

This item was submitted to Loughborough's Institutional Repository (<https://dspace.lboro.ac.uk/>) by the author and is made available under the following Creative Commons Licence conditions.

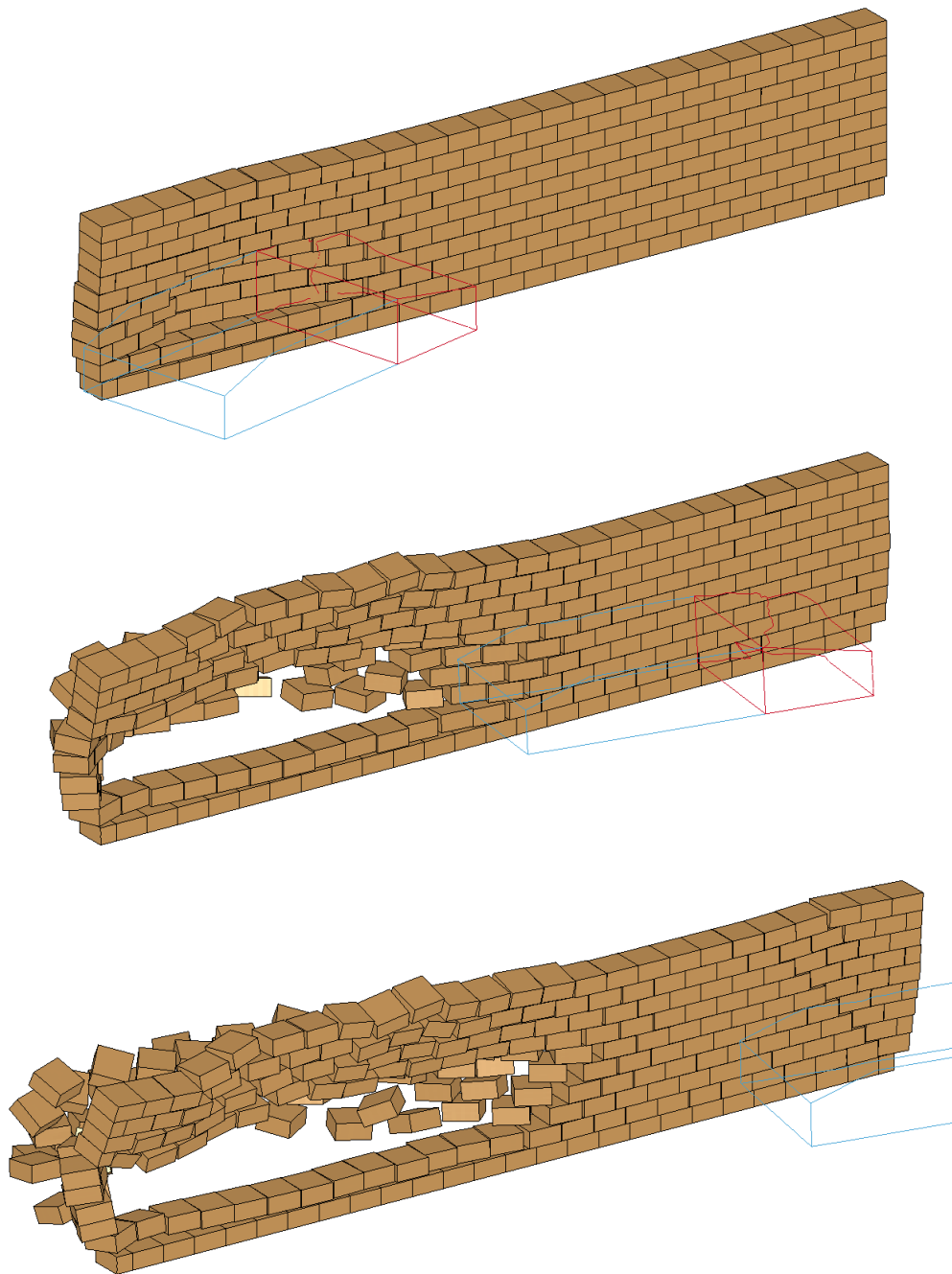


For the full text of this licence, please go to:
<http://creativecommons.org/licenses/by-nc-nd/2.5/>



Department
for Transport

Guidance on the Design, Assessment and Strengthening of Masonry Parapets on Highway Structures



Department for Transport
Great Minster House
33 Horseferry Road
London SW1P 4DR
Telephone 0300 330 3000
Website www.dft.gov.uk

© Queen's Printer and Controller of Her Majesty's Stationery Office, 2012, except where otherwise stated.

Copyright in the typographical arrangement rests with the Crown.

You may re-use this information (not including logos or third-party material) free of charge in any format or medium, under the terms of the Open Government Licence.

To view this licence, visit www.nationalarchives.gov.uk/doc/open-government-licence/ or write to the Information Policy Team, The National Archives, Kew, London TW9 4DU, or e-mail: psi@nationalarchives.gsi.gov.uk.

Where we have identified any third-party copyright information you will need to obtain permission from the copyright holders concerned.

Disclaimer

Although this report was commissioned by the Department for Transport (DfT), the findings and recommendations are those of the authors and do not necessarily represent the views of the DfT. The information or guidance in this document (including third party information, products and services), is provided by DfT on an 'as is' basis, without any representation or endorsement made and without warranty of any kind whether express or implied. The authors and publisher shall have neither liability nor responsibility to any person or entity with respect to any loss or damage arising from this document's use.

Table of Contents

Summary	5
Acknowledgements	6
Terms and Definitions	8
1 Introduction	10
2 Management of Parapets	12
3 Unreinforced Masonry Parapets	18
4 Reinforced Masonry Parapets	28
5 Condition Appraisal	32
6 Risk Assessment	36
Appendix A – Numerical Modelling	45
Appendix B – Basic Impact Mechanics	55
Appendix C – Relationship with BS EN 1317	59
Appendix D – Movement Joints in Unreinforced Masonry Parapets	63
Appendix E – Containment of Drystone Parapets	65
Appendix F – Retrofit Reinforcement: Sample Calculation	67
Appendix G – Calculation of Risk	69
Appendix H – Comparison with other risk assessment approaches for bridge parapets.	77
Appendix I – Risk Assessment Flowcharts	83
Appendix J – Sample Risk Assessment Calculations	85
References	92

This page is intentionally blank.

Summary

Masonry parapets are designed to provide protection for road users. This guidance document is designed to bring up to date previous advice on the design, assessment and strengthening of masonry parapets, drawing together guidance previously available in BS 6779:1999 Part 4 and in research papers, and bringing the terminology used in line with that used in BS EN 1317-2:1998 and BS EN 1996-1-1:2005.

Acknowledgements

This guidance document has been produced at the request of the Bridge Owners' Forum. The document was prepared by AECOM in collaboration with the University of Sheffield.

Authors

John Webb (AECOM)

Matthew Gilbert (University of Sheffield)

Amrit Ghose (AECOM)

Christian Christodoulou (AECOM)

Steering group

The research project was guided by a steering group which comprised:

Brian Bell (Network Rail) - Chair

Andy Bailey (Department for Transport)

Steve Berry (Department for Transport)

Graham Bessant (London Underground)

Rod Howe (Canal and River Trust (formerly British Waterways))

Andrew Oldland (Department for Transport)

Brian Poole (ADEPT / Durham County Council)

Tudor Roberts (Welsh Government)

Terms and Definitions

Terms and Definitions

“Accident Severity” – the degree to which there is personal injury.

“Ashlar stone parapet” – a Masonry Parapet which consists of stone blocks laid in courses with thin joints. The facing may occasionally be clad with another material to improve visual appearance. The blocks will generally extend between the inner and outer faces of the wall.

“Brickwork parapet” – a Masonry Parapet consisting of brick units laid in a specific pattern (e.g. ‘English Garden Wall’ bond) with mortared joints.

“Casualty” – a person injured as a result of an accident.

“Containment” – the ability to prevent a breach of the system when impacted under specified conditions.

“Dry stone parapet” – a Masonry Parapet which consists of multi-sized natural stone units constructed predominantly without mortar joints. The stones may be coursed or un-coursed and there are likely to be occasional through stones inter-linking the two faces of the wall.

“Errant vehicle” – a vehicle which is out of the control of the driver.

“Fatal accident” – an accident in which one or more persons is killed or dies within 30 days of the accident.

“Large Goods Vehicle (LGV)” – a vehicle over 3.5 tonnes in weight.

“Masonry Parapet” – a parapet constructed of brickwork or stone or concrete blocks, with or without mortar. Masonry parapets may be constructed using a variety of materials and may be Unreinforced or Reinforced.

“Parapet” – a safety barrier installed on the edge of a bridge or on a retaining wall or similar structure where there is a vertical drop and which may include additional protection and restraint for pedestrians and other road users.

“Random rubble stone parapet” – a Masonry Parapet which consists of multi-sized natural stone units with thick mortared joints. The stones may be coursed or un-coursed. In general this kind of parapet will have a mortared core with occasional stones passing through the core.

“Reinforced masonry parapet” – a Masonry Parapet with additional reinforcing elements incorporated.

“Road restraint systems” – general name for vehicle restraint system and pedestrian restraint system used on the road.

“Safety Fence” – a flexible metal safety barrier.

“Severity of an accident” – the severity of the most severely injured casualty (fatal, serious or slight). Of a casualty: killed, seriously injured or slightly injured.

“Unreinforced masonry parapet” - a Masonry Parapet which does not incorporate reinforcement.

Introduction

1 Introduction

Masonry parapets were in most cases originally constructed to protect pedestrians and livestock from precipitous drops but are now frequently called upon to contain errant vehicles.

To better understand the mode of behaviour of masonry parapets when subjected to vehicle impacts, research was initiated in the 1990s by the County Surveyors Society (now ADEPT), leading to a County Surveyors Society guidance document [1] and subsequently to BS 6779:1999 Part 4 [2]. Following the County Surveyors Society initiated research, academic research undertaken at the Universities of Liverpool, Sheffield and Teesside was undertaken. This research led to the development of improved numerical models and also indicated the types of upgrading strategies that would be most beneficial. The present guidance document incorporates these findings.

The terminology used in the present document has also been updated so as to be consistent with that used in the relevant Euro norms (e.g. BS EN 1317:1998 Part 2 [3]).

Masonry parapets have generally been built directly onto supporting structural elements, without any special provision for anchorage. Individual blocks or sections of masonry may be dislodged during a vehicle impact event. An assessment of the possible injury or damage risk from ejected masonry can be used to determine the acceptability of the use of an unreinforced masonry parapet at a particular site. A recommended risk assessment methodology is provided in Chapter 6.

Vehicle containment levels are related to defined vehicle impacts. For unreinforced masonry parapets only containment levels N1 and N2 (as defined in BS EN 1317:1998 Part 2) are considered explicitly in this document since higher levels of containment cannot generally be achieved.

Key objectives are to ensure parapets are capable of:

- providing specified levels of containment to limit the penetration by errant vehicles, and reducing the risk of such vehicles overtopping the parapet or overturning;
- protecting other highway users by either redirecting vehicles on to a path close to the line of the parapet, or arresting the vehicle motion with acceptable deceleration forces;
- protecting those in the vicinity of a parapet by ensuring any masonry ejected does not lead to disproportionate consequences.

It is possible to provide designs that meet the above objectives. In unreinforced masonry parapets much of the momentum from an impacting vehicle is transferred into the masonry, with the extent of masonry involved largely governed by the geometry of the wall and the unit-mortar bond strength (see Chapter 3). The criteria for unreinforced masonry parapets are, therefore, based on the materials of construction and dimensions of the parapets.

Due to the very diverse nature of masonry parapets it is not normally practicable to undertake conventional acceptance testing, as would be common for proprietary steel or reinforced concrete designs. The present guidance document is therefore designed to provide a practical alternative to acceptance testing.

In producing the parapet performance charts contained in this guidance document many sophisticated non-linear finite element simulations have been performed, allowing the performance of an impacting vehicle and the masonry to be characterised for a broad range of parameters.

Management of Parapets

2 Management of Parapets

2.1 Asset management

Asset management issues have been extensively treated in other guidance documents and hence are not considered here in detail. Useful reference documents that are available at the time of writing include:

CIRIA C656 [4]: Masonry arch bridges: condition appraisal and remedial treatment. Although written specifically for masonry arch bridges, this includes much about asset management, maintenance management, and environmental considerations.

CIRIA C676 [5]: Drystone retaining walls and their modifications – condition appraisal and remedial treatment. This includes guidelines on asset management and whole life cost methods.

PAS 55-1:2008 Asset management [6]. Part 1 - Specification for the optimised management of physical infrastructure assets; Part 2 - Guidelines for the application of Part 1. Standardisation of asset management as a specification, with information on implementing asset management distilled into key requirements.

Code of Practice on Transport Infrastructure Assets [7]: Guidance to Support Asset Management, Financial Management and Reporting (2010): This Code of Practice from The Chartered Institute of Public Finance and Accounting (CIPFA) provides guidance on the development and use of financial information to support asset management, financial management and reporting of local highways infrastructure assets.

The UK Roads Liaison Group [8] has published four documents produced by the UK Roads Board, giving guidance on asset management; the guidance comprises four documents forming a suite which provides a good overview of asset management. The four documents are available from: <http://www.ukroadsliasongroup.org> and include:

- Highway Asset Management Quick Start Guidance Note – getting started
- Highway Asset Management Quick Start Guidance Note – risk assessment
- Highway Asset Management Quick Start Guidance Note – levels of service
- Highway Asset Management Quick Start Guidance Note – life cycle planning

Any practitioner dealing with any aspect of masonry parapets will also need to refer to the relevant local maintenance organisation or responsible body, who are likely to have their own internal system.

2.2 Environmental Considerations

Guidance can be found in the CIRIA C656, Masonry Arch Bridges: condition appraisal and remedial treatment and C676, Drystone walls.

The environmental aspects listed in CIRIA C676 are:

- Air pollution
- Noise pollution
- Water pollution
- Soil and waste
- Discharge of water from any drainage system associated with the wall.
- Visual effects
- Land-use
- Flora and Fauna, particularly rare and endangered species
- Consumption of limited resources (materials and energy)

2.3 Planning Considerations

Cultural heritage, landscape and ecological issues can all influence choice of materials and methods used in parapet construction, as indicated in Tables 1, 2 and 3 respectively.

Note that statutory organisations are marked with an asterisk (*).

In addition to the Primary Legislations listed the principle of “Permitted Development” means that some work to bridges will not be prevented. Reference documents for this include the following:

- England and Wales: “Improving Permitted Development” – Department for Communities and Local Government.
- Scotland: The Town and Country Planning (General Permitted Development) (Scotland) Order 1992.
- Northern Ireland: The Planning (Environmental Impact Assessment) Regulations (Northern Ireland) 1999 (S.R.1999 No. 73).

Table 1 – Cultural heritage planning considerations: legislation, guidance available and design implications

Primary Legislation	Guidance/Polices	Designation	Typical Consultees and Stakeholders	Typical Requirements/Design Implications	Current Published Guidance
<ul style="list-style-type: none"> • Ancient Monuments and Archaeological Areas Act 1979 (as amended by the National Heritage Act 1983) (England and Wales) • Historic Environment (Scotland) (Amendment) Act 2011 • Planning (Listed Buildings and Conservation Areas) Act 1990 (England and Wales) • Planning (Listed Buildings and Conservation Areas) (Scotland) Act 1997 • Planning Act (Northern Ireland) 2011 	<ul style="list-style-type: none"> • Planning Policy Statement 5: Planning for the Historic Environment (PPS5) (England) • Planning Policy Statement 6: Planning, Archaeology and the Built Heritage (Northern Ireland) • Scottish Planning Policy: Historic Environment (Paragraphs 110 to 124) • Scottish Historic Environment Policy (Particularly Annexes 1, 2 & 7) • Planning Policy Wales (Edition 4, February 2011) (Particularly Chapter 6) • Various Local Plans 	<ul style="list-style-type: none"> • Scheduled Monument • Listed Building • Locally Listed Building • Within Conservation Area • Undesignated (Although may still be of historic significance) 	<ul style="list-style-type: none"> • English Heritage* • Historic Scotland* • NIEA* • CADW* • Local Archaeological Planning Officer • Local Government Conservation Officer • Local history/archaeology society • Society for the Protection of Ancient Buildings (SPAB) • Institute of Historic Building Conservation 	<ul style="list-style-type: none"> • Scheduled Monument Consent • Listed Building Consent • Conservation Area Consent • Planning Conditions e.g. sympathetic building design, building recording, use of specific materials/techniques, appropriate design conditions • Works nearby any designated site (e.g. Scheduled Monument, Listed Building, Site within a Conservation Area), the setting may have to be considered • Monitoring during any construction phase 	<ul style="list-style-type: none"> • DMRB Sub Topic Guidance: Vol 11 Part 2 HA 208/07 • English Heritage (2002) Building Regulations and Historic Buildings) • English Heritage (2004) Transport and the Historic Environment • English Heritage (2008) Conservation Principles) • NIEA Technical Notes • Institute for Archaeologists Standards and Guidance for the archaeological recording of standing buildings or structures

Table 2 – Landscape planning considerations: legislation, guidance available and design implications

Primary Legislation	Guidance/Polices	Designation	Typical Consultees and Stakeholders	Typical Requirements/Design Implications	Current Published Guidance
<ul style="list-style-type: none"> • National Heritage Act 1983 • Planning Policy Statement 6 Planning (NI) Order • National Parks and Access to the Countryside Act 1949 • National Parks (Scotland) Act 2000 • Natural Environment and Rural Communities Act 2006 • Countryside Act 1968 • Countryside and Rights of Way (CRoW) Act 2000 • PPS 7 Sustainable Development in Rural Areas • Nature Conservation and Amenity Lands Order (NI) 1985 (NCALO) • Environment Act 1995 • Historic Environment (Amendment) (Scotland) Act 2011 	<ul style="list-style-type: none"> • Planning Policy Statement 5: Planning for the Historic Environment (PPS5) (England) • Planning Policy Wales (Edition 4, February 2011) • Various Regional & Local Development Plans • Landscape Character Assessments may contain information on landscape sensitivity to change, landscape management and guidance for new developments • Statutory AONB Management Plan • Statutory National Park Plan 	<ul style="list-style-type: none"> • Registered Parks & Gardens of Historic Interest (England) • Gardens and Designed Landscapes (Scotland) • Register of Landscapes of Historic Interest (Wales) • Historic Parks, Gardens & Demesnes (N. Ireland) • Areas of Outstanding Natural Beauty (England, Wales, N. Ireland) • National Parks (UK) 	<ul style="list-style-type: none"> • English Heritage* • Historic Scotland* • CADW* • CCW* • Northern Ireland Environment Agency / Department of Environment* • Local Authority landscape officer* • SNH* • Natural England • Joint Action Committee (AONB) • National Parks Authority* 	<ul style="list-style-type: none"> • Planning Conditions • Works within or affecting the setting of a designated site may be subject to stricter planning controls (e.g. AONB, National Park) • Works may have to respect local landscape / townscape character or historic character e.g. sympathetic design, use of specific materials 	<ul style="list-style-type: none"> • English Heritage Registered Parks & Gardens • Historic Scotland Gardens & Designed Landscapes • CADW Landscapes of Historic Interest • NI Department of Environment Historic Parks, Gardens & Demesnes • AONB (England & Wales) • AONB (N. Ireland) • National Parks • Historic Landscape Characterisation (English Heritage) • Townscape Character (English Heritage) • Masterplanning & Design (English Heritage) • Landscape Character • SNH • N. Ireland Dept of Environment • Natural England • CCW.

Table 3 – Ecological planning considerations: legislation, guidance available and design implications

Primary & Other Legislation	Guidance/Polices	Designation	Typical Consultees and Stakeholders	Typical Requirements/Design Implications	Current Published Guidance
<ul style="list-style-type: none"> • Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora (The Habitats Directive, as amended) • Council Directive 79/409/EEC on the Conservation Of Wild Birds (The Birds Directive) • Wildlife and Countryside Act, 1981, as amended • Countryside & Rights of Way Act 2000 (CRoW) Act • Protection of Badgers Act 1992 • Convention on Biological Diversity • Natural Environment and Rural Communities 2006 (NERC Act 2006) 	<ul style="list-style-type: none"> • Planning Policy Statement 9: Biodiversity and Geological Conservation (PP9) (England). • Local Development Plans (LDP, LDD, LDF) • Scottish Planning Policy: (Paragraphs 134-148) • Welsh Government, Technical Advice Note 5, Nature Conservation and Planning (2009) • The Environmental Permitting Regulations (England and Wales) 2010 	<ul style="list-style-type: none"> • Ramsar • Special Protection Area (SPA) • Special Area of Conservation (SAC) • Site of Special Scientific Interest (SSSI) • National Nature Reserve (NNR) • Local Nature Reserve (LNR) • Site of Biological Interest (SBI) • Site of Interest for Nature Conservation (SINC) • County Wildlife Site (CWS) • Wildlife Trust Reserve • Ancient Woodland Inventory • RSPB Reserve • Important Bird Area 	<ul style="list-style-type: none"> • Natural England • Countryside Council for Wales (CCW) • Scottish Natural Heritage (SNH) • Scottish Environment Protection Agency (SEPA) • Local Council • Environment Agency (EA) 	<ul style="list-style-type: none"> • Protected species surveys, ecological site walkover/Phase 1 Habitat survey. • Protected Species Licences (from Natural England, CCW, SNH). • Test of Significance (TOS), Appropriate Assessment (AA) regarding works which could potentially affect Internationally Designated Sites. This would involve consultation with Natural England/CCW/SNH. • Consent to work within a SSSI (Natural England/CCW/SNH). • EA Permits/Licences, for example a 'waste management licence'. • Council Consent to work within a locally designated site. • Appropriate timing of works/ecological watching brief/mitigation measures. 	<ul style="list-style-type: none"> • Joint Nature Conservation Committee (JNCC) • Bat Conservation Trust (BCT) Guidance in relation to bats and bridges. • Natural England Wildlife Management and Licensing. • CCW • SNH • EA Permissions

Unreinforced Masonry Parapets

3 Unreinforced Masonry Parapets

3.1 Design

3.1.1 Overview

Unreinforced masonry parapets can provide an attractive, cost-effective and generally low maintenance means of protecting road users from precipitous drops on bridges, retaining structures and on steeply sloping ground. However, unreinforced masonry parapets typically have only a modest ability to contain errant vehicles and this guidance has been developed to enable engineers involved in the design of new or replacement masonry parapets to maximise the potential of this form of construction. An indication of the levels of wall debris that can be expected to be ejected during an impact event is also provided (derived from numerical modelling studies - see Appendix A for more details).

3.1.2 Geometric properties of parapets

In order to comply with the latest codes of practice for containment structures, masonry parapets should have a minimum length of 10 metres, or in cases where joints are present a minimum panel length between joints of 10 metres.

Irrespective of the curvature of the road, the parapet should have a minimum radius on the traffic face of 15 metres.

Paragraph 4.23 of TD19/06 [9] specifies the following: (note that *italicized* text is used to indicate a direct quote)

The height of vehicle parapets must be measured above the adjoining paved surface and must not be less than the following:

1000mm ^a	<i>For vehicle parapets except as below</i>
1250mm	<i>For all bridges and structures over railways carrying motorways, or roads to motorway standards, from which pedestrians, animals, cycles and vehicles drawn by animals are excluded by order</i>
1500mm	<i>For all other bridges and structures over railways, except as below</i>
1400mm	<i>For cycleways immediately adjacent to the vehicle parapet</i>
1500mm	<i>For accommodation bridges</i>
1500mm	<i>For very high containment level applications</i>
1800mm	<i>For bridleways or equestrian usage immediately adjacent to the vehicle parapet</i>
1800mm	<i>For automated railways and where there is a known vandalism problem over railways</i>

^aN.B. although the minimum height of 1000mm is accepted by TD19/06, it is less than the minimum of 1150mm stated in BS7818 "Specification for pedestrian restraint systems in metal".

Where the height of a parapet must be less than 1000mm then consideration should be given to the possibility of the errant vehicle overtopping the parapet. If other roadside items exist adjacent to the parapet that can cause an errant vehicle to gain height (e.g. raised kerbs, pavements, etc.) then the parapet performance charts provided within this document may erroneously indicate that the errant vehicle is likely to be contained.

3.1.3 Curved parapets

As noted in BS6779 part 4, for curved sections of parapets the potential beneficial effects of arching action will be increased on the convex face and decreased on the concave face. For sections of parapets where the radius of curvature exceeds 15 metres then the resultant decrease in arching action on the concave face will generally be negligible. Furthermore, as only the convex faces of the smaller radius curved walls sometimes used at the ends of masonry parapets are generally exposed to traffic, these will generally not reduce containment capacity and will also serve to reduce the likelihood of head on impact (see section 3.1.9).

3.1.4 Surface finish of parapets

BS6779 part 4 provides the following advice on surface finishes:

The front face profile should 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 (e.g. concrete core stone face parapets), the maximum difference between the steps should not be more than 30mm when measured with respect to a plane taken through the peaks. This plane should be flat for straight parapets and curved to follow the nominal parapet curvature for parapets which are curved on plan.

TD 19/06 also defines it a “hazard” if a wall does not have a “smooth” face adjacent to the traffic extending for at least 1.5m above the adjacent carriageway level, where the definition is given as:

“a ‘smooth’ face may include a surface that may have an irregular surface finish subject to the maximum amplitude of the steps and undulations in the surface not exceeding 30mm when measured with respect to a plane through the peaks. The plane must be broadly parallel to the road alignment. A structure that has a 25mm wide chamfered construction joint in its surface would be regarded as smooth.”

3.1.5 Parapet copings

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 or other suitably shaped coping, should be provided on the top face. Provision of steeple copings is mandatory on bridges over railways where there is access to pedestrians (Figure 1).

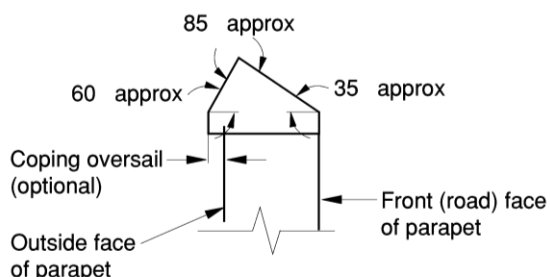


Figure 1 Parapet steeple coping: typical details (after BS 6779-4 [2])

Clause 9.17 of TD 19/06 requires that stone or precast copings used with pedestrian parapets must be secured to the concrete backing by fixings capable of resisting at the ultimate limit state a horizontal force of 33 kN per metre of coping.

3.1.6 Movement joints

For long walls constructed with high strength mortar (see definition in Table 4) the use of movement joints may be necessary. Further guidance is provided in Appendix D.

3.1.7 The use of bed joint reinforcement

The use of bed joint reinforcement is not recommended as recent laboratory tests have indicated that its use can be counterproductive, and can potentially cause premature fragmentation of the parapet into small pieces [10].

3.1.8 Damp proof course

The possible use of a damp proof course is commented on in Clause 6.7.2.1.3 of BS6779 part 4. However, where a damp proof course is considered to be necessary, provision of low permeability masonry units near the base of the parapet should be used in preference to a DPC membrane. (Alternatively a special high bond strength DPC membrane could be employed.)

3.1.9 Protection to ends of parapets

BS6779 part 4 provides the following guidance on protection to the ends of parapets:

Where there is a safety fence which terminates at a parapet the safety fence should be provided with a connection or anchorage system capable of resisting an ultimate longitudinal tensile force of not less than 330kN. The safety fence should extend along the parapet for not less than 1m from the end of the parapet. The connection to the parapet should be recessed, or the section of the parapet to the rear of an anchorage system should 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 [refer to Section 3.1.4 above].

Unreinforced masonry parapets designed in accordance with this guidance document resist impact forces applied to the parapet at not less than 1m from the parapet end. Impacts within 1m 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 directly 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 330kN.

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

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.

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 3m and the angle subtended by a parapet so curved does not exceed 40° approximately (i.e. length of curve for a 3m radius not greater than 2m approximately), giving a maximum

offset of about 0.67m 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 0.5m by the curvature.

Reference should also be made to TD19/06 [9], including the requirement for a safety barrier to be provided on each approach and departure end of the vehicle parapet to prevent direct impact (TD19/06 paragraph 3.30).

3.2 Assessment

When assessing an unreinforced masonry parapet it is necessary to first establish the form of construction of the wall and to then assess its condition; further guidance is provided in Chapter 5. Once this has been established the impact performance of the wall can be determined according to the advice given in Section 3.3.

3.3 Impact performance of unreinforced masonry parapets

3.3.1 Background

Unreinforced masonry parapets resist applied impact loadings as a result of (i) unit-mortar adhesion, which inhibits formation of initial cracks, followed by (ii) in-plane arching action, with (iii) inertial effects and (iv) frictional forces respectively delaying and potentially arresting subsequent movements. The degree to which these can be relied upon depends on the particular form of construction involved (e.g. in the case of dry-stone construction (i) and (ii) will be negligible or non-existent). In general unreinforced masonry parapets are built directly on top of a supporting element (e.g. the superstructure of a bridge) without provision of anchorage. The basic mechanics of impact are outlined in Appendix B.

Masonry parapets have some limitations with regards to their containment, and experience and tests have all illustrated that masonry can become detached during impact and therefore debris is likely to be ejected onto adjacent sites, potentially causing disruption of services and possibly injury. In most cases masonry parapets will have inadequate capacity to contain Large Goods Vehicles (LGVs), resulting in either penetration of the errant vehicle or an errant vehicle running over the parapet if this is low.

3.3.2 Performance by parapet material

a) Brickwork parapets

Parapets constructed of brickwork may have good mechanical strength as there are mortared joints and the courses of brickwork are also mortared together. Brickwork parapets frequently possess significant unit-mortar adhesion, which inhibits crack formation and ensures eventual failure involves the formation of large panels of masonry between fractures. However, in the case of brickwork parapets with very low unit-mortar adhesion, failure will typically involve a punching failure mode, with ejection of individual brick units. Numerical investigations have indicated that the particular bonding pattern used (e.g. 'English Bond' vs. 'English Garden Wall Bond') does not have a major effect on performance, provided that through-thickness units ('headers') are present [11].

b) Ashlar stone or concrete block parapets

Parapets constructed of ashlar stone or concrete blocks have in general high mass but typically very weak unit-mortar bond strength. A moderate impact loading can be resisted by arching action.

c) Rubble stone parapets

Rubble stone parapets typically comprise rough stone facings and a mortared core. Their weakness lies in the weak bond between the individual stone units which are a variety of sizes. A moderate impact loading can be resisted by arching action, but if mortar joints are not well filled, or if the mortar-bond is very low, then arching action may not develop.

d) Dry stone parapets

Parapets of dry stone have a very high mass but generally no mechanical strength due to the absence of mortared core and mortared joints. In dry stone parapets the presence of open joints means that the beneficial effects of the longitudinal arching action are unlikely to be developed. Therefore, dry stone masonry parapets will primarily resist impact forces by the inertia of the parapet. Upon impact, dry stone parapets will typically be damaged by punching through of the stones.

3.3.3 Parapet performance charts

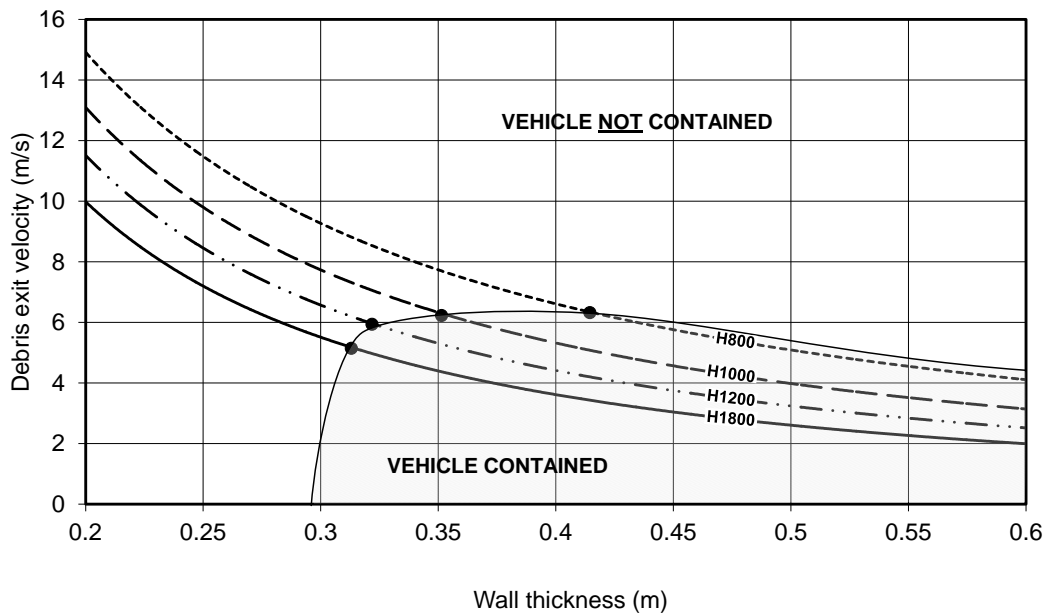
a) Mortared parapets

Parapet performance charts have been developed for the design of new parapets and for the assessment of existing parapets, provided there are no significant defects in the parapet and the construction details are known. The charts, shown in Figure 2 and Figure 3, allow both the ability of a given parapet to contain a vehicle and the likely extent of ejected debris to be determined from the indicated mean debris exit velocity.

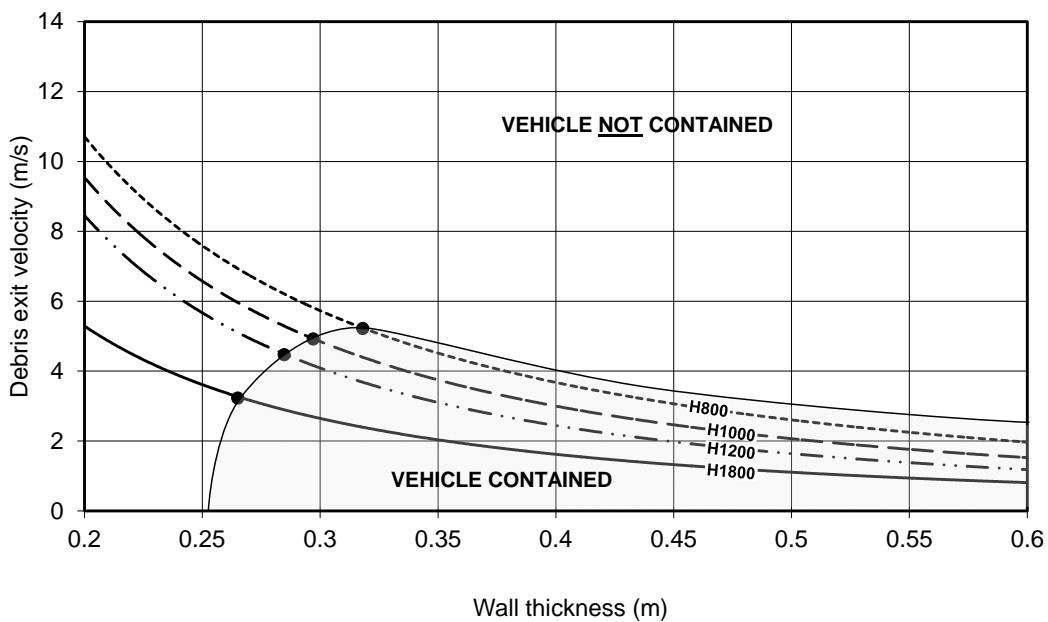
The definition of 'High' and 'Low' unit-mortar bond strength is given in Table 4.

Where data on the characteristic shear strengths between particular masonry units and mortar are not available, conservative values should be assumed or appropriate values determined from sample tests (BS EN 1052-3) [12] or in-situ tests (see section 5.2.2). Note that the values given in the National Annex of BS EN 1996-3 [13] for brickwork with various mortar mixes appear conservative (tests have shown that the specified 'High' unit-mortar adhesion can in some cases be satisfied by using an M4 (1:1:6) mortar in accordance with the UK National Annex of BS EN 1996-1-1[13], in conjunction with a class B engineering clay brick). For intermediate characteristic unit-mortar bond strengths, linear interpolation between the values given in Figure 2(a) and Figure 2(b), and Figure 3(a) and Figure 3(b), is permitted. Parapets built using bed-joint reinforcement should conservatively be assessed on the assumption that 'Low' unit-mortar bond strength is present.

Note also that for parapets less than the minimum height of 800mm or greater than the maximum height of 1.8 m, the containment capacity may be obtained by extrapolation from the values plotted on the parapet performance charts. It should however be recognized that where parapets are lower than 1000mm 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.

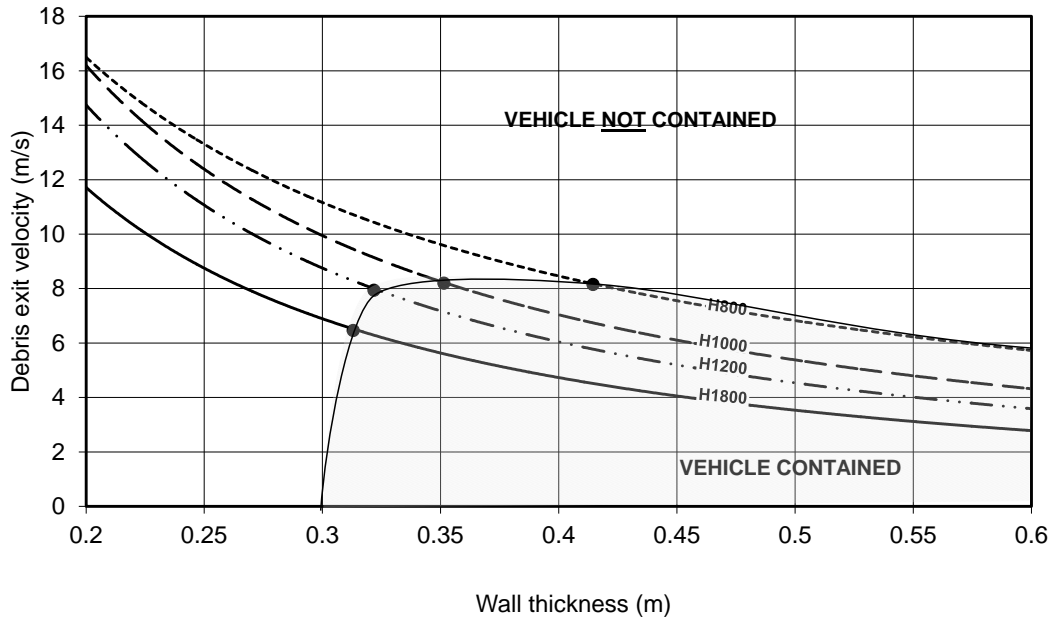


(a) Low unit-mortar bond strength

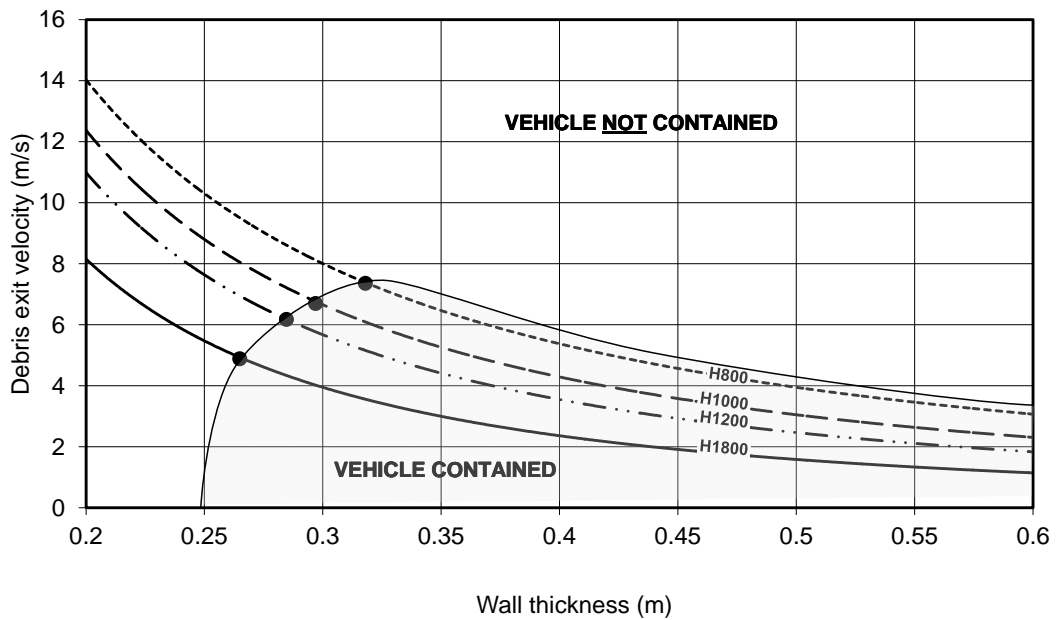


(b) High unit-mortar bond strength

Figure 2 Parapet performance chart: N1 (80km/h) containment for mortared parapets of various height, H (mm) (density: 2200kg/m³)



(a) Low unit-mortar bond strength



(b) High unit-mortar bond strength

Figure 3 Parapet performance chart: N2 (110km/h) containment for mortared parapets of various height, H (mm) (density: 2200kg/m³)

Table 4 - Criteria for unreinforced masonry parapets assessed or designed in accordance with Figure 2 and Figure 3:

Property	Unit-mortar adhesion	
	High	Low
Minimum characteristic initial unit-mortar shear bond strength	0.6 N/mm ²	0.1 N/mm ²
Minimum unit-mortar coefficient of friction	0.6	0.6

b) Drystone parapets

A conventional containment chart for drystone parapets is provided in Appendix E. Note that this chart gives no indication of debris exit velocity, which is likely to be at least as great as that indicated in Figure 2(a) and Figure 3(a), but will in practice depend on the precise form of wall construction (e.g. size of stones, degree to which interlocking allows spreading of impact load).

3.3.4 Influence of key parameters

a) Wall length

The parapet performance charts have been prepared for 10m long walls subject to impact 1m from the leading end of the wall.

For parapets which are longer than 10m, or for parapets subjected to impact nearer the middle of the wall, the indicated performance is likely to be conservative, both in terms of containment and in terms of the velocity of ejected debris. However, the degree of conservatism will often be relatively low; for example, numerical studies have indicated that the required thickness of a 1m high parapet impacted 4m from its mid-length is only 5 percent greater when the wall length is 10m rather than 20m long ('high' adhesion mortar and car travelling at 80km/h).

Conversely walls which are shorter than 10m, or for walls impacted near the trailing end of the wall, the indicated performance is likely to be non-conservative. It should also be borne in mind that very short walls can fail due to overturning.

b) Shear resistance

Where parapets are being rebuilt the bedding joints should provide a shear resistance at least equal to that which would be provided by friction, assuming a coefficient of friction of 0.6, to a minimum depth of 0.6H below the adjoining paved surface (where H = the parapet height).

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 parapet performance charts are, therefore, based on the assumption that only negligible bond strength is present at the level of the adjoining paved surface, together with friction, and assuming a coefficient of friction of 0.6.

The parapet performance charts have been derived assuming the perpend joints in the masonry are continuous through the thickness of the parapet, for example, as in ashlar stone masonry construction. Improved containment capacities, giving higher margins of safety, may be obtained where bond patterns in which the perpend joints are not continuous throughout the parapet thickness are used.

c) Parapet density

The density referred to in the parapet performance charts refers to the combined density of the masonry units and jointing material and should therefore be calculated based on the gross wall volume.

For all wall densities which are higher or lower than 2200kg/m^3 the parapet thickness required to contain a vehicle can conservatively be taken as the thickness determined from the chart $\times (2200 / \text{effective density of masonry to be used})$. Similarly, the debris exit velocity can conservatively be taken as the debris exit velocity from the chart $\times (2200 / \text{effective density of masonry to be used})$.

d) Vehicle speed and impact severity

The parapet performance charts (Figures 2 and 3) show that increasing the vehicle speed from 80km/h to 110km/h does not greatly affect whether or not a vehicle is contained. This is principally because although the impulse applied to the wall will be greater during a 110km/h impact event, correspondingly more masonry will generally be available to resist the impulse, due to movement of the vehicle parallel to the wall during a 20° impact event.

However, the mean debris exit velocity will increase with vehicle speed, and the impact severity level [3] will increase from 'A' at 80km/h to 'B' at 110km/h. These values have been derived from Accident Severity Index (ASI) values determined from the numerical models; refer to Appendix C for more details.

(Note that the containment curves given in BS6779-4 incorporate occupant safety issues and so mask the comparative insensitivity of wall behaviour to vehicle speed; refer to Appendix A and Appendix B for further information on this.)

Reinforced Masonry parapets

4 Reinforced Masonry Parapets

4.1 Overview

Unreinforced masonry parapets will often be found to be incapable of containing vehicles. Various options exist for parapet strengthening including parapet reconstruction and in-situ strengthening.

Parapet reconstruction schemes may involve pre-cast or in-situ reinforced concrete parapet units, potentially tied together across the bridge deck. A variation on the plain reinforced concrete solution is provision of a brick / concrete sandwich type parapet, comprising outer faces of brickwork with an in-situ reinforced concrete core. Although this form of parapet may have lower capacity than a conventional reinforced concrete version, it does offer a solution which can be aesthetically compatible with the existing structure. Such parapets can be designed using the same principles applied to reinforced concrete parapets and are therefore outside the scope of this guidance document.

Existing masonry and brickwork parapets can also be strengthened by introducing reinforcement into the existing structure; this is the focus of this section, which provides a brief review of recent research undertaken, and provides good practice guidance.

Hobbs et. al. 2009 [10] undertook a study of the effectiveness of various different methods of reinforcing masonry parapets. Considerations included: influence of reinforcement on mechanical behaviour, durability, ease of installation and aesthetics. Reinforcement types investigated included: bed joint reinforcement and two drilled-in reinforcement systems (a proprietary anchor system comprising grouted vertical and horizontal tendons and a generic system utilising diagonal bars bonded into pre-drilled holes in the parapet using epoxy resin).

The results of the testing programme indicated that bed joint reinforcement can increase the tendency for a masonry parapet to fragment into small pieces on impact, and therefore it was concluded that the use of bed joint reinforcement should be avoided in parapets. This is particularly important in the case of masonry parapets in highly populated areas, where flying debris could cause death or injury.

In contrast it was found that drilled-in reinforcement could significantly improve the containment capacity of masonry parapets. Significantly, it was found that the performance of an unreinforced parapet constructed with very weak mortar (low adhesion) could be significantly enhanced by the introduction of drilled-in diagonal reinforcement, which changed the behaviour of the parapet from a brittle punching failure mode to a ductile one.

4.2 Available Reinforcing Systems

The following reinforcing systems have been identified as enhancing the overall containment capacity of masonry parapets:

a) Anchor systems

Typically these are proprietary products which offer horizontal and diagonal reinforcement. They offer a very good solution as work can be undertaken with minimum road clearances that will not grossly affect the live traffic.

b) Epoxy bonded bars

This is another novel solution. Its main advantage is that drilling is only undertaken from the top face of the parapet and therefore it avoids any potential problems from having to undertake very long horizontal drilling. In addition, the technique can also readily be applied to curved parapets.

c) **Externally bonded reinforcement**

Externally bonded reinforcement has been used successfully in other engineering applications. The reinforcement is usually made out of various polymers to increase the tensile resistance of the structural member. With regards to masonry parapets, research on the use of externally bonded reinforcement is limited. The primary consideration with regards to their use is the surface roughness of masonry parapets and the potential for tearing off during installation or during an impact event.

4.3 Anchorage to underlying bridge superstructure

The danger of disproportionate damage (e.g. collapse of a connected part of the bridge superstructure) in the case of a severe impact means that provision of structural elements which mechanically fix a masonry parapet to the underlying bridge superstructure is not usually recommended and is therefore not considered further here.

4.4 Reinforcement within parapet only

Reinforcement can be provided to ensure that an existing or new parapet performs as a single large panel when impacted. This means that as a minimum the 'high' unit-mortar bond strength parapet performance charts [Figure 2(b) and Figure 3(b)] can be used, or alternatively the performance can be derived using a simple rigid-body dynamics representation of the parapet.

To achieve this, the following suggested design approach can be employed:

- Consider a notional out-of-plane force applied at the end of the wall (normally the most critical location for out-of-plane loading).
- Calculate the moment of resistance of the wall cross section required to allow the whole wall rotational base sliding mode to be activated without the wall failing in flexure, assuming base friction forces opposing wall movements are applied along the full length of the wall (method detailed in Appendix F, section F.2) .
- Provide reinforcement close to the mid-thickness surface to provide the required moment of resistance, applying suitable partial factors, and ensuring adequate reinforcement anchorage lengths are employed.

The use of overlapping diagonal reinforcement has been found to be especially effective for this application (e.g. Figure 4); sample design calculations are provided in Appendix F.

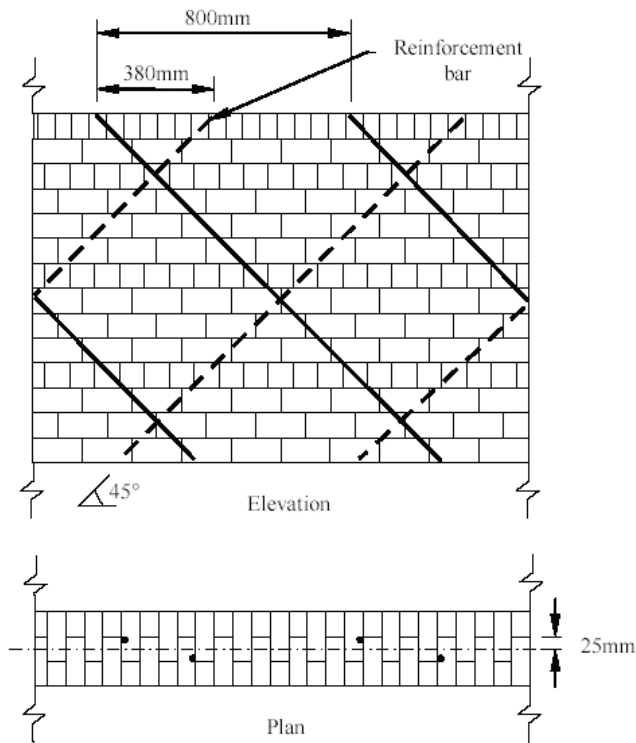


Figure 4 Example diagonal bar reinforcement layout

It should be noted that there are limits on the level of containment which will be achievable using the approach described above, and it is for example unrealistic to expect that containment levels significantly greater than N2 level will be achievable. Furthermore, without anchorage there is the potential for the whole parapet to overturn or slide off the bridge superstructure following impact. If higher levels of containment are required then recourse to alternative solutions is therefore recommended (e.g. provision of a brick / concrete sandwich type parapet).

4.5 Durability of Reinforcement

The success and durability of reinforcing existing masonry parapets relies largely on the durability of the reinforcement. When steel reinforcement is used it is recommended that the reinforcement receives a corrosion protection coating at the workshop, prior to installation. It is also important to ensure that grout injection is complete through the pre-formed cavities as the presence of voids in the grout can affect the durability of the system.

The use of polymer reinforcing bars such as FRP (fibre) or GFRP (glass) has the advantage of improved durability. Polymers are not affected by atmospheric corrosion to the same degree as steel. However, attention should be paid to detailing to protect the reinforcement from environmental effects such as water, frost etc. Severe exposure of the polymers may result in weathering of the material with subsequent reduced mechanical properties.

Condition Appraisal

5 Condition Appraisal

5.1 Introduction

The mode of response of a masonry parapet subjected to a vehicle impact is influenced by the integrity of the masonry and on the unit-mortar bond strength. It is therefore useful to establish as reliably as possible the nature and condition of the masonry, including the mortar joints.

Intrusive and non-intrusive testing techniques relevant to the investigation of parapet walls are shown on Table 5.

5.2 Appraisal

5.2.1 Visual inspection

Masonry is generally a long-lived, highly durable material. However, parapets tend to be very exposed and are therefore susceptible to a wide variety of potential problems, some of which can be identified in a visual inspection. These may include:

- Moisture saturation
- Freeze-thaw cycling
- Physical salt attack
- Sulphate attack
- Leaching of mortar
- Biological attack
- Repair with unsympathetic materials
- Expansion and contraction (from thermal and wetting and drying cycles)

Further general guidance on the above is provided in CIRIA C656: Masonry Arch Bridges: condition appraisal and remedial treatment [4].

In addition to the problems listed above, there may be evidence that the parapet has been previously subjected to an errant vehicle impact event, and cracks resulting from this may still be evident. Clearly the wall may perform poorly if a subsequent vehicle impact occurs close to such cracks, though this needs to be set against the likelihood of the parapet being impacted at a specific location.

5.2.2 Non-intrusive testing techniques

Various non-intrusive testing techniques for masonry have been proposed. For example, using electromagnetic wave propagation, Surface Penetrating Radar (SPR) can identify the presence of voids or steel within the masonry. Also, Infrared Thermography can distinguish between hollow and grout-filled cells in masonry using principals of thermal energy absorption. Thermography is often combined with either SPR or use of a covermeter (pachometer) [14].

5.2.3 Intrusive testing techniques

Coring and boroscopy are potentially useful to help the engineer understand more about the internal construction of a given parapet whilst in-situ jacking is designed to provide quantitative information on the unit-mortar bond

strength. This may for example be useful when assessing an existing brickwork parapet which narrowly fails to meet a given performance threshold (see Section 3.3) when using a conservative assumed strength.

The nature of masonry is that it is the sum of many parts, and in fact none of these tests are likely to produce a result that provides a truly reliable indication of the characteristics of the wall as a whole. Of those listed, the test by jacking is most likely to produce a result which is representative, if undertaken at a representative number of locations. However, this test also has the disadvantage that it is likely to be at least slightly destructive and requires special equipment that needs to be calibrated. The use of a specialist testing contractor for this would usually be considered prudent, although this is not absolutely necessary.

Table 5: Summary of in-situ testing techniques [15]

Method	Description	Use of Results	Advantages/disadvantages
Surface Penetrating Radar	Use of the properties of electromagnetic wave, and how they reflect or penetrate different materials	Identify size and depth of void, presence of reinforcement	Cannot distinguish diameters of steel bars. Requires expert interpretations
Infrared Thermography	Uses principles of thermal energy absorption.	Distinguish between hollow and grout-filled cells	Cannot detect presence of steel. Best used in combination with SPR or cover meter.
Coring and analysis of small diameter cores	Small diameter cores are drilled from the structure and analysed visually or in a laboratory	Identifying materials Hidden geometry Quantification of material properties Calibration of other tests	Reliable results Provides only localised information Slightly destructive, and needs to be repaired
Boroscopy	A small camera is inserted into boreholes drilled in the structure allowing a detailed study within its depth	Identifying materials Detection of cavities and defects Calibration of other tests	Reliable results Provides only localised information Slightly destructive, and needs to be repaired
Chemical analysis and petrological examination	Detailed characterisation of masonry materials taken from cores using microscopy and/or specialist chemical analysis techniques	Determination of cement content of mortar. Matching of materials for repairs	Specialist technique requiring expert interpretation Strength estimates may not be accurate
In-situ jacking to establish shear-bond strength	A calibrated hydraulic jack is pressurised in a void adjacent to a masonry unit which has been freed from adjacent masonry except for bedding planes. (e.g. see ASTM C1531-09)	Estimation of initial unit-mortar bond strength	Results not always reliable Provides only localised information Slightly destructive, and needs to be repaired

Risk Assessment

6 Risk Assessment

6.1 Introduction

The most important information required by an assessing engineer will often be whether or not a given parapet is likely to be able to contain a given errant vehicle. For unreinforced parapets this is dealt with in section 3.3, and in particular in sub-section 3.3.3

Further to the assessment of containment, a risk assessment can be carried out to determine the risk of death or injury to the vehicle occupants and users of property in the vicinity of a parapet following an impact event. This assessment can be used to justify or otherwise the use of a given type of parapet at a particular site.

6.2 Basis of Method

The method presented herein uses of the well-known risk equation, i.e.:

$$\text{'Risk'} = \text{'Likelihood'} \times \text{'Consequence'}$$

'Risk' can be conveniently and objectively quantified using the Fatal Accident Rate (FAR), defined as the risk of death per 100 million hours of exposure to a given activity. A key benefit of using FAR is that it allows different activities to be compared, e.g. see the following Table 3 for FAR values for common activities [16]:

Table 6: Fatal Accident Rate (FAR) for common activities

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

Using this approach, FAR values for a group of assessed masonry parapets can for example be collated to produce an objective 'risk ranking' table used to prioritise upgrading works.

6.3 'Likelihood' of errant vehicle impact

Reliable site data, if available, can be used to furnish return periods for impact events of prescribed severity, generally T_{C80} , T_{C110} , T_{L60} , as summarised in Table 7:

Table 7: Return Period Nomenclature

Return period	Vehicle type	Speed
T_{C80}	Car	80km/h
T_{C110}	Car	110km/h
T_{L60}	LGV	60km/h

Where site data is not available the approach given in Appendix G can be used to furnish return periods T_{C80} , T_{C110} , T_{L60} .

6.4 'Consequence' of errant vehicle impact

6.4.1 General

The 'Consequence' of each of the selected 'Likelihood' scenarios considered in Section 6.3 can be established:

- Whether the errant vehicle is contained (Figures 2 and 3).
- How far ejected debris is spread (calculated from mean debris exit velocity – see Section 6.4.3).

6.4.2 Consequence of failure to contain a vehicle

If a vehicle is not contained then this can normally be assumed to result in a single fatality, though a greater (or lesser) number of fatalities can be assumed depending on site conditions.

6.4.3 Consequence of wall debris ejection

Following a vehicle impact event, individual pieces or large panels of masonry will often become ejected or dislodged. The consequence of debris ejection can be serious when properties within range are occupied. The extent of the spread of debris, d , as defined in Figure 5, can be taken from Table 8.

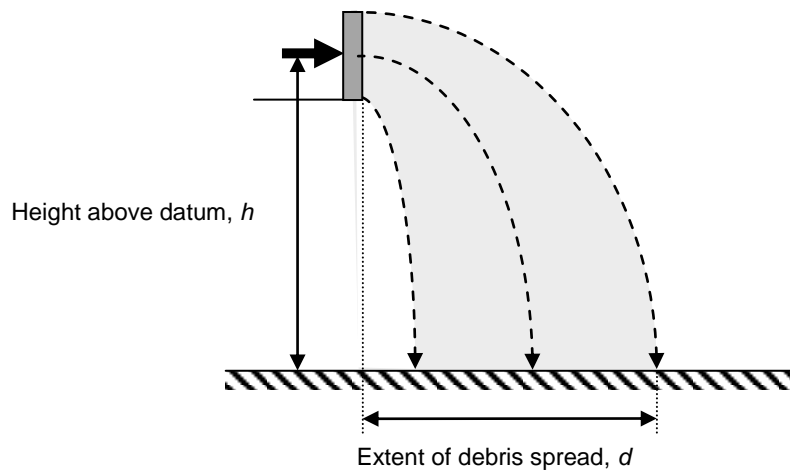


Figure 5 Extent of debris spread: definition

Table 8: Extent of debris spread: values of d

Mean debris exit velocity (m/s) (from Figure 2 or 3)	Height above datum h (to mid-height of parapet)				
	2m	4m	6m	8m	10m
1	1	2	2	3	3
2	3	4	4	5	6
3	4	5	7	8	9
4	5	7	9	10	11
5	6	9	11	13	14
6	8	11	13	15	17
7	9	13	15	18	20
8	10	14	18	20	23
9	11	16	20	23	26
10	13	18	22	26	29
11	14	20	24	28	31
12	15	22	27	31	34

Notes:

- i. Values calculated assuming (i) debris is ejected horizontally and in free flight; (ii) the extent of debris spread d is taken as twice the mean value, calculated from: $\bar{d} = \bar{v} \sqrt{2h/9.81}$.
- ii. It is recommended that the resulting extent of debris spread is rounded up to a whole number.

6.5 Road over road:

Direct and indirect impacts on vulnerable vehicles:

'Vulnerable vehicles' are those travelling on the road below the impacted parapet, which may be 'directly' or 'indirectly' affected by ejected debris, as indicated on Figure 6.

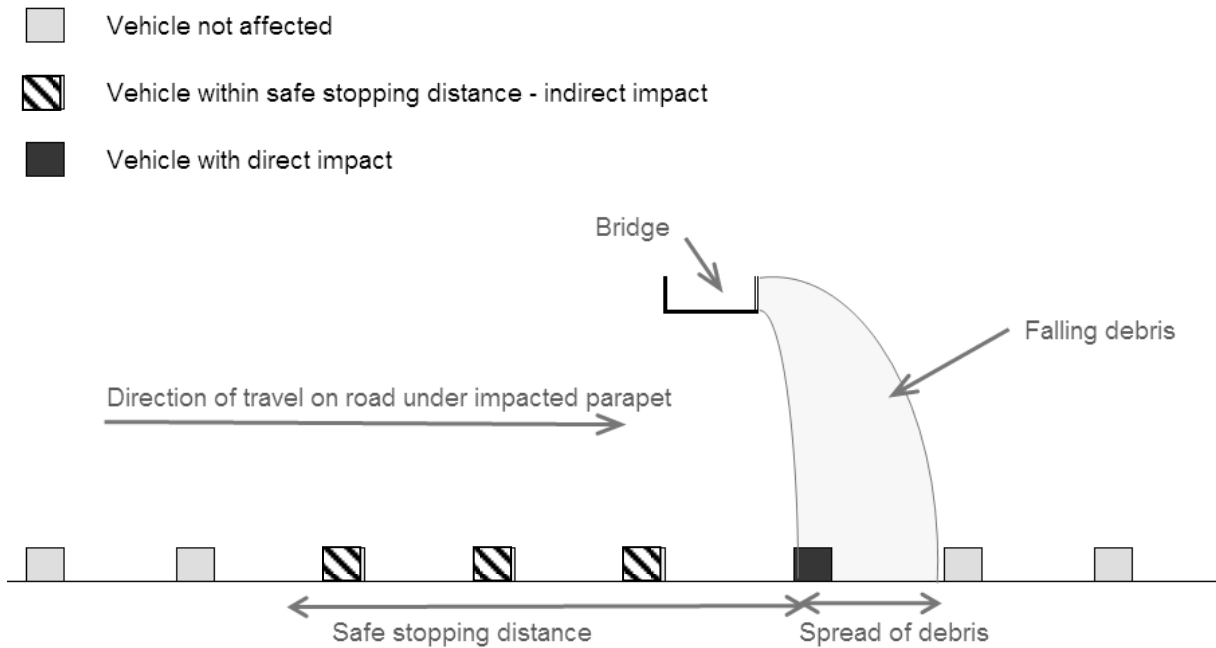


Figure 6 Definition of direct and indirect Impacts

(a) Direct impact with debris

This is the likelihood of a vulnerable vehicle being directly struck by falling debris.

The spacing between vulnerable vehicles = (speed of travel) / (rate of flow) and can be calculated or taken from a 'ready reckoner' such as equation G3 (Appendix G).

The number of vulnerable vehicles directly struck by falling debris N_{direct} will equal the extent of the debris spread d divided by the spacing between vehicles (assuming the length of vehicle is comparatively short). N_{direct} can be calculated from equation G4 (Appendix G).

(b) Indirect impact with debris

$N_{indirect}$ is the number of vulnerable vehicles not able to slow down to a safe speed in time to avoid hitting debris, and can be calculated from equation G5 (Appendix G).

The total number of vulnerable vehicles affected by the errant vehicle impact event, N_{total} :

$$N_{total} = N_{errant} + N_{direct} + N_{indirect} \quad \text{[equation 1]}$$

Where N_{errant} is taken as 0 or 1 depending on whether the original errant vehicle is contained or not.

6.6 Road over rail

For road over rail, the calculation for direct and indirect impact as done for road over road is more difficult, and it is suggested instead to use a risk ranking method as used in 'Managing the accidental obstruction of the railway by road vehicles' (DfT) [17], as shown in Table 9: (A similar method is also used in IAN 97/07 [18])

Table 9: Factors for road over rail; incursion risk ranking

Permissible Line Speed and Track Alignment
Score 1 for straight track up to 45mph Score 4 for straight track up to 75mph or curved up to 45mph. Score 8 for straight track up to 90mph or curved up to 75mph. Score 12 for straight track up to 100mph or curved up to 90mph. Score 16 for straight track up to 125mph or curved up to 100mph. Score 20 for straight track up to 140mph or curved up to 125mph. Score 24 for straight track above 140mph or curved up to 125mph.
Type of Rail Traffic
Score 1 for Non-Dangerous Goods Freight Score 3 for Loco-Hauled Stock Score 5 for Sliding Door Multiple Units (up to 100mph) or Dangerous Good Freight Score 7 for Slam Door Multiple Unit or Sliding Door Multiple Units (over 100mph) Score 11 for Light Rail
Volume of Rail Traffic
Score 1 for seldom used route (fewer than 500 trains per year) Score 3 for lightly used route (501 to 3000 trains per year) Score 5 for medium use route (3,001 to 10,000 trains per year) Score 8 for heavily used routes (10,0001 to 50,000 trains per year) Score 12 for very heavily used route (more than 50,000 trains per year)

Using this Table, the minimum score would be 3, and the maximum is 47.

With reference to Formula F1: $N_{direct} = (\text{score from Table 9}) / 47$ **[equation 2]**

(An example of use is given in Appendix J)

6.7 Calculated FAR value

The absolute risk can now be determined by computing the Fatal Accident Rate (FAR) value:

$$FAR = 100,000,000 / [T_0 / N_{total}] \quad \text{[equation 3]}$$

Where: T_0 is the return period (from Section 6.3, converted into hours)

N_{total} is total number of vehicles affected by the errant vehicle impact event

Note that in Formula F2 it is implicitly assumed that there will be one fatality per vehicle, though a greater (or lesser) number of fatalities per vehicle can be assumed depending on site conditions. Further information about car occupancy is obtainable from the DfT document “Car Occupancy by Trip Purpose” NTS0906 [19].

6.8 Flowcharts and example calculations

Flowcharts and sample calculations which demonstrate how a FAR value is calculated are provided in Appendices I and J.

Appendices

This page intentionally blank

Appendix A – Numerical Modelling

A.1 Background

To support the development of the original County Surveyors Society Guidance Note on masonry parapets [1] (which led to the development of BS 6779-4 [2]) various full-scale vehicle impact tests were undertaken together with parallel numerical modelling studies, undertaken using the general-purpose dynamic finite element package LS-DYNA.

However when this modelling work was undertaken (in the early 1990s), understanding of the fundamental response of masonry subject to impact loadings was relatively poor and the numerical models necessarily incorporated many simplifications (e.g. artificially high values for the unit mortar shear and tensile strengths had to be used to ensure good correlation with the wall test results). Because the full vehicle–wall interaction problem is undeniably complex, it was also found to be difficult to properly isolate masonry response from vehicle response. These issues were addressed in subsequent EPSRC funded research work, as outlined in the next section.

A.2 Findings from EPSRC funded research work

EPSRC funded research undertaken after the original County Surveyors Society work involved the use of alternative, more controllable, laboratory test apparatus which allowed the fundamental mode of response of masonry walls to impact loading to be better understood.

Furthermore, it was realised that provided masonry joints are modelled in a suitably detailed way (e.g. including joint fracture energy and joint dilatancy), there is no need to use artificially high ‘dynamic’ material properties in the numerical models in order to achieve good correlation with the parapet wall test results [11].

The research also indicated that:

- i. Unit-mortar adhesion is important:
 - a. if unit-mortar adhesion is above a given threshold then walls will fail due to the formation of fracture lines delineating large panels, with subsequent resistance provided by in-plane arching action and base friction;
 - b. conversely walls with low unit-mortar adhesion are prone to punching failure, with large numbers of individual masonry units ejected from the wall.
- ii. Blockwork and brickwork walls will often behave broadly similarly.
- iii. Walls containing low unit-mortar adhesion can be strengthened using diagonal bars, which transforms the mode of response to one involving large panels rather than punching failure.

A.3 Modelling undertaken for the present guide

Completely new modelling studies were undertaken to underpin the present guidance document, using the numerical model described in Burnett et al. [11].

The objectives of the new modelling studies were to:

- i. Verify, and if necessary amend, results from the previous modelling studies.
- ii. Record the extent of debris ejected following impact.
- iii. Allow the behaviour of walls not modelled previously to be investigated (e.g. tall walls).

Parapet models

Stretcher bonded blockwork (with a face area of 400x200xthickness and half blocks at wall ends) was used for all simulations, to represent both brickwork and stone masonry parapets. Details of the parameters used in the model are shown in Table A1.

Table A1: Parapet model parameters

Parameter	Value	Notes
Density (kg/m ³)	2200	
Elastic modulus (kN/mm ²)	20	Elastic material used, with non-linearity confined to joints
Poisson's ratio	0.3	
Joint coefficient of friction	0.6	Supplemented by dilatant coefficient of friction of 0.1 (active to 0.8mm shear displacement)
Joint shear strength	Varies	Fracture energy with exponential softening; limiting displacement 0.65mm
Joint tensile strength	0.7 x joint shear strength	Fracture energy with exponential softening; limiting displacement 0.15mm
Base shear strength	0.1 x joint shear strength	Reduced value to account for weathering etc.
Base tensile strength	0.7 x base shear strength	Reduced value to account for weathering etc.
Base coefficient of friction	0.6	Supplemented by dilatant coefficient of friction of 0.1 (active to 0.8mm shear displacement)

Vehicle model

Various standard vehicles from the U.S. based National Crash Analysis Centre were investigated. However, these increased the run-time and, because of the particulate nature of many of the masonry wall failures, mid-analysis failures caused by overlapping vehicle/masonry elements were frequent. Hence for the runs undertaken here the same simplified vehicle model as used for the original CSS work underpinning BS6779-4 was used. Details of the model are shown in Table A2.

Table A2: Vehicle model parameters

Parameter	Value	Notes
Density (kg/m ³)	480 / 190	Values for front / back of vehicle respectively
Shear modulus (N/mm ²)	76.9	
Yield strength (N/mm ²)	0.2	
Hardening modulus (N/mm ²)	0.02	
Bulk modulus (N/mm ²)	167	

Validation

The numerical model was validated using:

- Laboratory test data collected during the course of the EPSRC funded research work [20]
- MIRA tests undertaken for the original CSS-funded project [1].

Models run

A total of 120 model simulations were performed to generate the parapet performance charts included in the present guidance document; the key parameters investigated are shown in Table A3.

Table A3 Modelling simulations performed

Speeds (km/h)	Mortar shear-bond strength (N/mm ²)	Wall height (m)	Wall thickness (m)
80	1.2 ('Strong')	0.8	0.2
		1.0	0.3
110	0.6 ('Medium')	1.2	0.4
		1.8	0.5
	0.1 ('Weak')	1.2	0.5
		1.8	0.6

Results interpretation

Containment

Vehicles were assumed to be contained provided that penetration of the front of the vehicle was not greater than the parapet wall thickness (note that MIRA tests indicated that when penetration was significant there was a tendency for the errant vehicle to 'snag' on the wall even if the vehicle sometimes still appeared to be 'contained' in the parallel numerical modelling studies).

Mean debris velocity

The mean debris exit velocity was calculated as follows:

$$\bar{v} = \sqrt{\frac{2KE}{m_{moving}}}$$

Where KE is the kinetic energy of the wall, m_{moving} is the mass of moving blocks (threshold: 0.5m/s or greater). It was found that the mean debris exit velocity typically reached a plateau at a time of 0.3 seconds after the impact event and hence the velocity was calculated at this time in all cases. (Note that for wall failure modes involving formation of large panels of masonry this assumption is likely to lead to a slight over-estimate the actual exit velocity, since the effect of base friction and/or the tendency for wall panels to potentially later rock backwards are both ignored).

Maximum debris velocity

The maximum velocity of the ejected debris was also taken from each model. However the values obtained appeared quite variable and the maximum debris exit velocity used in the parapet performance charts is twice the mean debris exit velocity. Figure A1 shows the relationship between the measured and assumed debris exit velocities, indicating that the assumption is generally conservative.

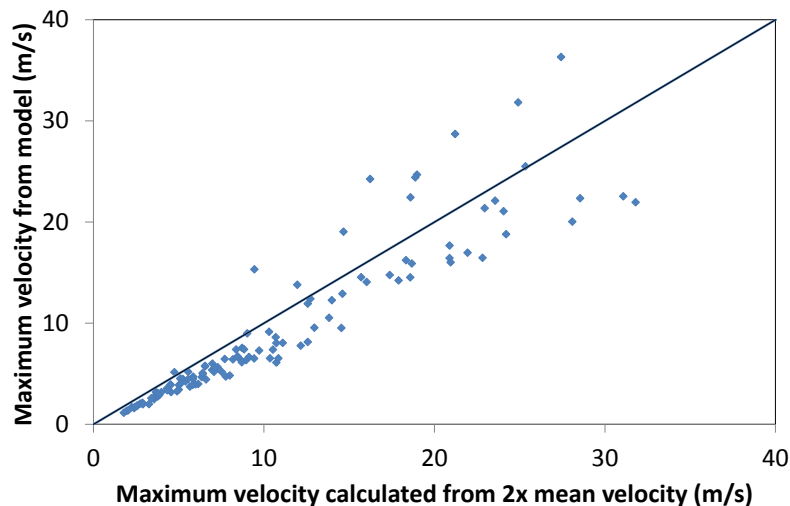


Figure A1 – Relationship between measured and assumed maximum debris exit velocities

A.4 Sample results from numerical simulations

Results from sample numerical simulations of impacts on masonry parapets are shown on Figures A2-A5; these illustrate the wide range of failure mechanisms likely to be encountered.

A.5 Influence of shear-bond strength

Although the numerical simulations indicated differences between the responses of walls constructed using ‘Strong’ and ‘Medium’ unit-mortar bond strength (e.g. see Figure A2), in terms of containment and debris ejection, differences between the responses were found to be generally very small, with walls employing the ‘Strong’ unit-mortar bond not always performing more favourably. Given of variability of individual numerical models it was considered pragmatic to combine the ‘Strong’ and ‘Medium’ results into a new ‘High’ unit-mortar bond category, as described in Section 3 of this guidance document.

A.6 Comparison with BS6779-4

Parapet thicknesses required to contain a vehicle differ from those presented previously in BS6779-4, as indicated in Table A4 and Table A5 for 80km/h and 110km/h impacts respectively.

The differences appear to be due to the following issues:

- In the new numerical models, which have been validated against carefully controlled laboratory tests, significant ‘strength’ arises from the micro-scale behaviour of joints, and in particular the initial dilation which causes ‘inertial clamping’ of joints. Hence the influence of parapet density is increased (i.e. relative to bond-strength).
- Because of the increased influence of parapet density, conservative results for low density parapets can justifiably now be calculated by scaling, although this may introduce some conservatism.
- In the new simulations it was found that higher vehicle speed did not necessarily adversely affect the ability of a parapet to contain a vehicle (see Appendix B.5 for a discussion of the physics underlying this phenomenon).
- In BS6779-4 a partial factor of 2.0 is applied to the bond strength for design purposes; no such factor is introduced here.

Table A4 – Comparison of BS6779-4 and current required wall thickness for vehicle containment (1m high wall, 80km/h)

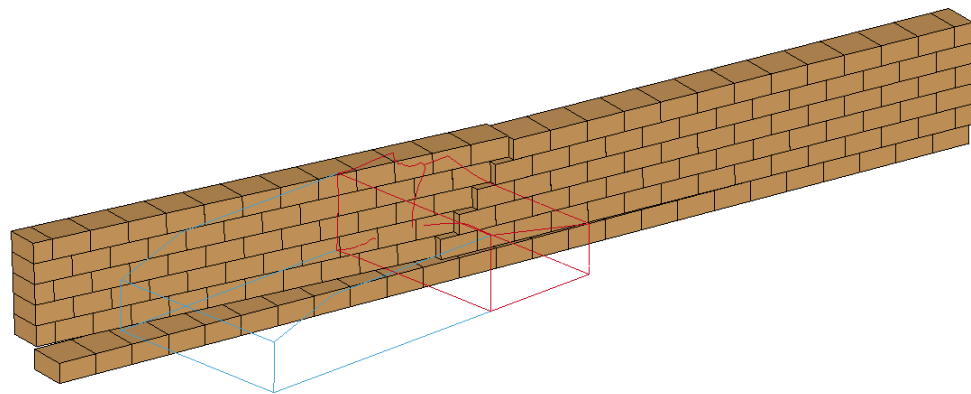
Current masonry strength descriptor	BS6779-4 masonry strength descriptor	Required wall thickness (mm)			
		BS6779-4		Current	
		Wall density 2200kg/m ³	Wall density 1300kg/m ³	Wall density 2200kg/m ³	Wall density 1300kg/m ³
'High'	'High'	275	340	285	480*
	'Medium'	315	350		
'Low'	'Low'	350	500	350	590*

* obtained by scaling, as described in section 3.3.4

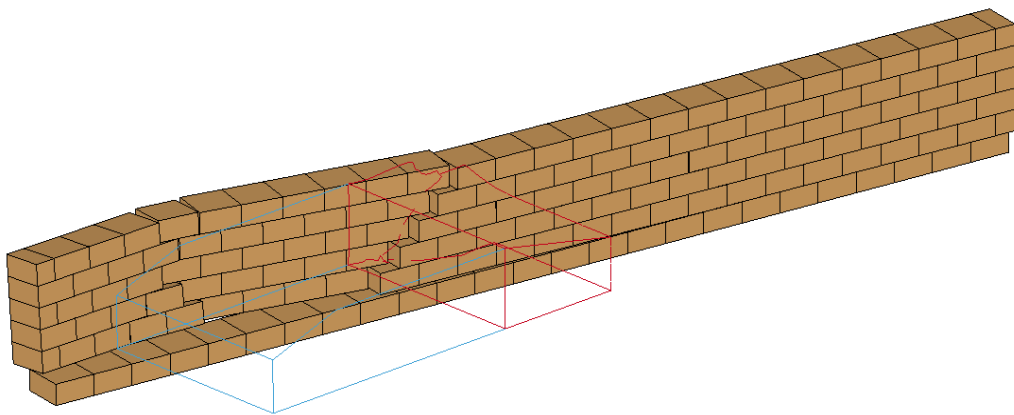
Table A5 - Comparison of BS6779-4 and current required wall thickness for vehicle containment (1m high wall, 110km/h)

Current masonry strength descriptor	BS6779-4 masonry strength descriptor	Required wall thickness (mm)			
		BS6779-4		Current	
		Wall density 2200kg/m ³	Wall density 1300kg/m ³	Wall density 2200kg/m ³	Wall density 1300kg/m ³
'High'	'High'	340	425	285	480*
	'Medium'	390	445		
'Low'	'Low'	435	>600	350	590*

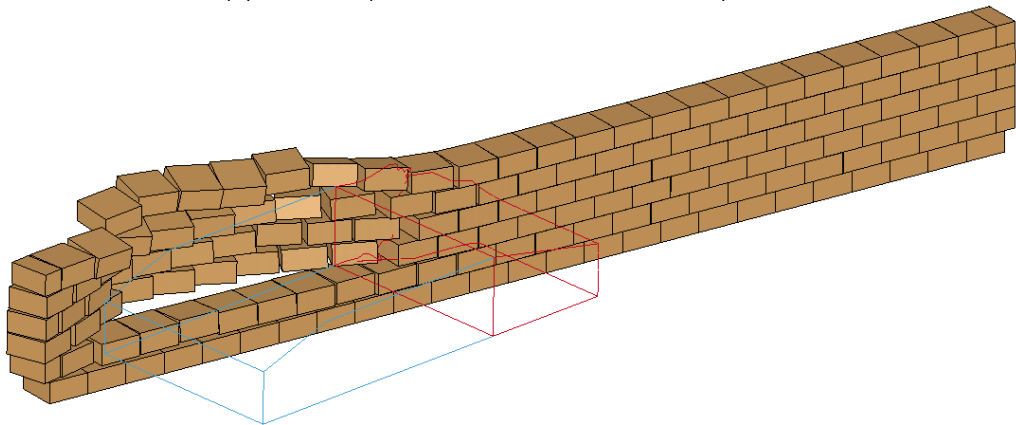
* obtained by scaling, as described in section 3.3.4



(a) High (V80-H1000-T400-S@160mS)

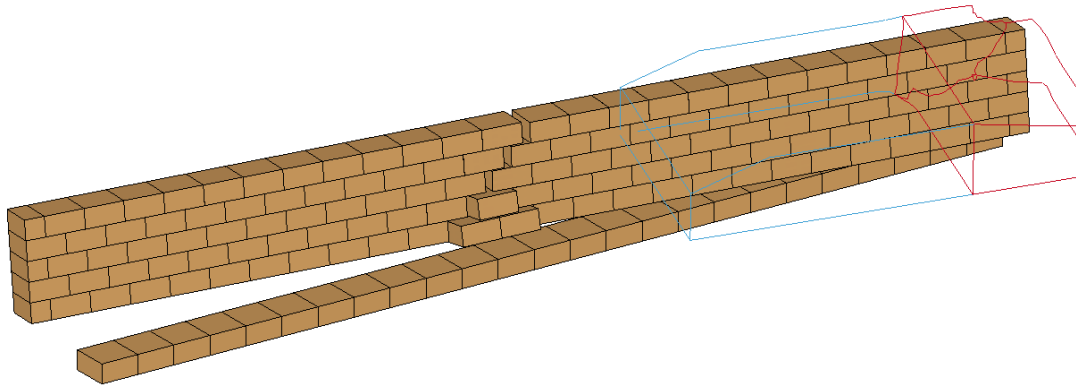


(b) Medium (V80-H1000-T400-M@160mS)

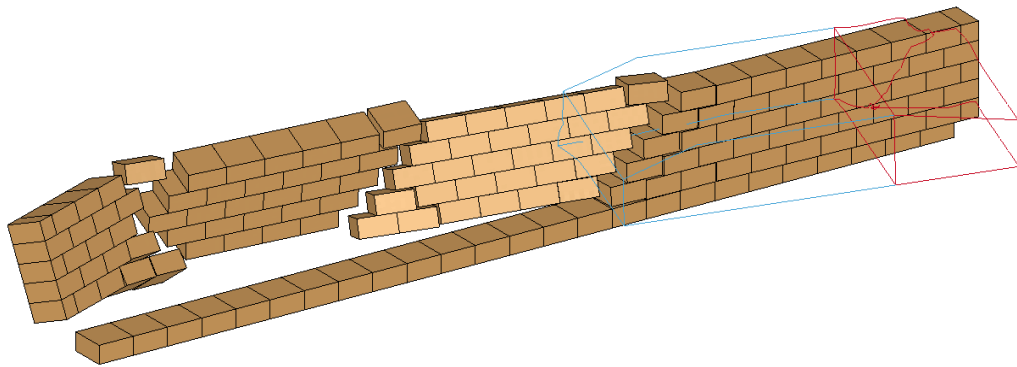


(c) Low (V80-H1000-T400-W@160mS)

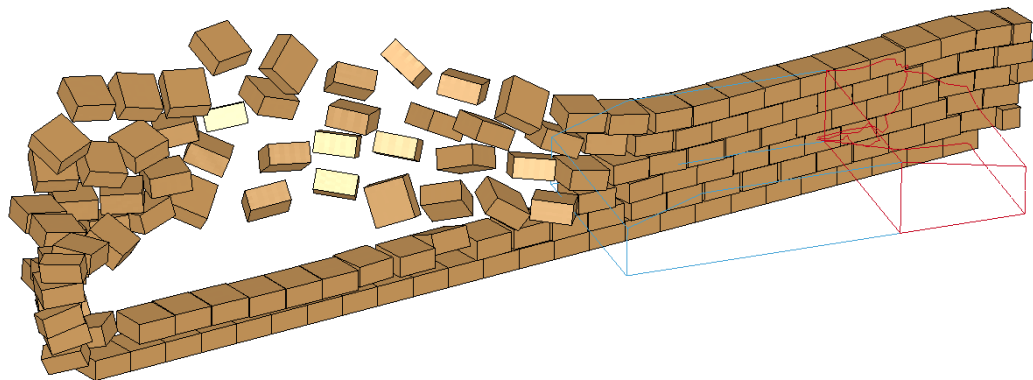
Figure A2 - 1.0m high walls: 'High', 'Medium' and 'Low' strength unit-mortar adhesion at 160mS
(Key: Velocity-Height-Thickness-Strong/Medium/Weak adhesion @ time)



(a) High (V80-H1000-T400-S@450mS)

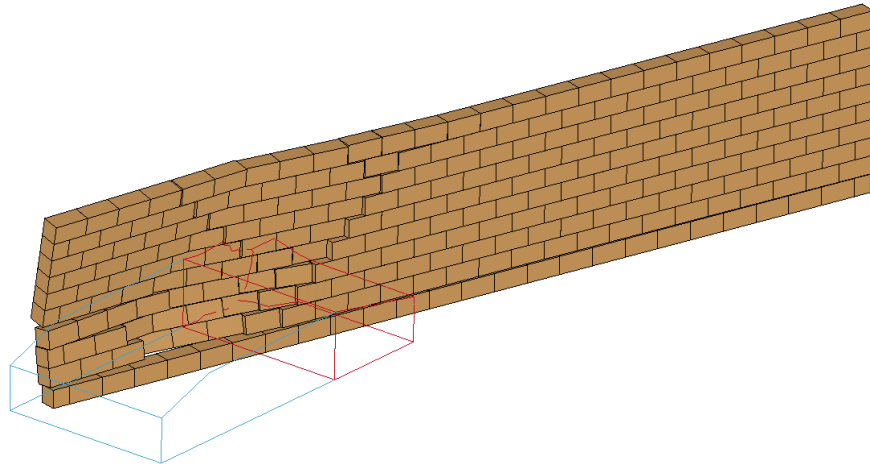


(b) Medium (V80-H1000-T400-M@450mS)

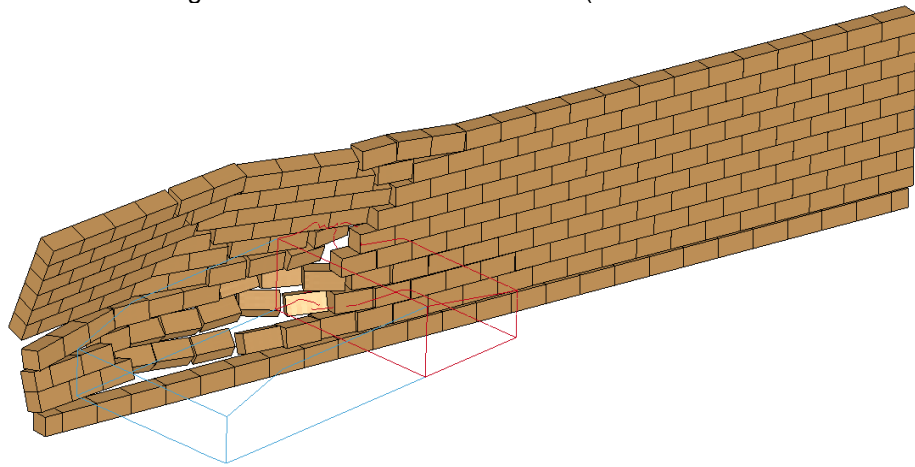


(c) Low (V80-H1000-T400-W@450mS)

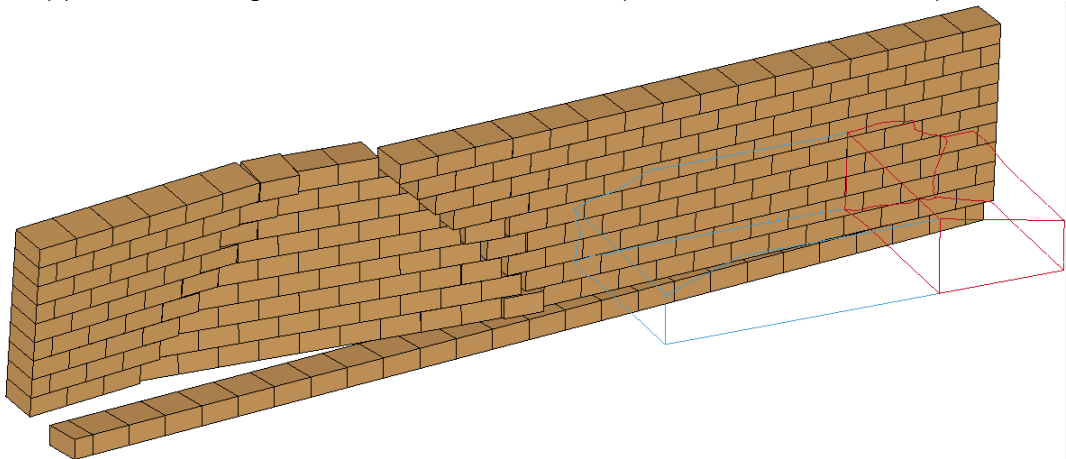
Figure A3 - 1.0m high walls: 'High', 'Medium' and 'Low' strength unit-mortar adhesion at 450mS
(Key: **V**elocity-**H**eight-**T**hickness-**S**trong/**M**edium/**W**weak adhesion @ time)



(a) Thin wall with high unit-mortar adhesion at 85mS (V80-H1800-T200-S@85mS)

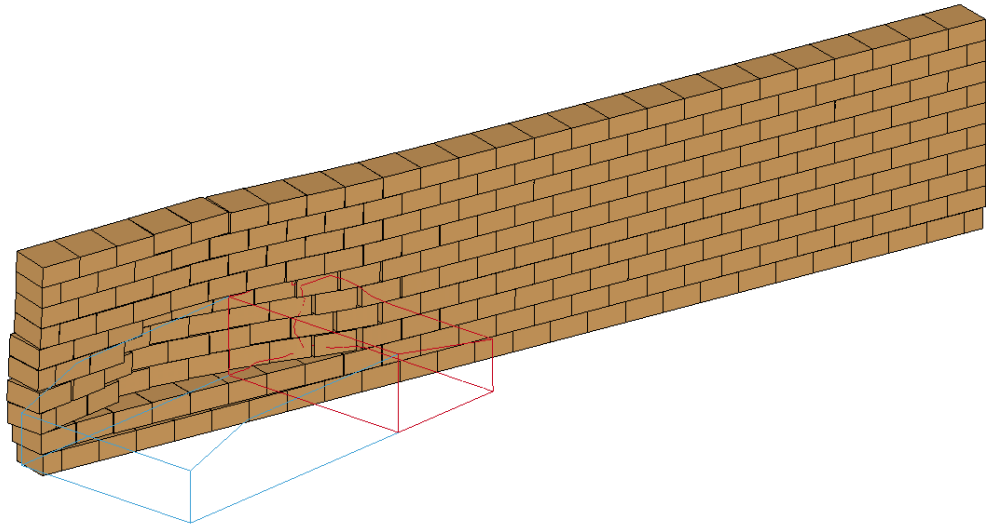


(b) Thin wall with high unit-mortar adhesion at 145mS (V80-H1800-T200-S@145mS)

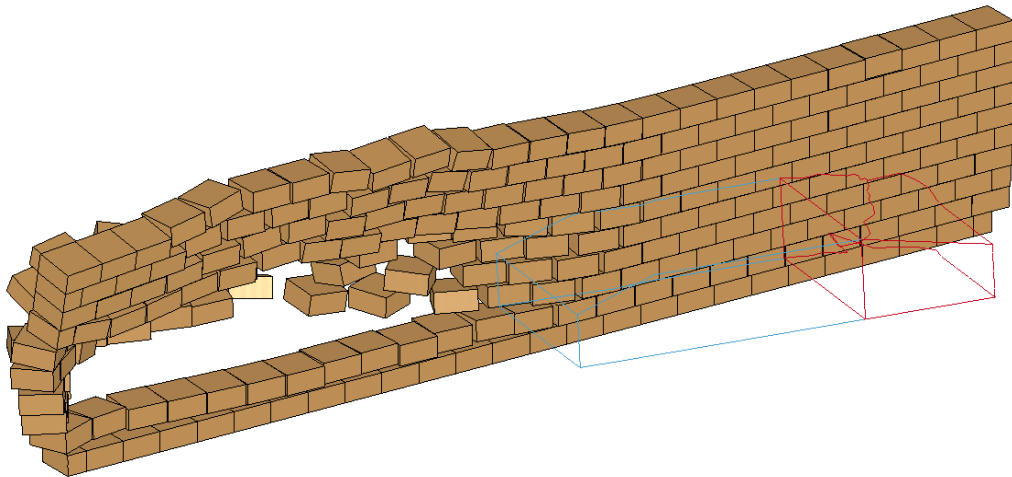


(c) Medium unit-mortar adhesion at 430mS (V80-H1800-T400-M@430mS)

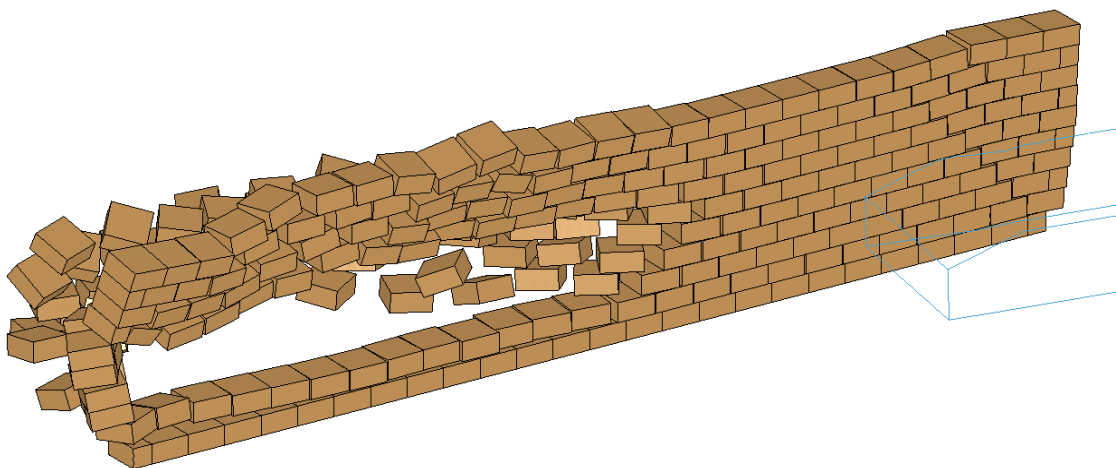
Figure A4 - 1.8m high walls: various thickness, strength and time configurations (Key: Velocity-Height-Thickness-Strong/Medium/Weak adhesion @ time)



(a) Low unit-mortar adhesion at 105mS (V80-H1800-T400-W@105mS)



(b) Low unit-mortar adhesion at 405mS (V80-H1800-T400-W@405mS)



(c) Low unit-mortar adhesion at 600mS (V80-H1800-T400-W@600mS)

Figure A5 - 1.8m high walls: low unit-mortar strength at various times (Key: Velocity-Height-Thickness-Strong/Medium/Weak adhesion @ time)

This page is intentionally blank

Appendix B – Basic Impact Mechanics

B.1 Introduction

This Appendix provides simplified calculations which describe the fundamental mechanics of a vehicle impact event. (Although the example calculations presented describe car impacts, the same basic principles can potentially be applied to non-articulated goods vehicle impacts.)

B.2 General approach

So-called 'equivalent static loads' are often used in the design of steel or concrete parapets but are generally not useful when modelling masonry parapets. This is because masonry parapets typically have low flexural strength but relatively high mass, and hence high inertial resistance to the short duration applied forces usually associated with a vehicle impact event. It is therefore generally more useful to instead consider the applied impulse and momentum transfer.

B.3 Applied impulse

For a car impacting a wall at an angle of 20 degrees, the force imparted on a wall can be approximated as a triangular impulse of overall duration 100mS. This allows calculation of the approximate peak force, F , as indicated on Figure B1.

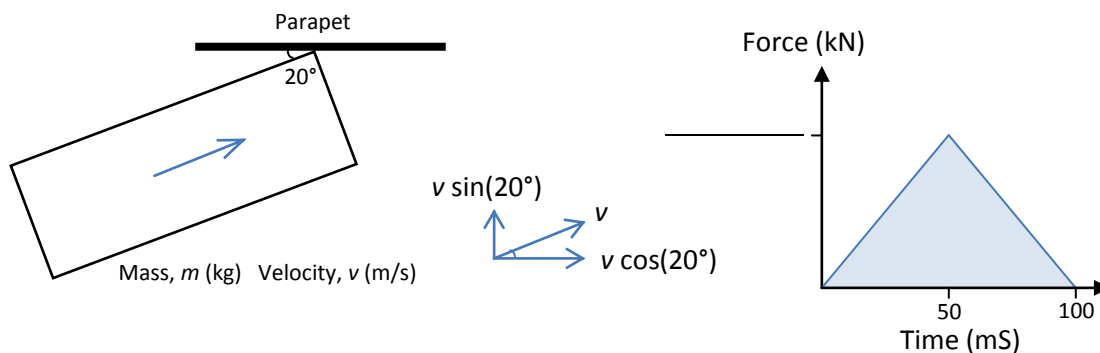


Figure B1 – Calculation of applied impulse

Note that in practice the precise form of the force-time history will depend on the specific characteristics of the vehicle and parapet involved. Figure B2 shows the situation for MIRA test parapet 1 (1500kg Rover SD1 impact at 100km/h), where the wall exhibited negligible visible damage following impact.

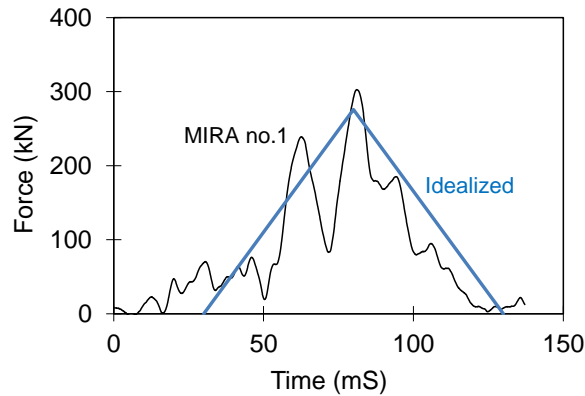


Figure B2 – Recorded and idealised force-time histories: MIRA test parapet 1 [1]

B.3 Momentum transfer

The proportion of the applied impulse which will be transferred into movements of the masonry will depend on the initial resistance of the wall and the form of the applied force-time history. Various outcomes are possible, as indicated in Table B1.

Momentum transfer considerations clearly show that a parapet wall composed of high density masonry can sustain a higher applied impulse than a comparable wall composed of low density masonry, and is therefore more capable of containing vehicles.

B.4 Potential parapet modes of response

The mechanical properties of the parapet will govern its specific mode of response, as indicated in Table B2.

Table B2 Influence of mechanical properties on mode of response of parapet

Mode	Masonry unit-mortar bond strength	Likely limiting mode of response
A	Low	Punching failure, involving ejection of individual masonry units
B	High	Fracture-lines delineating large panels of masonry
C	Very high	Global failure of parapet (sliding and/or overturning)

A failure involving formation of large panels of masonry is generally beneficial because the high inertia of the panels means that movements during the impact event will often be very small, often only becoming significant when the vehicle has safely been contained.

Table B1 Potential outcomes of the impulse generated during an impact event

Applied impulse in relation to wall resistance	Applied impulse and momentum transfer	Outcome
Low	<p>A graph with 'Force' on the vertical axis and 'Time' on the horizontal axis. A horizontal dashed line represents the 'Wall crack load' at level F_{cr}. A triangular force curve starts at the origin, rises to a peak below F_{cr}, and then falls back to zero. The area under the curve is shaded light blue.</p>	<p>Parapet resists peak force without cracking.</p> <p>Vehicle contained (though may suffer significant damage, depending on impact speed).</p>
Medium	<p>A graph with 'Force' on the vertical axis and 'Time' on the horizontal axis. A horizontal dashed line represents the 'Wall crack load' at level F_{cr}. A triangular force curve starts at the origin, rises to a peak exactly at F_{cr}, and then falls back to zero. The area under the curve is shaded light blue. The portion of the curve above the F_{cr} threshold is shaded dark blue.</p>	<p>Parapet cracks and remaining impulse / momentum is transferred to wall, leading to movement of the constituent masonry.</p> <p>Vehicle contained (though may suffer significant damage, depending on impact speed).</p>
High	<p>A graph with 'Force' on the vertical axis and 'Time' on the horizontal axis. A horizontal dashed line represents the 'Wall crack load' at level F_{cr}. A triangular force curve starts at the origin, rises to a peak above F_{cr}, and then falls back to zero. The area under the curve is shaded light blue. The portion of the curve above the F_{cr} threshold is shaded dark blue and labeled 'Wall failure & vehicle not contained'.</p>	<p>Parapet cracks, some momentum transfer to wall takes place but wall unable to sustain full impulse.</p> <p>Vehicle not contained and passes through the parapet.</p>
<p>Key: momentum transferred to masonry</p>		

B.5 Influence of vehicle speed

The applied impulse is a function of the mass m and velocity v of the impacting vehicle. For a 20° impact the impulse I can be calculated from:

$$I = mv \sin(20^\circ)$$

Therefore as vehicle speed increases, so the applied impulse increases, and it might therefore be expected that a vehicle travelling at an increased speed will always be more onerous to contain.

Although this is true for a parapet which fails due to a global failure mode (e.g. overturning), in other circumstances the effectiveness of the parapet in resisting an impact will often be largely unaffected by vehicle speed (as indicated by the parapet performance charts contained in the present guidance document). Consider for example a masonry parapet which fails due to punching failure of individual, effectively isolated, masonry units in contact with the vehicle. Because a vehicle impacting at higher speed moves a greater distance parallel to the wall during a finite duration impact event, a correspondingly increased volume of masonry will be available to resist the impact, thereby mitigating the effect of the increased speed.

Appendix C – Relationship with BS EN 1317

C.1 Introduction

BS EN 1317-2:1998 describes performance classes and acceptance criteria for road restraint systems, i.e.

- containment level, i.e. N1, N2, etc.;
- impact severity levels;
- deformation, as expressed by the working width, i.e. W1, W2, etc.

BS EN 1317-2:1998 is written in the context of the ‘product testing’ of metallic or concrete parapets, and is therefore not directly applicable to masonry parapets. The extent to which masonry parapets are capable of complying with the prescribed model of behaviour is outlined in this Appendix.

C.2 Acceptance criteria

Safety barrier behaviour

The extent to which the performance requirements described in Section 4.2 of BS EN 1317-2:1998 can be met by traditional masonry parapets is indicated in Table C1.

Table C1 – Safety barrier behaviour requirements

BS EN 1317-2:1998 requirement	Comment
‘The safety barrier shall contain and redirect the vehicle without complete breakage of the principal longitudinal elements of the system.’	Masonry parapets are capable of containing and redirecting vehicles but complete breakage of longitudinal elements will generally occur.
‘No major part of the safety barrier shall become totally detached or present an undue hazard to other traffic, pedestrians or personnel in a work zone.’	Parts of a masonry parapet will often become detached following impact; risk assessment calculations described in this guidance document can be used to determine whether the associated risk is acceptable.
‘Elements of the safety barrier shall not penetrate the passenger compartment of the vehicle.’	The particulate nature of masonry walls, and complex interactions which can occur on impact, means that it is not possible to eliminate the possibility of penetrations of the passenger compartment.
‘Deformations of, or intrusions into the passenger compartment that can cause serious injuries are not permitted.’	
‘Ground anchorages and fixings shall perform according to the design of the safety barrier system.’	Masonry parapets are generally designed without ground anchorages or fixings.

Vehicle behaviour

The extent to which the vehicle behaviour requirements described in Section 4.3 of BS EN 1317-2:1998 can be met by traditional masonry parapets is indicated in Table C2.

Table C2 – Vehicle behaviour requirements

BS EN 1317-2:1998 requirement	Comment
'The centre of gravity of the vehicle shall not cross the centreline of the deformed system.'	Can be expected to be satisfied if vehicle contained according to the parapet performance charts given in the present guidance document.
'The vehicle shall remain upright during and after impact, although moderate rolling, pitching and yawing are acceptable.'	
The vehicle will stay within a prescribed 'exit box' following impact.	

Impact severity

Accident Severity Index (ASI) values were extracted from the models used to produce the parapet performance charts presented in the present guide. The ASI values extracted were found to be strongly related to vehicle speed, and somewhat insensitive to specific parapet response. Impact severity levels A, B and C, as defined in BS EN 1317-2:1998, can be derived from these ASI values, as indicated on Table C3.

Table C3 – Impact severity level computed from simulations

Speed	ASI (min)	ASI (max)	Impact Severity Level*
80km/h	0.58	0.87	A (ASI < 1.0)
110km/h	0.91	1.28	B (1.0 < ASI < 1.4)

*Based on ASI only as PHD not computed

Note that the above ASI values are comparable to those derived from actual vehicle impact tests undertaken by the County Surveyors Society at MIRA [1], which ranged from 0.76 to 1.21, for various 60mph and 70mph impact tests.

Safety barrier deformation

BS EN 1317-2:1998 defines the 'working width' as the 'distance between the side facing the traffic before the impact of the road restraint system and the maximum dynamic lateral position of any major part of the system'.

In an impact event involving a masonry parapet the concept of 'working width' is not particularly useful due to the way in which a masonry parapet resists an applied impact: sections of a parapet will often become dislodged during the impact event, and may be ejected at a relatively high velocity (as indicated in the parapet performance charts contained in the present guidance document).

This page is intentionally blank

Appendix D – Movement Joints in Unreinforced Masonry Parapets

D.1 Background

The good practice guidance contained here is largely taken from BS6779-4 [2].

D.2 Guidance (after BS6779-4)

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

The containment / parapet performance charts have been devised for parapets without any movement joints and are applicable for impacts occurring a minimum distance of 1m from the end of the parapet. The charts are applicable for parapets with movement joints, and panel lengths not less than 10m, 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 should conform to Table D1. Intermediate values may be determined by linear interpolation.

Table D1 Shear transfer at movement joints

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

The shear transfer arrangement should 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 should 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 $Y_m = 2$ should be applied to the average of the test results for design purposes.

Tests using a class (iii) mortar (1:1:6) in accordance with BS 5628-3 [21] (equivalent to an M4 mortar as defined in the UK National Annex of BS EN 1996-1-1) in conjunction with class B engineering clay bricks in accordance with BS 3921 [22] showed that 10mm diameter stainless steel dowel bars in 12mm thick bed joints had an average shear resistance of 4.2kN per dowel over a deflection in excess of 50mm prior to failure. There were a pair of dowels in a bed joint projecting 150mm each side of the joint. Stainless steel dowel bars 16mm diameter in 20mm thick bed joints had a similar average shear resistance. Failure in each case was due to loss of 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 0.13kg/m²/min to 0.19kg/m²/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 1m high parapet will provide an adequate shear connection.

This page is intentionally blank

Appendix E – Containment of Drystone Parapets

E.1 Background

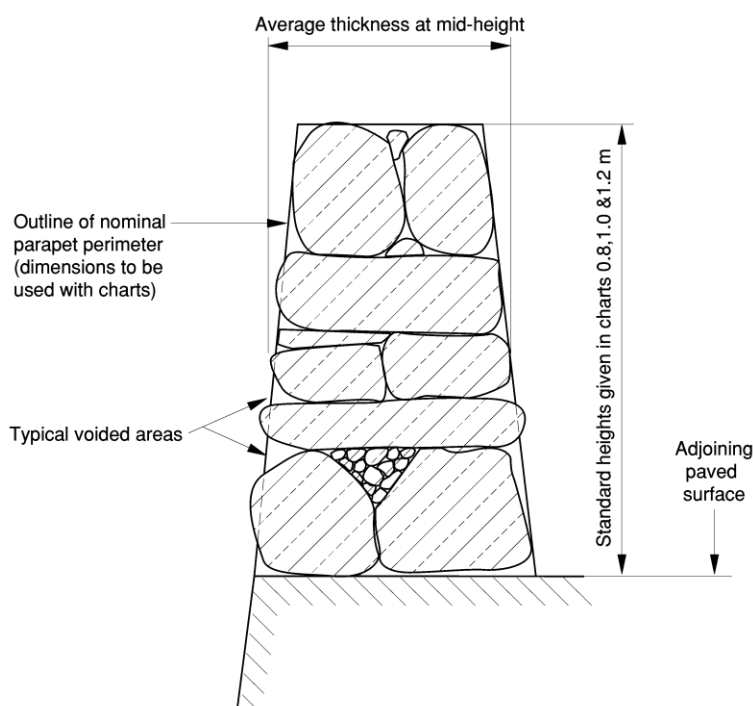
The good practice guidance contained here is based on that given in BS6779-4 [2].

E.2 Containment chart: design of drystone parapets, and unreinforced masonry parapets with masonry units of slate or similar smooth or impervious material

The parapets should be designed or assessed using the containment chart in Figure E1.

NOTE: The chart is based on an assumed effective density of the parapet of 1920kg/m^3 which is equivalent to the parapet being constructed of stone with a density of 2250kg/m^3 and having a 15% void ratio (i.e. 15% voids 85% stone). The sketch shown in Figure E2 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 should be assumed to provide containment by mass alone. Consequently, when designing parapets using the containment chart, adjustments should 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 = thickness determined from chart x $(1920 / \text{effective density of masonry to be used})$.



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

Figure E2 Drystone construction showing the basis for determining voids percentage

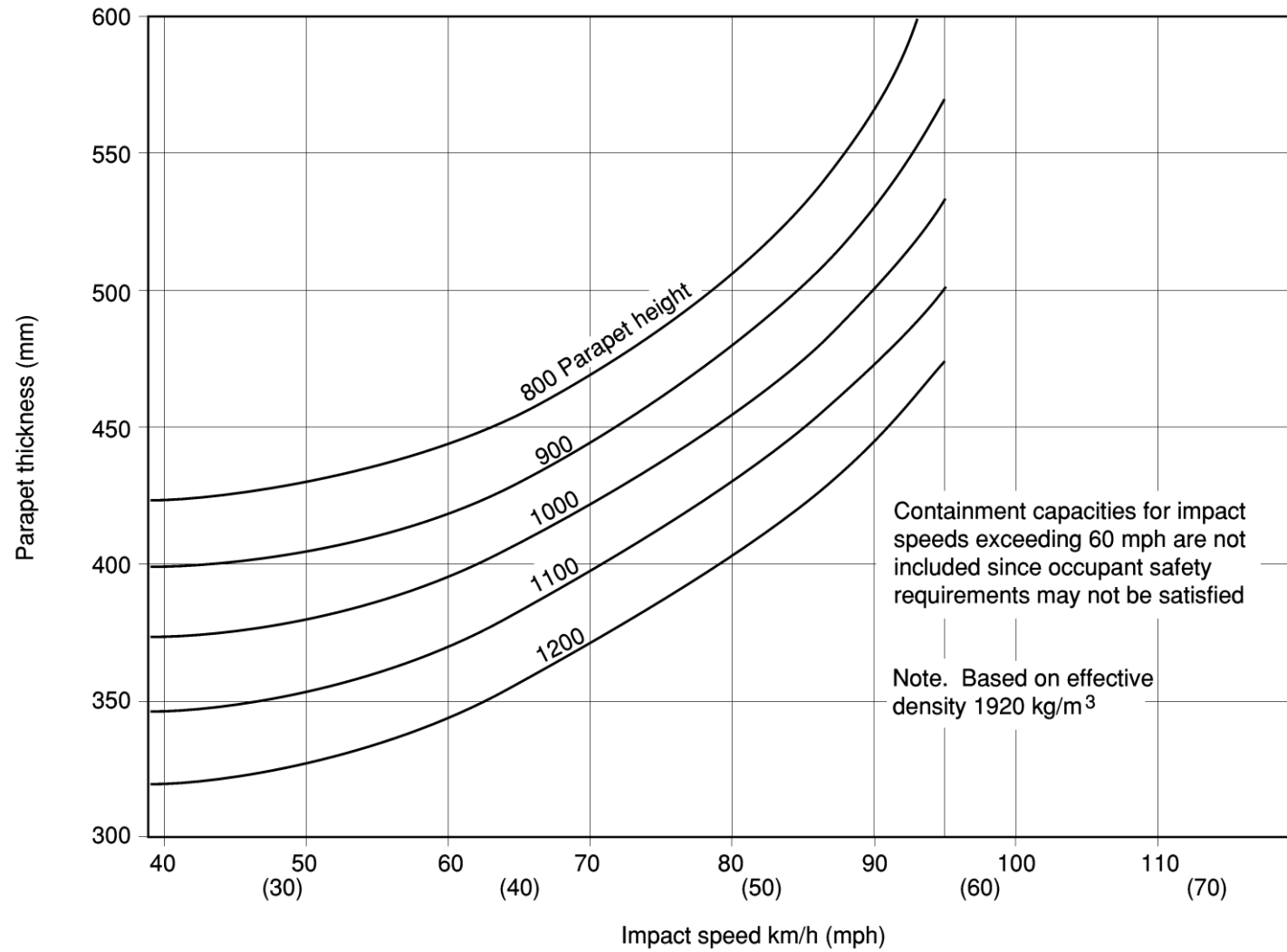


Figure E1 Containment chart, drystone or mortared slate or similar parapets

Appendix F – Retrofit Reinforcement: Sample Calculation

F.1 Design objective

Enhance the containment capacity of an existing 10m long, 1m high, 330mm thick, weakly mortared brickwork parapet to allow it to contain cars travelling at 110km/h.

F.2 Design approach

The following design approach is suitable when a parapet with 'low' shear-bond strength needs to be upgraded to that of a parapet with 'high' shear-bond strength. (The example parapet is only capable of containing a car travelling at 110km/h if the shear-bond strength is 'high'; see Figure 3.)

Steps:

1. Assume a notional quasi-static out-of-plane force F is applied at the end of the parapet.
2. Calculate the maximum bending moment in the parapet M_{static} when F is sufficient to cause sliding of the parapet on its base ($F = F_{static}$).
3. Specify reinforcement to (i) ensure M_{static} can be resisted, and (ii) to enhance the overall ductility of the parapet.

Commentary: The rationale is that although the peak force associated with an actual vehicle impact will generally be much higher than F_{static} , and once movements commence inertial effects will change the bending moment distribution (leading to moments in excess of M_{static} in some locations), the reinforced section can be designed to deform in a ductile manner and to hold the parapet together during a short duration impact event, absorbing energy and ensuring that a large volume of masonry is mobilised in resisting the impact. (This has been verified in laboratory impact tests [10].)

However, it should be noted that introduction of reinforcement which ensures the parapet behaves effectively as a monolith will increase the likelihood of the entire reinforced parapet from sliding off the supporting structure and/or overturning following a heavy impact. Although this will often occur after an errant car has successfully been contained, additional checks should be made if this type of behaviour is unacceptable.

F.3 Calculations

Design data:

- Estimated wall density = 2200kg/m³
- Coefficient of friction at base = 0.6
- Acceleration due to gravity = 9.81m/s²

Steps:

1. Calculate out-of-plane quasi-static force applied at end of wall required to cause parapet to slide on its base (in the mode indicated in Figure F1):

$$F_{static} = q * (x_{rot} - l_w)$$

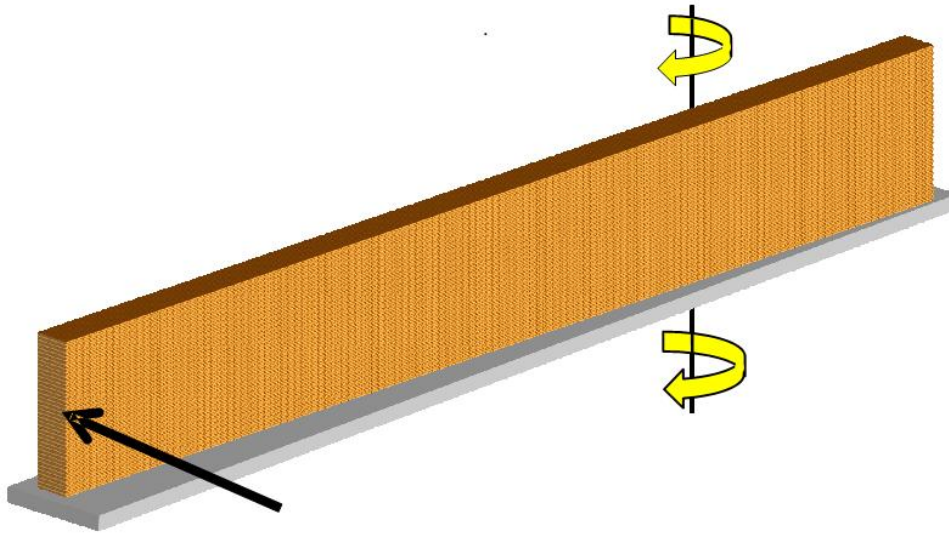


Figure F1 Assumed mode of response of parapet

Where q is the resistance to sliding per unit length, l_w is the wall length and x_{rot} is the distance of the centre of rotation of the parapet from the leading end, which from statics can be shown to be equal to $l_w/\sqrt{2}$, leaving:

$$F_{static} = 0.414 * q * l_w$$

2. Calculate maximum pseudo-static moment M_{static} in the parapet:

The moment at any point x from the leading edge of the parapet can be determined from statics to be:

$$M_x = \frac{q * x^2}{2} - 0.414 * q * l_w * x$$

The maximum moment will occur when the shear force is zero, i.e. when $x = 0.414 * l_w$, so that the maximum moment can be shown to be:

$$M_{static} = -0.0875 * q * l_w^2$$

Substituting $q = \mu * m_x * g$ gives:

$$M_{static} = -0.0875 * \mu * m_x * g * l_w^2$$

Where μ is the coefficient of friction, m_x is the mass per metre length and g is the acceleration due to gravity. Now substituting in the design data gives:

$$M_{static} = -0.0875 * 0.6 * 2200 * 0.33 * 9.81 * 10^2 = -36.6 * 10^3 \text{ Nm} = -36.6 \text{ kNm}$$

3. Design reinforcement to provide M_{static}

Diagonal reinforcement (see Figure 4) should be designed to ensure the moment $M_{static} = 36.6 \text{ kNm}$ can be resisted along the full length of the parapet, according to the principles outlined in BS EN1996. Reduced partial factors can be used at the discretion of the engineer to account for the fact that the construction is not new. The reinforcement should be detailed to ensure the response is as ductile as possible.

Appendix G – Calculation of Risk

G.1 Introduction

Risk is calculated as: likelihood x consequence

The likelihood is the inverse of the frequency of impact, where frequency is defined as the ‘return period’.

Note that the risk calculations described herein differ from those applied previously in a number of respects – see Appendix H.

G.2 Likelihood

When site data is not available a formula for the return period can be used:

$$T_0 = f(\text{AADT}) * (\text{EF}) \quad \text{Equation G1}$$

Where:

- i. AADT is the average daily two-way daily traffic flow on the road adjacent to the parapet (or twice the AADT on roads with one-way traffic).
- ii. EF is a factor which is related to the conditions of the site, expressed as “site environmental factor” and derived from Table G1.
- iii. T_0 is a notional return period. This notional return period is calculated and is used as the “likelihood” component of the risk calculation. This may be expressed in further definitions as T_{C80} (for general vehicles at 80km/h), T_{C110} (for general vehicles at 110km/h), or T_{L60} (LGV at 60km/h).

G.2 Environmental Factor

There are several other potential factors which influence likelihood. Using principles described in IAN97/07 [18], the environmental modification factor to use is the sum of the factors listed in Table G1, selected from those used in Appendix B tables in IAN97/07 that affect likelihood. As far as reasonably possible, the same scoring has been used to maintain consistency and to enable any existing analysis to be re-used without significant re-working.

Lowest possible total of these environmental factors = 5 (best possible condition)

Highest possible total = 34 (worst condition)

Table G1 Environmental Factors (based on IAN97/07)

Factor	Score (derived from IAN97/07)
Road Alignment (Horizontal)	Score 1 for straight road with at least 7.3m carriageway Score 3 for straight less than 7.3m carriageway or curved at least 7.3m carriageway Score 7 for curved road less than 7.3m carriageway Score 10 for reverse curves less than 7.3m carriageway
Road Alignment (Vertical)	Score 1 for level or constant grade Score 2 for gentle gradients and/or slight hump back Score 3 for moderate gradients and/or hump back with inter-visibility Score 5 for steep gradients and/or hump back with no inter-visibility
Speed of traffic	Score 1 for <10mph Score 3 for <30mph (or less) Score 5 for <50mph Score 7 for <70mph
Road Verges and Footpaths	Score 1 for at least 2m on both sides Score 2 for at least 1m on both sides Score 3 for one or both verges less than 1m
Other hazards increasing likelihood of RTA.	Score 1 for no obvious additional hazards, including no significant risk of freezing Score 5 for single site specific hazard including risk of freezing conditions. Score 9 for multiple minor hazards or single major hazard. e.g.: farm access, road junction, private driveway, lay-by, nearby junctions, bus stop, school, hospital, additional visibility limits (consider overhanging trees), etc

G.3 Derivation of Return Period T_0

The maximum result for the Site Environmental factor (EF) is 34.

The following means of calculating T_0 is proposed:

$$T_0 = K (35 - EF) / (\text{AADT score}) \quad \text{Equation G2}$$

This notional formula is arranged so that a high environmental factor (poor road conditions) and high traffic flow will reduce the return period.

K is a constant used to adjust the range of T_0 to within what may be realistically anticipated, and is derived empirically. When making an empirical estimation for a reasonable value of K, it is to be noted that the extreme ranges of EF are unlikely to occur because of the unusual combination of factors required (such as wide, straight but very slow speed roads, or otherwise narrow, sharply curving but high speed roads). EF is more likely to vary between a minimum of 10 and maximum of 30.

After testing various values, a K value of 5 is considered to give a realistic result for T_0 and which results in a meaningful risk calculation.

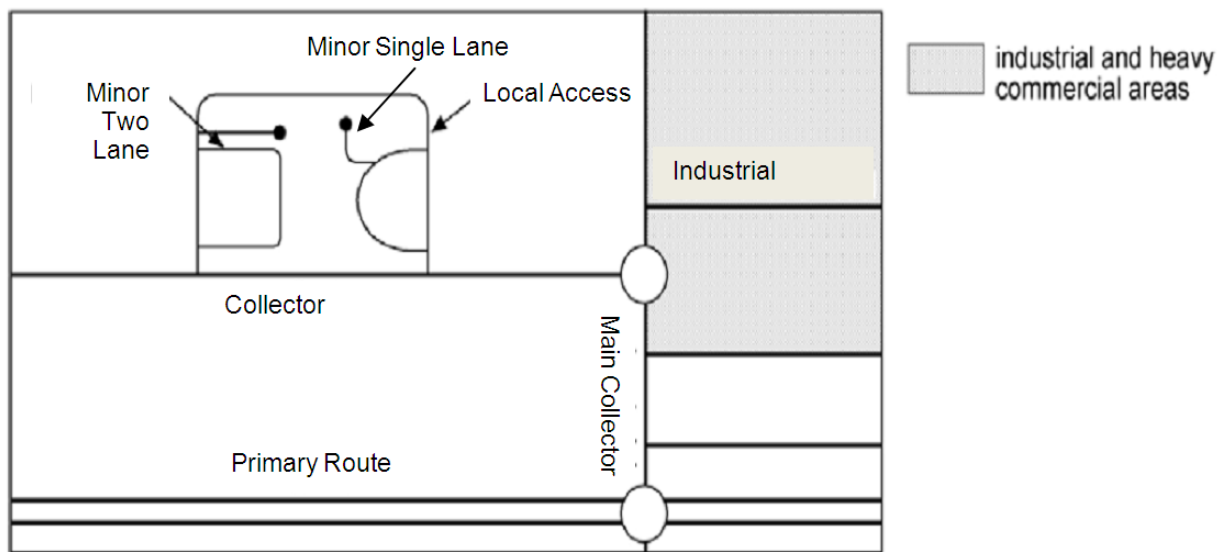
The 'AADT score' given in Table G2 has been derived specifically for this purpose:

Table G2: Derivation of “Score” equivalent for AADT.

AADT Score	AADT	Typical description	
1	<50	Minor single lane (generally green lane or farm access)	
2	50 – 100	Minor two lane (generally unclassified)	
3	101 – 500	Local access (generally C or B class)	
4	501 – 1,500	Collector (no buses)	(generally 'Other Strategic' roads)
5	1,501 – 5,000	Collector (with buses or industrial)	
4	501 – 1,500	(generally 'Primary Routes') Usually, roads of sufficient size will either have a known AADT or can be “deduced” by comparison to a nearby road that does.	
5	1,501 – 5,000		
6	5,001 – 20,000		
7	20,001 – 40,000		
8	40,001 – 60,000		

Where AADT figures are not known, they can be estimated based on the class and character of the road.

The following Figure G1 is adapted from Austroads Pavement Structural Design Guide (AGPT02/10) [23], and can be used to identify the road types (as “Typical Description” in Table G2).

Figure G1: Typical Descriptions of Road Types

The notional return period T_0 can then be calculated from:

$$T_0 = 5 * (35 - EF) / (\text{AADT score}) \quad \text{Equation G2}$$

The results are listed in Table G3, which is simply a 'look up' table using the above formula.

G.4 Consideration of LGV impact

As noted in the introduction, impact performance of unreinforced masonry parapets is considered only for N1 and N2 containment levels, and so LGV impact is not included. It is, however, possible to apply the same process as for other vehicles to arrive at a return period T_{L60} (see Table 7). The results arising from this are more notional than precise, but could be used as an additional tool for the purpose of comparisons of different sites and for prioritisation work. It is suggested that this is more useful where the LGV flow is significantly different at the sites being compared.

From "Land Transport Accident Statistics" [24] the road accident fatality rates on all roads for cars are given as four times the rate for LGVs.

From Equation G2, T_{L60} can then be calculated from:

$$T_0 = 20 * (35 - EF) / (\text{AADT score}) \quad \text{Equation G2A}$$

Table G3: T_0 for different site environmental factors (from Table G1) and AADT Score (from Table G2)

AADT	8	7	6	5	4	3	2	1
EF	T₀							
5	18.750	21.429	25.000	30.000	37.500	50.000	75.000	150.000
6	18.125	20.714	24.167	29.000	36.250	48.333	72.500	145.000
7	17.500	20.000	23.333	28.000	35.000	46.667	70.000	140.000
8	16.875	19.286	22.500	27.000	33.750	45.000	67.500	135.000
9	16.250	18.571	21.667	26.000	32.500	43.333	65.000	130.000
10	15.625	17.857	20.833	25.000	31.250	41.667	62.500	125.000
11	15.000	17.143	20.000	24.000	30.000	40.000	60.000	120.000
12	14.375	16.429	19.167	23.000	28.750	38.333	57.500	115.000
13	13.750	15.714	18.333	22.000	27.500	36.667	55.000	110.000
14	13.125	15.000	17.500	21.000	26.250	35.000	52.500	105.000
15	12.500	14.286	16.667	20.000	25.000	33.333	50.000	100.000
16	11.875	13.571	15.833	19.000	23.750	31.667	47.500	95.000
17	11.250	12.857	15.000	18.000	22.500	30.000	45.000	90.000
18	10.625	12.143	14.167	17.000	21.250	28.333	42.500	85.000
19	10.000	11.429	13.333	16.000	20.000	26.667	40.000	80.000
20	9.375	10.714	12.500	15.000	18.750	25.000	37.500	75.000
21	8.750	10.000	11.667	14.000	17.500	23.333	35.000	70.000
22	8.125	9.286	10.833	13.000	16.250	21.667	32.500	65.000
23	7.500	8.571	10.000	12.000	15.000	20.000	30.000	60.000
24	6.875	7.857	9.167	11.000	13.750	18.333	27.500	55.000
25	6.250	7.143	8.333	10.000	12.500	16.667	25.000	50.000
26	5.625	6.429	7.500	9.000	11.250	15.000	22.500	45.000
27	5.000	5.714	6.667	8.000	10.000	13.333	20.000	40.000
28	4.375	5.000	5.833	7.000	8.750	11.667	17.500	35.000
29	3.750	4.286	5.000	6.000	7.500	10.000	15.000	30.000
30	3.125	3.571	4.167	5.000	6.250	8.333	12.500	25.000
31	2.500	2.857	3.333	4.000	5.000	6.667	10.000	20.000
32	1.875	2.143	2.500	3.000	3.750	5.000	7.500	15.000
33	1.250	1.429	1.667	2.000	2.500	3.333	5.000	10.000
34	0.625	0.714	0.833	1.000	1.250	1.667	2.500	5.000

G.4 Consequence calculations

Spacing of vehicles is based on simple calculation of speed divided by rate of flow, and can be calculated using equation G3:

$$\text{Spacing} = \left(\frac{\text{Road speed in km/h}}{\text{AADT}/24} \right) * 1000 \quad \text{Equation G3}$$

The number of vehicles struck directly, N_{direct} can be calculated as debris spread divided by spacing, and can be calculated using equation G4:

$$N_{direct} = \left(\frac{\text{Debris spread}}{\text{Spacing}} \right) \quad \text{Equation G4}$$

Where debris spread is derived from Table 8, and spacing from Equation G3.

G.5 Calculation for indirect impacts

Consider ‘vulnerable vehicles’ moving along a road beneath a parapet just impacted by an errant vehicle. Some ‘vulnerable vehicles’ will be struck directly by falling debris, and other vehicles will collide with fallen debris because they cannot stop in time.

Research shows that the 50th percentile speed for seriously injured drivers is 24 mph and for fatally injured drivers is 34 mph [25].

A 30mph road presents relatively low risk, because drivers may be assumed to have opportunity to mitigate impact by swerving, and are in any event unlikely to be fatally injured.

‘Vulnerable distance’ = thinking distance + distance required to slow down to 34mph

Results for this calculation are shown in Table G4, (the source data for the thinking and stopping distance are published in the Highway Code).

The number of vehicles which are in indirect impact with debris, $N_{indirect}$ is calculated as the number of vehicles not able to slow down to a safe speed in time to avoid hitting debris, and can be calculated from equation G5.

Table G4 Number of vulnerable vehicles indirectly affected per impact event

Road Speed	mph	40	50	60	70
	km/h	64	80	97	113
Thinking distance		12	15	18	21
Stopping distance		24	38	55	75
Slowing distance (to safer speed, 34mph)		20.4	25.8	31.2	36.4
Total slowing distance to safer speed		32.8	40.8	49.2	57.4

$$N_{indirect} = \left(\frac{\text{Total slowing distance to safer speed}}{\text{Spacing}} \right) \quad \text{Equation G5}$$

Where the total slowing distance to safer speed is derived from Table G4, and spacing from equation G3.

This page is intentionally blank

Appendix H – Comparison with other risk assessment approaches for bridge parapets.

Summary

Other existing risk assessment methods for bridge parapets are discussed, namely the method described in IAN 97/07 [18], a method used for TfL bridges [26], and that described in BS6779 part 4 [2].

IAN 97/07 method

IAN 97/07 (Interim Advice Note 97/07, Assessment and Upgrading of Existing Vehicle Parapets) is a risk based approach, based on TD19/06.

IAN 97/07 uses a step by step system of risk assessment, which can be summarised very briefly as follows:

- 1) Assess R_{inc} = incursion risk ranking score, based on 14 factors.
- 2) Assess remnant proportion of capacity compared to required capacity.
- 3) Assess remnant proportion of capacity compared to minimum “allowed” capacity.
- 4) Assess R_{ALARP} : based on the formula:
(Traffic Volume) x (Containment factor) x (site features factor) x (ease of upgrade).

An advantage of using IAN 97/07 for the assessment of masonry parapets is that it is an established method, with a body of experience in using it already established. It would also allow for possible comparison with other non-masonry parapets which also use the same methods.

However, there are various difficulties to consider if trying to apply IAN 97/07 specifically to masonry parapets, which are summarised briefly below (in no particular order):

1. The method compares the parapet to the defined qualities of “required” and “allowed” capacity. This comparison is suitable when comparing different types of parapets, but not so useful when comparing different masonry parapets.
2. The method requires assessment of remnant capacity to be expressed as a proportion of required containment. This is based on engineering judgement in three categories: 0-33%, 33-66% and 66-100%: this may be difficult to judge for masonry parapets.
3. The factor for “Site features” includes types of parapet, which is not a variable if only masonry parapets are considered.
4. The “Ease of upgrade factor” is not really a safety issue, and seems to be in a different category to all other factors considered. It may be better to assess this completely separately, after the other safety related items.
5. R_{inc} is noted as not needing to be assessed in road over road cases where the two-way AADT on either the upper or lower road is less than 25000. This would eliminate the need to use R_{inc} for most if not all masonry parapets which tend not to feature on roads with such high volumes of traffic.
6. There are no factors related to the risk of detachment of masonry, which is an important risk factor.

7. The outcome is to define risk into one of: “very low”, “low”, “medium” or “high”. Anything more than “very low” is designated for upgrading. These rather definite outcomes from the risk assessment may result in a large proportion of masonry parapets being designated for upgrading, which would be impractical.

The following points apply generally to the IAN 97/07 process, and not only to how it can be applied to masonry parapets:

8. It is unclear how the scoring of the 14 factors for R_{inc} are weighted. For example, scoring for factors ranges between 1-24 (for approach containment) to 1-3 (for verges and footpath). This means that there has been some decision that approach containment is effectively eight times more important than the width of the verges, but it is not clear how this decision has been reached.
9. The inclusion of “ease of upgrade” as a factor does not seem to fit with the overall intent to consider safety risk factors. The ease of upgrade factor would seem to fit better into a cost-benefit or value management exercise to be carried out subsequent and separate to the risk assessment.
10. The factor for road speed considers the actual speed, but this is difficult to judge and may need a traffic survey to be carried out – this may not be practical to carry out for every parapet.

Parts of the IAN97/07 method are however used or applied herein:

- The basic principle of the factors used to identify “site features” and the ways in which they are defined.
- The basic principle of how R_{ALARP} is calculated by multiplying factors together including one based on traffic volume and one based on the site factors.

TfL Method

A parapet prioritisation study was carried out by Hyder for TfL in June 2009 [26]. The Hyder study recognised that IAN 97/07 is best suited for use on the stock of structures for which the Highways Agency is responsible, and attempted to devise a method more suited to the TfL road network.

The stated intent of the Hyder study was to produce “a very high level assessment methodology”. A series of relevant factors were first identified, based on the same principle as the factors identified in IAN97/07. An algorithm was used to derive a weighting / scoring system for the identified factors.

The key formula used for the scoring of parapets was:

$$P_s = I_s * C_s / M_f$$

Where:

P_s = parapet score (subsequently converted into an “index” by expression as a percentage of P_s max).

I_s = incidental score: based on properties of the road and parapet (8 factors)

C_s = consequential score – based only on what the parapet is over.

M_f = mitigation factor – based on 6 factors:

An additional and separate “confidence factor” was also used, based on how much is known about the bridge in question.

However, there are various disadvantages or difficulties to consider if trying to apply the TfL method specifically to masonry parapets, which are summarised briefly below (in no particular order):

1. There are 8 factors used to determine the “incidental score” and 4 factors used to determine the “mitigation factor”, but all of these apply to any sort of parapet, potentially leading to inadequate differentiation between different masonry parapets.
2. The mitigating factors include “parapet type” which is not a variable when considering only masonry parapets.
3. The mitigating factors include a “vulnerability factor” which has no clear definition except engineering judgement.
4. The factors do not account for the risks associated with detached masonry.

The following points apply generally to the TfL method, and not only to how it may apply to masonry parapets:

1. The 8 factors used to determine the incidence factor include volume of traffic. In comparison IAN 97/07 considers traffic volume important enough to be an independent factor. The inclusion of volume into the general calculation reduces its impact on the overall outcome.
2. It is unclear how mitigating factors are distinguished from the incidence factors. For example: “proximity to traffic”, is included as a mitigation factor but would seem to fit just as well in the incidence factor list.
3. The confidence factor seems like a good idea in principle, but the scoring system attributed to the availability of the various factors used to build up the score seems a little arbitrary. For example, there is a score of between 0 and 6 depending on the completeness of the Form 277 record. The result, built up from adding up scores from several factors, gives a rather scientific appearance to what is really an estimation tool.
4. The algorithm used to determine the weighting factor is based on the analytical hierarchy technique. This system assumes that the parameters are initially theoretically equal, and then a weighting is arrived at by comparing each pair in turn. The outcome is a weighting factor expressed to three decimal places, appearing to be very precise but actually arrived at by a series of engineering judgements between separate pairs of factors.

The scoring system is very thorough, and derives values for ‘Incidental Score’, ‘Consequential Score’ and ‘Mitigation Factor.’

The value of I_s (Incidental Score) is calculated using the following:

- Traffic volume.
- Traffic Speed.
- Traffic Manoeuvres/Junctions.
- Highway Alignment (Horizontal and vertical)
- Carriageway Configuration.
- Parapet Length (including proportion protected by safety fence)
- Visibility
- Highway Interactions (other issues about road use etc).

The value of C_s (Consequential Score) is calculated using the following:

- Railways
- Industrial and utility complexes
- Highway adjacent to or below
- Schools, hospitals, social complexes, car parks and recreational areas.
- Residential Properties

Value of M_f (Mitigation Factor) is calculated using the following:

- Parapet Type.
- Proximity to Carriageway.
- Orientation to Direction of Travel.
- Parapet Condition Factor.
- Additional Vehicle Restraint System.

Score Calculation:

The table below describes the scoring system and provides a commentary on how it is implemented for a specific example (extracted from the Hyder/TfL document).

Table H1: TfL Scoring system and examples

	System	Example
1	Various Characteristics are attributed to each factor	Characteristics of parapets types are listed, ranging from Cast Iron through to P6 or H4a.
2	A Value is attributed to each factor. The decision for this value appears to be based on judgement alone, and no explanation is given.	Values range from 10 for H4a or P6 type parapets to 1 for cast iron or P4 types (masonry parapets are given a value of 3)
3	The Factor is decided, in some way proportional to the Value.	In the example of parapet type, the Factor is equal to the Value.
4	The Range is simply the difference between the maximum and minimum possible Factor.	The range for parapet types is from 1 to 10.
5	Divisor : the figure required to reduce all Factors to unity. This has the effect of producing a maximum of 1.	The Divisor for parapet types is 10, so that even the maximum possible factor is $10/10 = 1$.
6	Weighting is applied using a weighting factor derived from analytical hierarchy techniques. These weightings are developed empirically using an actuary approach to the analysis by comparing the relative effects of each pair of parameters in turn, starting with the assumption that they are initially at least equal.	In the example quoted, the weighting factor is derived as 0.259

Parts of the TfL method are used herein:

- The basic principle of breaking down the large number of factors into separate groups, “incidence”, “consequence” and “mitigation” is useful, serving the purpose of making the final result more sensitive to individual factors. This principle appears to increase sensitivity of the calculation to individual factors when compared to the IAN97/07 method, in which factors are simply added together.
- A very wide range of factors are used in the calculations, and it is intended to use the most relevant of these for the risk assessment model for masonry parapets.

BS6779 part 4

Risk Assessment

The assessment of risk in Annex A of the British Standard is based on FAR (fatal accident rate, per 100 million hours of exposure, described in a paper by Hambly and Hambly [16]). This risk assessment process involves calculating likelihood of detached masonry striking someone or something in the hazard zone below the parapet. The Hambly and Hambly paper gave a list, (“league table”), of approximate FAR values of actual events based on records.

Other workers have developed or cited the FAR assessment approach, including Vrouwenvelder et al. [27].

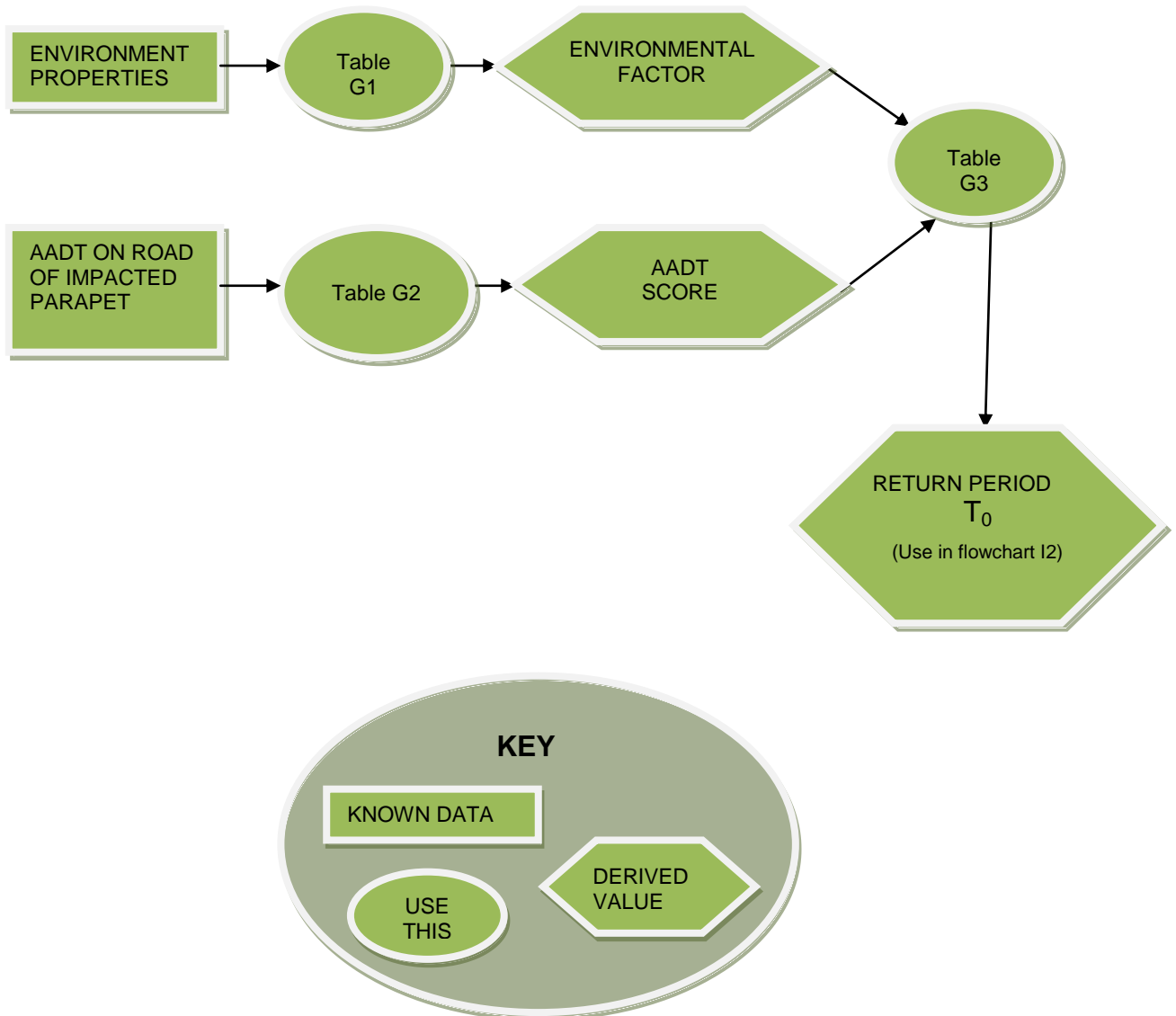
The calculations are based on estimating the size of the hazard zone (from charts based on height above datum), time taken for masonry to fall, estimated frequency of impacts and the frequency of occupancy of the hazard zone. The resulting value can be assessed using the Hambly’s league table (which may, for example, deem the risk broadly acceptable) or can simply be used for risk ranking.

This process deals specifically with detachment of masonry, a topic that other risk ranking methodologies do not address. Thus the approach is used in the risk assessment method described in the present document.

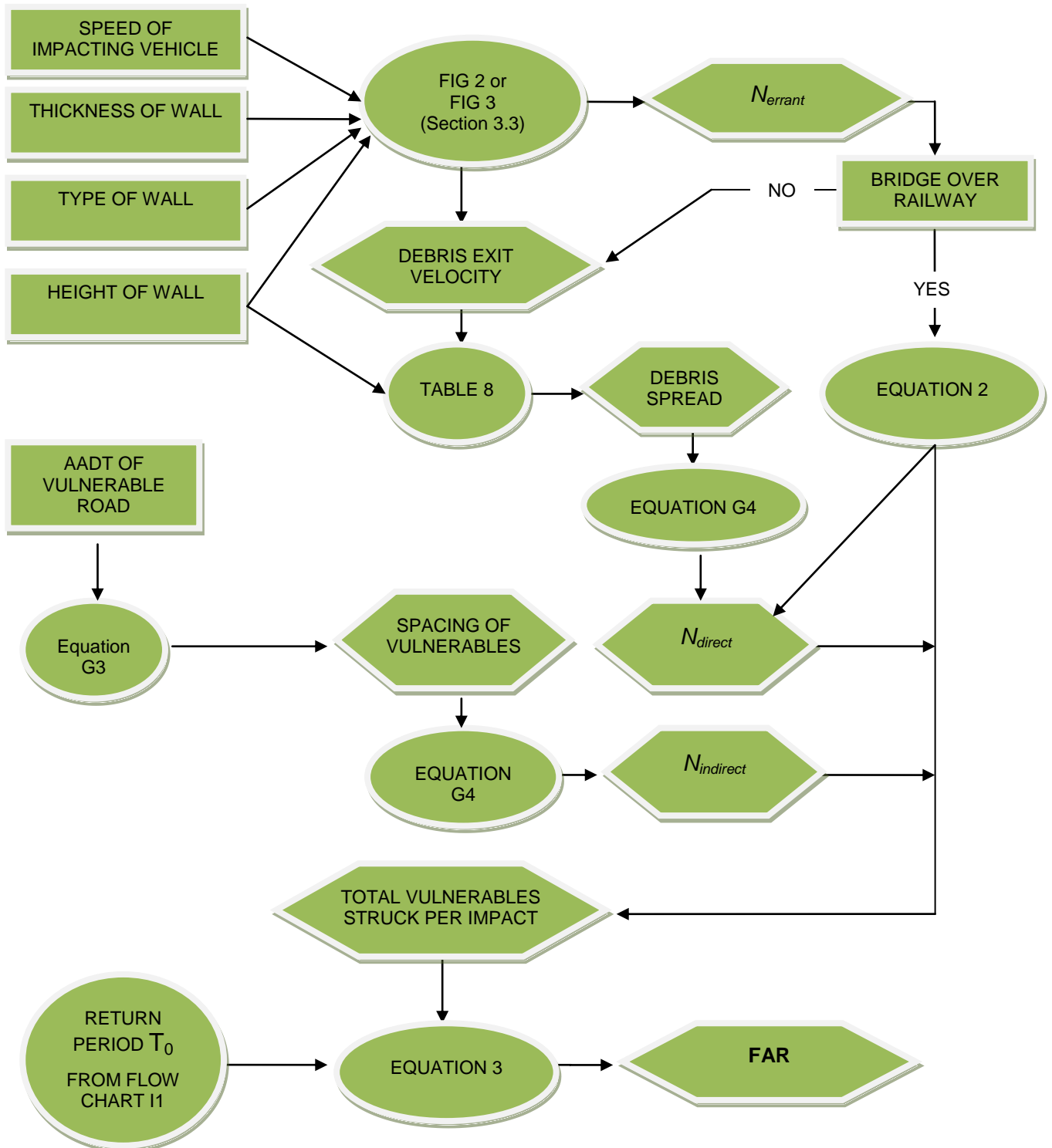
This page is intentionally blank

Appendix I – Risk Assessment Flowcharts

I1 ‘Likelihood’ flowchart



12 'Consequence' flowchart



Appendix J – Sample Risk Assessment Calculations

Example 1: Country road over road

Known Data: road with AADT of 4,500, 2 lane country road, width less than 7.5m, curved horizontal alignment, slight gradient, traffic moves at up to 70mph, wall height 1.80m, wall thickness 510mm, wall height above datum at 8m to mid-height of parapet, low mortar strength, LGV volume: 101-500 per day and a single site specific hazard. For road below, traffic moves at 60mph, 5150 AADT.

Step 1: Likelihood – return period of vehicle impact

Use Flow Chart I1:

From **Table G1:** Environmental factor:

Factor	Score
Road Alignment (Horizontal)	Score 7 for curved road less than 7.3m carriageway
Road Alignment (Vertical)	Score 2 for gentle gradients and/or slight hump back
Speed of traffic	Score 7 for <70mph
Road Verges and Footpaths	Score 3 for one or both verges less than 1m
Other hazards increasing likelihood of RTA	Score 5 for single site specific hazard including risk of freezing conditions.
Total	24

From **Table G2:** For AADT = 4500: **AADT score = 5**

From **Table G3:** For EF of 24, AADT Score of 5: Return Period **T₀ = 11.0 years**

Step 2: Consequence - number of vehicles affected

Use Flow Chart I2:

From **Fig 3:** (Vehicle impact 70mph = 110km/h, wall 1800mm high, 510mm thick, low strength mortar):

- **debris exit velocity of 3.5m/s**
- **vehicle is contained.**

From **Table 8:** (parapet mid-point at 8m high above road below, and using exit velocity of 3.5m/s derived):

- **distance (spread) of debris of 9.0m**

From **equation G3:** (vehicles on local road speed of 60mph (97kph), AADT = 5,150):

- **spacing = 452m**

From **equation G4:**

Calculate direct vulnerable vehicles struck per impact = spread / spacing = 9.0 / 452 = **0.020 (N_{direct})**

Use **Table G4**: road speed 60mph, **total distance slowing to safer speed is 49.2m**

From **equation G5**: calculate indirect vulnerable vehicles struck per impact = $49.2 / 452 = 0.109$ ($N_{indirect}$)

Use **equation 1**: (Note: from Fig 3, vehicle is contained so $N_{errant} = 0$)

- **Total vulnerable vehicles struck per impact N = 0.020 + 0.109 = 0.129**

Step 3: Fatal Accident Rate, FAR

From **equation 3**:

- $$\begin{aligned} \text{FAR} &= 100,000,000 / [(365 * 24 * T_0) / N] \\ &= 100,000,000 / [(365 * 24 * 11.0) / 0.129] \\ &= \mathbf{134} \end{aligned}$$

Comparing to **Table 6**, this is more dangerous than walking beside a road (20) and less dangerous than travel by motorcycle (300).

If we wish to take into account LGV impact:

Step 1: Likelihood – return period of vehicle impact

From **Table G2**: For maximum LGV AADT = 500: **AAADT score = 3**

From **equation G2A**
$$\begin{aligned} T_{L60} &= K * (35 - EF) / (\text{AAADT score}) \\ &= 20 * (35 - 24) / 3 \\ &= \mathbf{73.3 \text{ years}} \end{aligned}$$

Step 2: Consequence – number of vehicles affected

To calculate total vulnerable struck (direct and indirect) per impact **N**, assume:

- Errant vehicle, $N_{errant} = 1$
- N_{direct} and $N_{indirect}$ assumed same as normal vehicle calculation.

$$N = 1.0 + 0.020 + 0.110 = 1.130$$

Step 3: Fatal Accident Rate, FAR

From **equation 3**:

$$\begin{aligned} \text{FAR} &= 100,000,000 / [(365 * 24 * T_{L60}) / N] \\ &= 100,000,000 / [(365 * 24 * 73.3) / 1.1308] \\ &= 176 \end{aligned}$$

$$\mathbf{\text{Total FAR} = 134 + 176 = 310}$$

Example 2: Wychnor Bridge Junction (road over canal)

(Example, photograph and map with permission from Canal & River Trust, formerly British Waterways)

Known Data: A38: from DfT website AADT = 45,302 (on A38), assume 50mph, curved road, close to junction, wall height above datum at 2m to mid-height of parapet, 1800mm high and 450mm thick.

Step 1: Likelihood – return period of vehicle impact

Use Flow Chart I1:

From Table G1: Environmental factor:



Factor	Score
Road Alignment (Horizontal)	Score 7 for curved road less than 7.3m carriageway
Road Alignment (Vertical)	Score 2 for gentle gradients and/or slight hump back
Speed of traffic	Score 7 for <70mph
Road Verges and Footpaths	Score 3 for one or both verges less than 1m
Other hazards increasing likelihood of RTA.	Score 5 for single site specific hazard (Junction)
Total	24

From **Table G2:** For AADT = 45,300: **AADT score = 8**

From **Table G3:** For EF of 24, AADT Score of 8: Return Period $T_0 = 6.875$ years

Step 2: Consequence – number of vehicles affected

Use Flow Chart I2:

From **Fig 2:** (car impact at 80km/h, wall 1800mm high, 450mm thick, assumed low strength mortar)

- **debris exit velocity of 3.0m/s**
- **vehicle is contained.**

As this is a canal, a decision would need to be made if to proceed with risk assessment because of the low traffic volume vulnerable to falling debris. The towpath should also be considered, as it may be a through path with potential volume of pedestrian traffic for some local route.

The following gives an example calculation taking barge traffic but not pedestrians, and assumes barge spacing at 200m:

From **Table 8:** (for height above datum at 2m to mid-height of parapet and using exit velocity of 3m/s):

- distance (spread) of debris of **4m**

From **equation G4**:

Calculate direct vulnerable vehicles struck per impact = spread / spacing = $4.0 / 200 = 0.020$ (N_{direct})

For canal traffic: assume indirect is negligible.

Use **equation 1**: (Note: from Fig 3, vehicle is contained so $N_{errant} = 0$)

- **Total vulnerable vehicles struck per impact N = 0.020**

Step 3: Fatal Accident Ratio, FAR

From **equation 3**:

$$\begin{aligned} \text{FAR} &= 100,000,000 / [(365 * 24 * T_0) / N] \\ &= 100,000,000 / [(365 * 24 * 6.875) / 0.020] \\ &= 33 \end{aligned}$$

Comparing to **Table 6**, this is a higher than walking beside a road (20).

If we wish to take into account LGV impact:

Step 1: Likelihood – return period of vehicle impact

In this case, LGV flow is unknown but based on the road type and using **Table G2, AADT score = 3**

From **equation G2A** $T_{L60} = K * (35 - EF) / (\text{AADT score})$

$$\begin{aligned} &= 20 * (35 - 24) / 3 \\ &= 73.3 \text{ years} \end{aligned}$$

Step 2: Consequence – number of vehicles affected

To calculate total vulnerable struck (direct and indirect) per impact **N**, assume:

- Errant vehicle, $N_{errant} = 1$
- N_{direct} and $N_{indirect}$ assumed same as normal vehicle calculation.

$$N = 1.0 + 0.020 = 1.020$$

Step 3: Fatal Accident Rate, FAR

From **equation 3**:

$$\begin{aligned} \text{FAR} &= 100,000,000 / [(365 * 24 * T_{L60}) / N] \\ &= 100,000,000 / [(365 * 24 * 73.3) / 1.020] \\ &= 159 \end{aligned}$$

$$\text{Total FAR} = 33 + 159 = 192$$

Example 3: Bloxwich Road Bridge (road over rail, Walsall)

Required AADT flow is at the bridge shown with red circle.

From the DfT website: (<http://www.dft.gov.uk/matrix/>):

Nearest AADT record is shown with green dot, given as = 17,056

Assume flow at required point is approximately one third = 5,400 (based on brief observations)

Speed limit is 30mph but for risk assessment assume 40mph

Two footpaths at either end of the bridge of at least 1.0m width, parapet wall 1200mm high, 410mm thick and high strength mortar.



Reproduced from Ordnance Survey digital map data © Crown copyright 2012. All rights reserved. Licence number 0100031673



(AECOM photo)

Step 1: Likelihood – number of vehicles affected

Use Flow Chart 1: Environmental factor:

Factor	Score (derived from IAN97/07)
Road Alignment (Horizontal)	Score 3 for straight less than 7.3m carriageway or curved at least 7.3m carriageway
Road Alignment (Vertical)	Score 2 for gentle gradients and/or slight hump back
Speed of traffic	Score 5 for <50mph
Road Verges and Footpaths	Score 2 for at least 1m on both sides
Other hazards increasing likelihood of RTA.	Score 5 for single site specific hazard including risk of freezing conditions. (nearby junction and commercial entrance)
Total	17

From **Table G2**: for AADT = 5400, **AADT score = 6**

From **Table G3**: for EF = 17, AADT score = 6: Return Period **T₀ = 15.0 years**

Step 2: Consequence – number of vehicles affected**Use Flow Chart I2:**

From Fig 2: (car impact at 80km/h, wall 1200mm high, 410mm thick, high strength mortar)

- debris exit velocity of 2.5m/s
- vehicle is contained.

Refer to item 6.6 (“Road over Rail”) of main text to calculate the N value, using risk method as IAN 97/07:

Factor	Score (derived from IAN97/07)
Permissible line speed	Score 1: up to 45mph
Type of rail traffic	Score 5: sliding door multiple units
Volume of rail traffic	Score 12: very heavily used
Total	18

As described in item 6.6: $N_{direct} = 18 / 47 = 0.38$

Step 3: Fatal Accident Rate, FAR

From equation 3:

$$\begin{aligned}
 \text{FAR} &= 100,000,000 / [(365 * 24 * T_0) / N] \\
 &= 100,000,000 / [(365 * 24 * 15) / 0.38] = \mathbf{289}
 \end{aligned}$$

Comparing to Table 6, this is more dangerous than walking beside a road and less dangerous than travel by motorcycle (300).

Example 4: Typical rural road over other rural road

This example is given as typical because many masonry parapets are on roads with unknown flow data.

A local minor two way road with no recorded AADT and not in a speed limit area passes over similar local minor road.

With reference to **Table G1**, on a scale 5 – 34 assume the local road ‘site environment factor’ is 15.

The parapet is 0.450m thick stone with unknown mortar, assumed to be of low strength, wall height above datum at 8m to mid-height of parapet

Step 1: Likelihood – return period of vehicle impact

Use Flow Chart I1:

Use Environmental factor of 15:

From **Table G2**: Minor two way road **AADT score = 2**

From **Table G3**: for EF = 15, AADT score = 2: **T₀ = 50 years**

Step 2: Consequence – number of vehicles affected

Use Flow Chart I2:

From **Fig 3**: (For most extreme risk assessment, review impact at 110km/h: wall 1200mm high, 450m thick, low strength)

- **Debris exit velocity of 5.20m/s.**
- **The vehicle is contained.**

From **Table 8**: (for wall height above datum at 8m to mid-height of parapet, and using exit velocity of 5.20m/s derived):

- Distance (spread) of debris of **14m** (rounded up)

From **equation G3**:

For vehicles on local road (below) speed of 30mph (48kph), at low AADT, spacing is very high: For purpose of risk assessment, use maximum 100m:

From **equation G4**:

Calculate direct vulnerable vehicles struck per impact = spread / spacing = 14 / 100 = **0.14 (N_{direct})**

On a low volume use road, assume indirect is negligible.

Use **equation 1**: (Note: from Fig 3, vehicle is contained so **N_{errant} = 0**)

- **Total vulnerable vehicles struck per impact N = 0.14**

Step 3: Fatal Accident Rate, FAR

From **equation 3**:

$$\begin{aligned} \text{FAR} &= 100,000,000 / [(365 * 24 * T_0) / N] \\ &= 100,000,000 / [(365 * 24 * 50) / 0.14] \\ &= \mathbf{32} \end{aligned}$$

Comparing to the values given in **Table 6**, this is more than walking beside a road (20)

References

1. County Surveyors' Society Guidance Note, *The Assessment and Design of Unreinforced Masonry Vehicle Parapets*, Report No. 1/95, Lancashire County Council, Preston, UK
2. British Standards Institution, 1999, BS 6779-4:1999, *Highway parapets for bridges and other structures - Part 4: Specification for parapets of reinforced and unreinforced masonry construction*, London: BSI.
3. British Standards Institution, 1998, BS EN 1317-2:1998, *Road restraint systems - Part 2: Performance classes, impact test acceptance criteria and test methods for safety barriers*, London: BSI.
4. McKibbins L., Melbourne C., Sawar N., and Sicilia Gallard C., *Masonry arch bridges: Condition appraisal and remedial treatment*, CIRIA C656, 2006.
5. O'Reilly M., *Drystone Retaining Walls and their modifications – condition appraisal and remedial treatment*, CIRIA C676, 2009.
6. British Standards Institution, PAS 55:2008, *Asset Management; Part 1 - Specification for the optimised management of physical infrastructure assets; Part 2 - Guidelines for the application of Part 1*, London: BSI.
7. Code of Practice on Transport Infrastructure Assets: *Guidance to Support Asset Management, Financial Management and Reporting*, CIPFA, 2010.
8. *Highway Asset Management Quick Start Guidance note – getting started*, 2009
Highway Asset Management Quick Start Guidance note – risk assessment, 2009
Highway Asset Management Quick Start Guidance note – levels of service, 2009
Highway Asset Management Quick Start Guidance note – life cycle planning, 2009
<http://www.ukroadsliasongroup.org/>, UK Roads Board (Accessed 24th May 2012)II
9. Design Manual for Roads and Bridges, Volume 2, Section 2, Part 8, *TD 19/06, Requirement For Road Restraint Systems*, Departmental Standard, UK.
10. Hobbs B., Gilbert M., Molyneaux T.C.K., Newton P., Beattie G., and Burnett S.J., Improving the impact resistance of masonry parapet walls, Proceedings of the Institution of Civil Engineers, *Structures and Buildings*, Vol. 162, pp. 57-67, 2009.
11. Burnett S.J., Gilbert M., Molyneaux T.C.K., Beattie G., and Hobbs B., The performance of unreinforced masonry walls subjected to low-velocity impacts: finite-element analysis, *International Journal of Impact Engineering*, Vol. 34, No. 8, pp. 1433-1450, 2007.
12. British Standards Institution, 2002, BS EN1052-3: 2002, *Methods of test for masonry. Determination of initial shear strength*, London: BSI.

13. British Standards Institution, 2005, BS EN1996:2005, *Design of Masonry Structures, Part 1 – General rules for reinforced and unreinforced masonry structures and National Annex, Part 2 – Simplified calculation methods for unreinforced masonry structures*, London: BSI.
14. Dalrymple G., *Non-destructive Test Methods for Evaluating Masonry Structures*, Mason Contractors Association of America, 2006.
15. UIC Leaflet 778-3: *Recommendations for the inspection, assessment and maintenance of masonry arch bridges*, 2nd Edition, 2011.
16. Hambly E.C., and Hambly E.A., Risk evaluation and realism, *Proc. ICE Civil Engineering*, Vol. 102, pp. 64-71, 1994.
17. Department for Transport: *Managing the accidental obstruction of the railway by road vehicles*, London, 2003.
18. Interim Advice Note 97/07, *Assessment and Upgrading of Existing Vehicle Parapets*, 2007.
19. Department for Transport, NTS0906 Car Occupancy by trip purpose, London, 2011.
20. Gilbert M., Hobbs B., and Molyneaux T.C.K., The performance of unreinforced masonry walls subjected to low-velocity impacts: experiments, *International Journal of Impact Engineering*, Vol. 27, pp. 231-251, 2002.
21. British Standards Institution, BS 5628-3: 2005, *Code of Practice for the Use of Masonry. Materials and components, Design and Workmanship*, London: BSI.
22. British Standards Institution, BS 3921:1985, *Specification for Clay Bricks*, London: BSI.
23. Austroads 2010b, *Guide to pavement technology, part 2: pavement structural design*, AGPT02/10, Austroads, New South Wales, Sydney, Australia.
24. International Association of Oil & Gas Producers, *Land transport accident statistics*, Risk Assessment Data Directory, Report No. 434 – 9, March 2010.
25. Department for Transport, Road Safety Web Publication: *The Relationship between speed and car driver injury severity*, <http://www.dft.gov.uk/pgr/roadsafety/research/> (Accessed 24th May 2012).
26. Transport for London: “*Parapet Prioritisation Study, Phase 1 Report*”, doc 5006-LN00999-LN-R-02-F703, June 2009.
27. Vrouwenvelder A., Holicky B.M. and Tanner C.P., ‘*Risk assessment and risk communication in civil engineering*’, CIB Report, 2001.