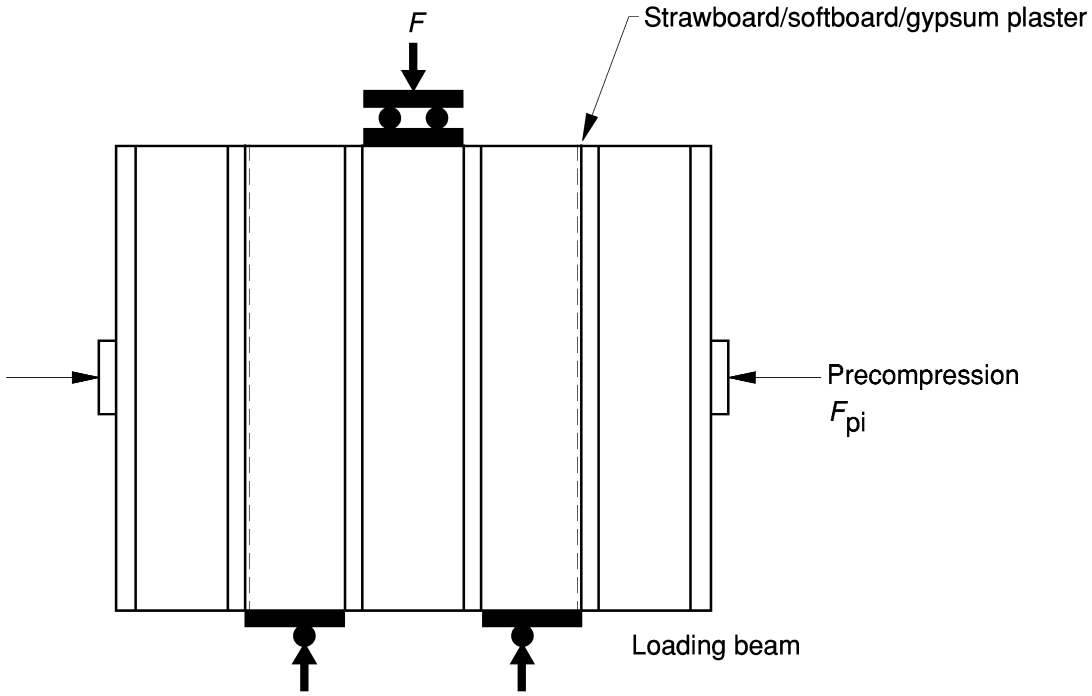
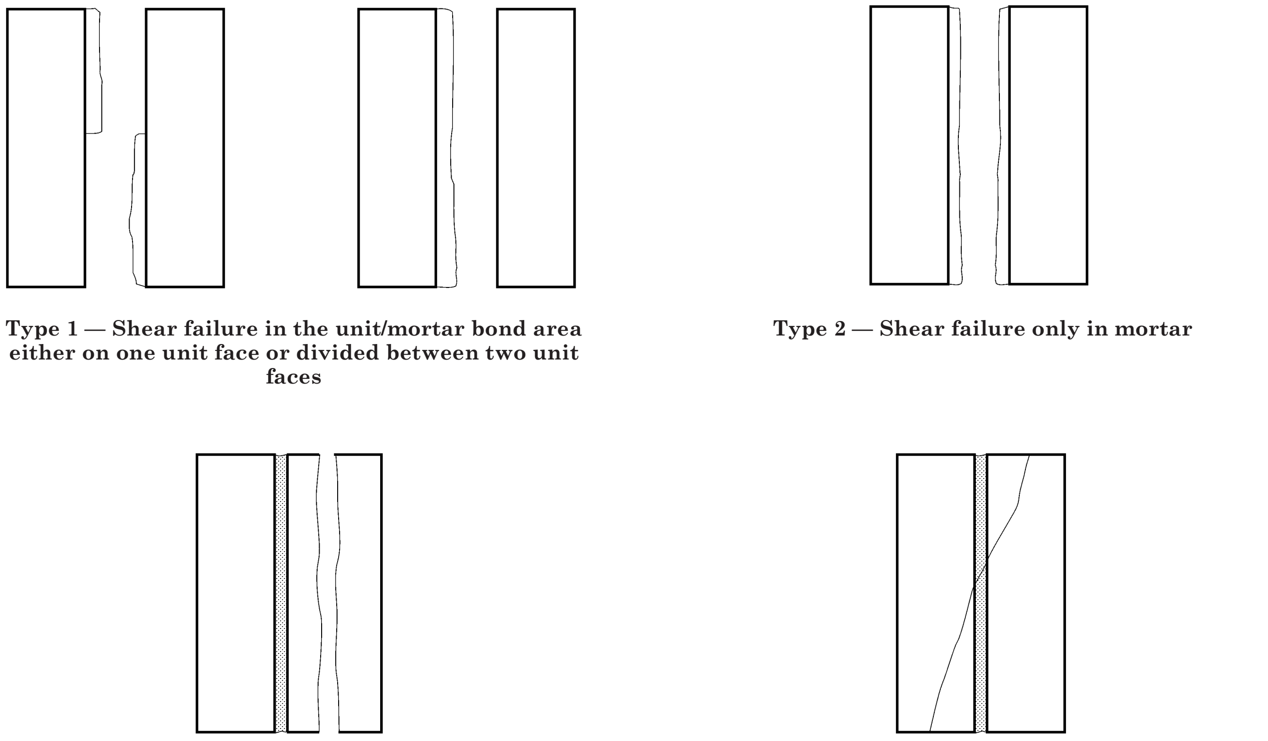


Figure E.3 — Precompression load



Type 1 — Shear failure in the unit/mortar bond area either on one unit face or divided between two unit faces

Type 2 — Shear failure only in mortar

Type 3 — Shear failure in the unit

Type 4 — Crushing or splitting failure in the units

Figure E.4 — Types of failure

E.7 Calculations

For each specimen calculate the shear strength f_{voi} and the precompression stress f_{pi} to the nearest 0.1 N/mm² using the following formulae:

$f_{voi} = F_{i,max}/2A_i$

$f_{pi} = F_{pi}/A_i$

E.8 Evaluation of results

Plot a graph of f_{voi} against the normal compressive stress f_{pi}, as shown in Figure E.5. Plot the line determined from a linear regression of the points. Record the mean initial shear strength f_{vo} at zero normal stress to the nearest 0.01 N/mm² from the intercept of the line with the vertical axis, and the angle of internal friction to the nearest degree, from the slope of the line.

The characteristic value of the initial shear strength is f_{vok} where $f_{vok} = 0.8f_{vo}$ and the characteristic angle of internal friction from $\tan \alpha_k = 0.8 \tan \alpha$.

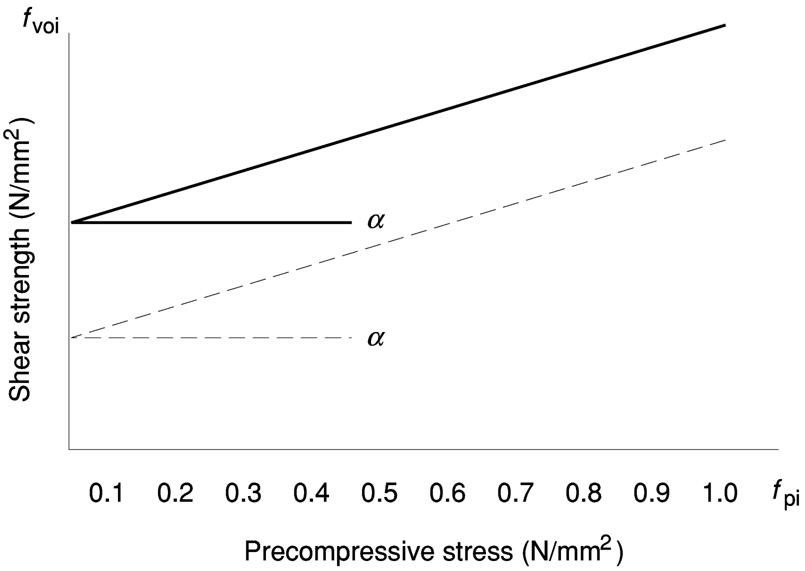


Figure E.5 — Shear strength and angle of internal friction

E.9 Test report

The test report shall contain the following information:

a) name of the testing laboratory;

b) number and description of the specimens;

c) date of building the specimens;

d) curing conditions (e.g. time, temperature, humidity);

e) initial surface suctions and moisture contents of representative samples of the masonry units at the time of building the specimens;

f) date of testing the specimens;

g) description of the specimens including dimensions;

h) age and condition of non-autoclaved concrete units at the time of testing the specimens;

i) type of mortar and the mixing procedure of the mortar;

j) maximum load reached by the test specimens;

k) individual values for the shear strength and precompression stress for each specimen in N/mm^2 to the nearest 0.01 N/mm^2 and the description of the failure mechanism of each specimen;

l) mean and characteristic initial shear strength in N/mm^2 to the nearest 0.01 N/mm^2;

m) angle of internal friction;

n) remarks, if any.

Annex F (informative)
Background to the derivation of the containment charts for unreinforced masonry parapets

In July 1993, at the initiative of the Bridges Group of the UK County Surveyors' Society, a research project was commenced with the aim of developing analytical methods of determining the vehicle containment capacity of unreinforced masonry highway parapets. The consultants Parkman were awarded the commission for the research project and they appointed the University of Liverpool and the Motor Industry Research Association to assist them. The research reports, which were contained in three volumes [3], [4] and [5] were completed in the spring of 1995 and form the basis of the requirements for unreinforced masonry parapets in this part of BS 6779.

Analytical methods for predicting the effects of vehicle impacts on unreinforced masonry parapets were developed at the University of Liverpool using the OASYS DYNA-3D [6] computer program, in conjunction with laboratory testing. DYNA-3D is a highly sophisticated program capable of carrying out a dynamic analysis of impacts utilizing three dimensional finite element modelling. The program cannot readily be used by a practising bridge engineer and specialist advice would normally be required. The predictions of the effects of vehicle impacts developed by Parkman and the University of Liverpool covered parapets of brickwork and stonework in ashlar, random rubble and drystone forms of construction. Six full scale vehicle impact tests were subsequently carried out at the Motor Industry Research Association which confirmed the predicted behaviour.

Following the completion of the full scale tests, the DYNA-3D program was then used to develop the containment charts incorporating various conservative assumptions, for example:

a) limiting the penetration of the vehicle into the parapet to restrict the risk of major damage to the vehicle and the risk of serious injury to the occupants;

b) assuming only frictional resistance is present in the parapet at the level of the adjoining paved surface, to allow for possible deterioration in the bedding mortar at this level; and

c) applying a partial safety factor (γ_m) of 1.6 to the characteristic tensile and shear strengths at the mortar to brick or stone interface to allow for possible variations in materials or workmanship.

Test results for dynamic shear strength have shown significant and fairly constant percentage increases at a given strain rate compared to static values. These enhancements in dynamic shear strength have been taken into account in the derivation of the containment charts. Similar increases in tensile strength may also occur under dynamic loading but since the containment capacity of a parapet is relatively insensitive to the value of the tensile strength, static values have been assumed. For simplicity the application of each containment chart is related to specified static characteristic values of shear strength.

Annex G (informative)
Movement joints in unreinforced masonry parapets

It is extremely difficult, if not impossible, to predict with any degree of certainty the expansion or contraction movement that will occur in a masonry parapet. The movement is a complex combination of movements caused by such factors as temperature and moisture variations and the degree of restraint to movement. Parapets constructed with clay bricks will be subject to long term expansion movement as water is absorbed from the atmosphere. Concrete bricks will be subject to long term shrinkage. Thicker walls will be subject to smaller movement than thin walls. Any estimation of movement has to rely to a great extent on experience and engineering judgement.

Reference to BS 5628-3:1985, **20.3.2**, suggests that the spacing of movement joints in parapets on buildings should never exceed 15 m, unless bed joint reinforcement is used. The parapets on bridges will usually be much thicker than those on buildings and this will reduce the amount of movement. The structure supporting highway parapets will often be without provision for movement, (e.g. masonry arch bridges), and will to some extent move in harmony with the parapet, thus reducing the need for movement joints in the parapet. Traditionally masonry parapets have performed satisfactorily when constructed with no movement joints and in very long lengths. However, it should be recognized that such parapets may have been built using weak hydraulic lime mortars which are able to accommodate movement better than modern mortars, and with non-kiln fresh bricks.

Suggested spacings of movement joints in clay brickwork and concrete masonry are given in Table G.1. These may be modified at the designer's discretion, in the light of experience and manufacturers information on particular masonry units. For natural stone masonry in limestone and marble the movements may be assumed to be similar to those for clay brickwork, and the movements in granite, sandstone and slate masonry may be assumed to be similar to those for concrete masonry. If necessary, detailed advice should be sought from the masonry supplier or from specialist organizations such as the Building Research Establishment [7].

Table G.1 — Suggested spacing of movement joints in unreinforced masonry parapets

Masonry type	No bed joint reinforcement	Bed joint reinforcement[a]	Bed joint reinforcement[b]
Clay brickwork	10 m	18 m	24 m
Concrete masonry (brickwork and blockwork)	6 m	10 m	15 m

[a] Bed joint reinforcement at maximum 450 mm centres vertically and total cross-sectional area of longitudinal bars not less than 0.015 % of gross masonry cross-sectional area.

[b] Bed joint reinforcement at maximum 225 mm centres vertically and total cross-sectional area of longitudinal bars not less than 0.03 % of gross masonry cross-sectional area.

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