Multiple Framework Agreement for Transport Research

Suitability of kerb heights & layouts
Phase 1 Report

November 2021

Mott MacDonald
Floor 1 Greenside
12 Blenheim Place
Edinburgh EH7 5JH
United Kingdom

T +44 (0)131 221 2300
mottmac.com

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Executive summary

This report documents a search and evaluation of published literature relating to kerb heights and kerb related infrastructure as the primary deliverable of Phase 1 of a Transport Scotland commissioned research study undertaken by Mott MacDonald.

Scope and purpose

Kerbs provide physical or visual delineation and minor restraint, particularly between surfaces intended for different users such as footways and carriageways and also create drainage channels. As such, they form a common, yet key part of transport infrastructure.

The initial objectives for the study were:

- The issues around kerb heights affects multiple user groups. Most importantly it affects the most vulnerable user groups in the hierarchy of travel modes and users. The research will seek to find evidence-based conclusions to what constitute appropriate kerb heights.
- A literature review will be conducted during Phase One, looking at relevant previous research and future research identified in past studies.

Phase One initially consisted of a literature review, evaluating currently cited research, including outside the UK. The study has focused on the aim of providing an evidence base to assist roads authorities in recommending effective kerb installations which provide good accessibility for all road users.

During the study, it became apparent that factors other than, or in conjunction with, kerb height (upstand) have potential to affect accessibility and accordingly the scope was broadened to consider kerb profile and adjacent surfacing texture and appearance. As a result, the scope of the study was expanded to incorporate an additional objective, as follows:

- Determine the optimum height or layout of kerbing when attempting to balance safety and accessibility for all users with the technical demands of drainage, edge support, containment, and market availability of kerb types.

Methodology

A structured literature review was conducted to evaluate relevant published academic research, and appropriate design policies, guidance and standards. Informal literature, including internet blogs, were also considered. Some 76 separate documents were reviewed as part of the study.

To categorise the various aspects of information on kerb heights the initial analysis looked at the following kerb interfaces that segregate modes of transport:

- Footway and vehicular carriageway (not at a crossing or footway crossover location);
- Footway and vehicular carriageway at crossing point;
- Footway and vehicular carriageway at footway crossover (driveway or vehicular access);
- Segregated footway/footpath and cycle track/cycleway;
- Segregated cycle track/cycleway and vehicular carriageway, and
- Vehicular carriageway at raised bus stop boarding area.

The study also looked at:

- shared space locations;
- inclusive design, and
- engineering aspects.

Findings

There was surprisingly little research into justifying kerb heights, with only two papers identified with a clear research basis. One paper had carried out laboratory research in relation to what constitutes an appropriate upstand for pedestrians with visual impairment. Another paper appraised ramped access for cyclists at footway crossover locations.

Numerous design policies, standards and guidance documents were reviewed. For a given interface, each often gave different kerb heights and did not provide justification for the dimensions stated. For example, at the key interface between footway and vehicular carriageway (not at a crossing or footway crossover location) there was commonly a 60mm height recommended. Most documents did not give a reason for the specified kerb height. Accordingly, there would therefore appear to be a gap in the reasoning behind specified kerb heights.

In summary, the following key findings emerged during the literature review:

- Only some of the design standards, policies and guidance considered specified kerb heights and ranges.
- Only two academic papers were identified that specifically researched kerb heights.
- Only two design policies, standards or guidance documents, in addition to the September 2021 revision to Cycling by Design (Transport Scotland, 2020), cited academic research.
- There are multiple instances where standards, policies or guidelines specify kerb upstand heights and ranges without citing supporting evidence.
- Specified kerb heights and ranges are often dependent on kerb profile and adjacent features.

- A 60mm upstand is generally considered to be an appropriate standard kerb height that can be reliably detected by people with sight impairment, but it is not yet certain as to whether a 50mm height kerb is similarly effective.
- There appears to be clear benefits for cyclists through the implementation of chamfered kerbs at track edges, though the suitability of such installations for pedestrians with various forms of disability is not yet ascertained.
- A 25mm raised kerb height at footway crossover locations is generally accepted as suitable to allow a vehicle to drive over at low speed.
- At pedestrian crossing locations, a 6mm maximum upstand is appropriate.
- The design of bus stops is a specialist multi-factored area, where kerb heights are not the only factor affecting accessibility.
- Shared space design is complex, and multi factored and associated interface or pedestrian ‘comfort space’ (or ‘safe area’) edge delineation design and specification should not be considered in isolation.
- There is a requirement, under the 2010 Equality Act, to be inclusive in design (including design of kerbs installations) and in practice to recognise the importance of consistency and familiarity for disabled street users. The study notes there is a large range of road users that have some form of disability or mobility impairment that may be impacted by kerb height, including non-physical impairments such as mental health, age and certain conditions such as diabetes. To be truly inclusive, kerb height and form design should account for as wide a range of disabilities (user types) as possible, whilst acknowledging there may be conflicting influences between some user types.

Recommendations

Areas recommended for further research are the most common, linear kerb interfaces between:

- footway and vehicular carriageway (not at a crossing or footway crossover location);
- segregated footway/footpath and cycle track/cycleway, and
- segregated cycle track/cycleway and vehicular carriageway.

The first stage of a potential Phase 2 should involve the development of a refined and appropriate study methodology and delivery programme, through structured dialogue with stakeholders. Potentially this could be achieved through a structured workshop or using appropriate data analysis, during which:

- the findings of Phase 1 would be reviewed;
- precise objectives set, and
- agreement is reached as to the scope of specific issues to be addressed, based on risk, i.e. to identify key user types and location scenarios (e.g. shopping centres, residential) to be studied.

Potential Phase 2 of this study could include:

- workshop or data analysis to allow the study to focus on key factors affecting kerb heights/form.
- study surveys at locations with standard kerb upstand heights at and below 60mm.
- study surveys at locations focused on the key risk factors related to user type and different forms (upstands and profiles) of kerb interfaces between pedestrian and cyclist spaces.
- study surveys at locations focused on the key risk factors related to user type and different forms (kerb upstands and alternat treatments) of interfaces between cyclists and motor vehicles.

The research should seek to identify interface treatments, including kerb height and kerb profile specifications, that support access for most users, but recognise that due to the limitations of any on site interviews, surveys and observations undertaken that it may not be possible to make generalisations that can then be applied to the population as a whole. For example, the study could focus on visually impaired users at specific locations, coupled with data analysis and general survey feedback, to determine if these observations could then be generalised to the wider population, i.e., other disability user types and locations. If not, the study would need to recommend the need for further investigations such as laboratory testing to consider kerb height effect on those other specific road user types.

1 Introduction

This report documents a search and evaluation of published literature relating to kerb heights and kerb related infrastructure as the primary output of Phase 1 of a Scottish Road Research Board (SRRB) commissioned research study.

Mott MacDonald was commissioned by Transport Scotland on behalf of SRRB to implement Phase 1 of the study.

1.1 Scope and purpose

Objectives for the research study were originally defined at project inception stage, paraphrased as follows:

- The issue around kerb heights affects multiple user groups. Most importantly it affects the most vulnerable user groups in the hierarchy of travel modes and users. The research will seek to find evidence-based conclusions to what constitutes appropriate kerb heights.
- A literature review will be conducted during Phase 1, looking at relevant previous research and future research identified in past studies.

The study initially consisted of evaluating a wide range of appropriate literature, including published design guidance and research papers. The study has focused on the aim of providing an evidence base to assist roads authorities in recommending effective kerb installations which provide a reasonable degree of accessibility for all road users.

During the study, as agreed through progress meeting dialogue, it became apparent that factors other than, or in conjunction with, kerb height (also referred to as kerb upstand) have potential to affect accessibility and accordingly the study scope was broadened to include a review of factors such as kerb profile and high-level consideration of adjacent surfacing texture and appearance.

Further to review of the Phase 1 DRAFT report (revision A, 23/11/20) and subsequent dialogue during December 2020, Transport Scotland agreed that the scope of the study should be broadened to the following:

- Determine the optimum height or layout of kerbing when attempting to balance safety and accessibility for all users (specifically including pedestrians, cyclists and public transport users) with the technical demands of drainage, edge support, containment, construction safety and market availability of kerb types.

1.2 Methodology

A structured literature review was conducted to evaluate relevant published academic research, and design policies, standards and guidance documents. Grey literature, including internet blogs, was also considered.

Through the course of developing the research study, regular progress meetings were held involving representatives of Transport Scotland and the Mott MacDonald study team.

1.3 Report structure

Following this introduction, **Section 2** provides a definition of a kerb followed by standard reasons for constructing kerbs and a summary of kerb types commonly adopted on public roads and public spaces across Scotland.

Section 3 presents an overview, methodology and high-level observations arising from the literature, in addition to documenting the detailed findings with respect to the study objectives.

Section 4 provides discussions and conclusions on the key matters raised through evaluation of the published literature.

High level recommendations for Phase 2 of the study are set out in **Section 5**.

A list of references cited in this report are listed in **Section 6**.

Report appendices provide relevant supporting information.

2 Kerbs

This section sets out a kerb definition, standard reasons for constructing kerbs and a summary of kerb types commonly implemented on public roads and public spaces in Scotland.

2.1 Definition

There are many published definitions of 'kerb'. The Oxford Lexico online dictionary, for example, defines the noun kerb as: 'A stone edging to a pavement or raised path. Origin: Mid17th century (denoting a raised border or frame): variant of curb.' (Oxford University Press, 2021). For the purposes of this study, a kerb is as described by this definition.

2.2 Purpose of kerbs

There are many published sources of information describing the purpose of kerbs, including the Design Manual for Roads and Bridges (DMRB) CD 127 Highway cross-sections (Standards for Highways, 2021) which conveniently summates these.

Kerbs are used to:

- Provide physical or visual delineation and minor restraint, particularly between surfaces intended for different users such as footways and carriageways; and/or
- Create drainage channels.

Aside from the primary purposes of kerbs defined in the DMRB, kerbs can perform additional functions, such as:

- forming suitable pedestrian crossing points; controlled or uncontrolled.
- providing wayfinding guidance for blind and partially sighted people.
- assisting in making buses accessible.
- discouraging footway parking.

Kerbs therefore form a common, yet key part of transport infrastructure.

2.3 Common kerb types

Kerbs types are available in a variety of forms, profiles and materials and those in common use in Scotland are listed below. More detailed information is provided in **Appendix A**:

- Bus stop kerbs.
- Half-battered.
- Bull-nosed kerbs.
- Containment kerbs.
- Dropper and dropped kerbs.
- Edge restraint kerbs.
- Extruded kerbs.
- Kerb drains.
- Quadrant/angle kerbs.
- Square kerbs.
- Splay kerbs.
- Transition kerbs.

3 Literature Review

This section documents a summary of the key findings arising from the search and evaluation of published literature relating to kerb heights and kerb related infrastructure.

3.1 Overview

The literature review initially aimed to find answers to the following questions:

1. **What are the fundamental principles that determine current kerb heights?**
2. **What is the optimum kerb height when considering safety, accessibility, drainage, and constructability?**

During searches, it became apparent that there is a limited amount of literature specifically relating to kerb "height" when compared to other factors, such as kerb "type" or "layout". It was subsequently agreed with Transport Scotland that the first objective would remain the same, but the second objective of the literature review should be broadened, and refined to:

2. **What is the optimum height or layout of kerbing when attempting to balance safety and accessibility for all users with the technical demands of drainage, edge support, containment, construction safety and market availability of kerb types?**

3.2 Methodology

Initially, internet and academic article searches using key words on sites such as Google Scholar, ResearchGate and Science Direct were carried out. Such key words included ‘kerb heights’, ’upstand’, ‘curb heights’ ‘Non-Motorised User (NMU)’, ’blind and partially sighted’, ‘visually impaired’, ‘wheelchair users’, ‘drainage’, ‘safety’, ‘cyclists;’ all within a highway design/assessment context.

The literature review was limited to items published in the English language. The first sift involved a web search based on specific terms and first 40 results under each term. The second sift was based on specific guidance from Transport Scotland, professional judgement, and the industry experience of the Mott MacDonald study team.

A list of references cited throughout the report is provided in **Section 6** and a list of documents reviewed but not cited is given in **Appendix B**.

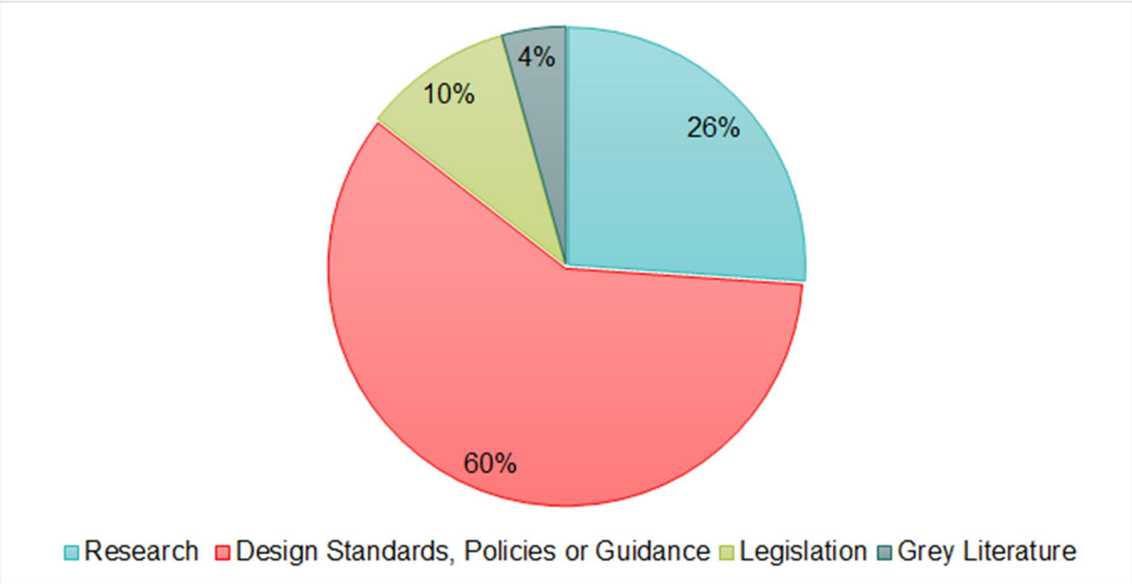
3.3 Observations on literature

3.3.1 Type of literature sources

Figure 3.1 shows the breakdown of literature reviewed by type. The number of relevant peer-reviewed published research papers specifically addressing the study objectives was less than might have been expected, given the importance of kerbs to transport infrastructure. More relevant standards, policies and guidance documents were identified, by comparison with research papers.

Literature reviewed that has been cited in this report is listed in **Section 6 References**, whilst literature reviewed but has not been cited in this report is listed in **Appendix B**.

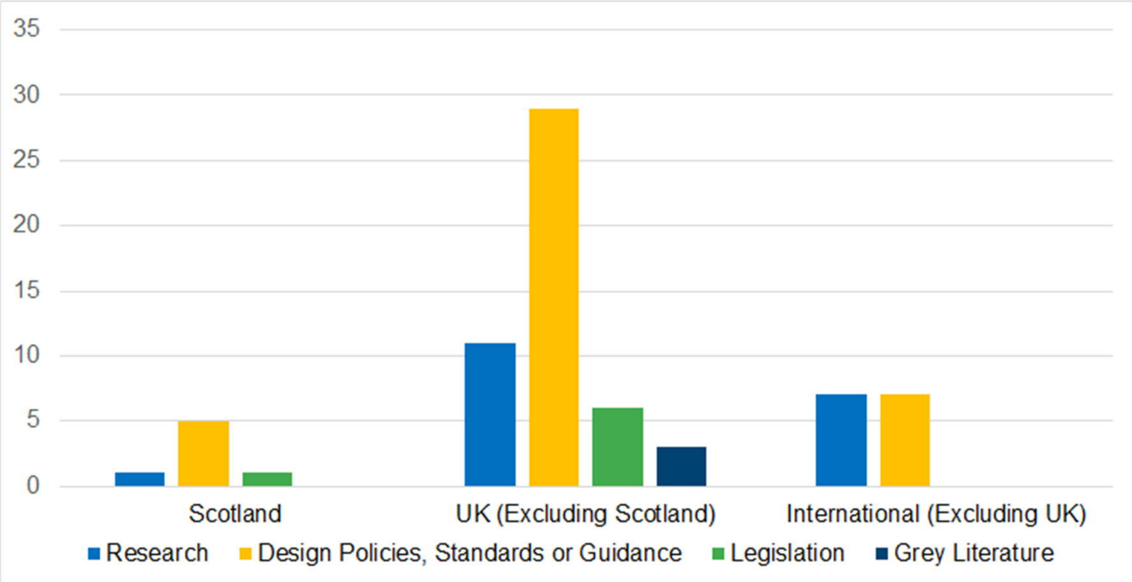
Figure 3.1: Literature reviewed by type



3.3.2 Publishing Jurisdiction

Figure 3.2illustrates the relative proportion of literature sources identified originating from Scotland, the UK (excluding Scotland) and International (excluding UK) respectively. It shows that most of the literature reviewed came from with the UK, including Scotland.

Figure 3.2: Literature reviewed by publishing jurisdiction



3.4 Objective 1 - What are the fundamental principles that determine current kerb heights?

Kerbs provide visual edge definition between pedestrians and vehicles, including pedal cycles, in street environments.

Kerbs can also perform engineering functions including edge restraint, vehicular containment, and channelling of surface water.

The design and specification of the most appropriate form and height of kerb segregation is dependent on each mode of transport. Designers are therefore required to consider multiple factors and scenarios including:

- Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location).
- Kerb interface between footway and vehicular carriageway at crossing point.
- Kerb interface between footway and vehicular carriageway at footway. crossover (driveway or vehicular access).
- Kerb interface between segregated footway/footpath and cycle track/cycleway.
- Kerb interface between segregated cycle track/cycleway and vehicular carriageway.
- Kerb interface at raised bus stop boarding area .
- Shared space locations
- Engineering aspects:
  - Surface water drainage.
  - Vehicular containment.
  - Edge restraint.
  - Construction safety.
  - Local availability of kerb forms.
- Kerb interface with potential future forms of mobility, e.g., autonomous vehicles.

A key document entitled 'Effective Kerb Heights for Blind and Partially Sighted People' (Childs, et al., 2009) was identified that included supporting experimental evidence as the basis to inform what standard kerb heights are reliably detectable and therefore effective for safely guiding visually impaired people.

Childs et al. (2009) is the most widely cited research on the study of pedestrian interface with kerbs of differing heights. It focused on the results of laboratory tests carried out with visually impaired users. Key findings from this research are:

- "Kerb heights of 60mm and above were detectable when stepping up and stepping down and induced the greatest confidence in what they were, and what they signified."
- "Kerb heights less than 40mm appear to be less consistent in detection rates and thus consideration should be given to avoiding them if possible."
- "Epidemiological tests would be required to determine if 50mm kerbs would be a problem in the wider population of people who are blind or partially sighted."
- "It is unlikely that the kerb edge profile makes a significant difference if the kerb face is approximately vertical."

The Childs, et al. (2009) research was undertaken in controlled laboratory conditions; however, analysis of the sample group has identified some doubt as to the societal representation of visually impaired participants. For example, females and people older than 60 years were underrepresented. The Childs, et al. (2009) research was also evidently limited in some key areas:

1. A range of kerb heights were assessed, but only two kerb profiles were tested: bullnose and half battered profiles. There are several other kerb profiles which are commonly available in the UK which were not tested, e.g., splay kerbs are commonly utilised at interfaces between pedestrian and cyclist spaces. It is notable that this profile was not tested.
2. Different surface textures, on either the kerb top or adjacent hardstanding, were not appraised.
3. Only one disability was considered, sight impairment. This is not societally representative or inclusive.
4. All tests were undertaken in laboratory conditions and therefore did not, for example, account for sensory effects associated with different weather conditions or traffic noise which have potential to influence pedestrian behaviour.

It is acknowledged in other sources that most of the published research on design for the needs of those with disabilities has focused on the requirements for those with sight related disability (Gamache, et al., 2019). Childs, et al. (2009) did not account for the requirements of those with other forms of disability.

The journal article entitled 'Accounting for the Needs of Blind and Visually Impaired People in Public Realm Design' by Parkin & Smithies (2012) questions commonly held concerns in relation to shared use spaces. It reports that blind and partially sighted people can identify many different surface types and delineators, and they use these, along with other features of the urban environment, in creative ways to identify their location and guide themselves. This research suggests that surface treatment can be a significant consideration in the design of appropriate infrastructure solutions to cater for the requirements of blind and partially sighted people. It is therefore apparent that considering kerb height in isolation is insufficient when appraising the suitability of kerbs.

A research study undertaken in Sweden entitled ‘Detection of warning surfaces in pedestrian environments: The importance for blind people of kerbs, depth, and structure of tactile surfaces’ (Ståhl, et al., 2010) involved only completely blind participants, without guide dogs, using large white canes for orientation. The study incorporated quantitative and qualitative methods, and the main part of the study incorporated an in-situ test (in a medium-sized Swedish town) to identify how blind participants negotiated access to locations interfacing pedestrian footway and a live road traffic carriageway. The test route incorporated 14 sites with differing depths and forms of tactile surface, some with observable kerb upstands and some without. The research paper did not define the height of any kerb, merely whether a kerb upstand existed or otherwise and concluded that the presence of a kerb does not make a difference for the detection of warning surfaces among pedestrians with blindness.

Research undertaken in Japan entitled ‘How does the edge height of curb ramps obstruct bicycles’ (Hayashi, et al., 2012) is specifically focused on access for cyclists at interfaces between road carriageways and vehicular access (footway crossover) locations.

Also, in relation to cycleways, Janssen et al. (2018) notes “Available literature shows that right angled kerbs are usually not preferred or recommended since they do not allow cyclists to make mistakes, in other words, they are not forgiving.” This conclusion is not contradicted by any of the other literature reviewed as part of this study.

3.5 Objective 2 - What is the optimum height or layout of kerbing when attempting to balance safety and accessibility for all users with the technical demands of drainage, edge support, containment, and issues associated with construction?

As the literature review progressed, it became apparent that a wide range of kerb upstand heights were stated and that this was most obviously influenced by layout (i.e., what features the kerb was acting as the interface between).

Table 3.1 summarises references to a specific kerb upstand height or range, according to the interface it demarcates.

It is notable that in **Table 3.1**, whilst several documents give various recommended kerb heights, in almost all cases no justification or research is cited to justify these decisions. However, Streetscape Guidance (TfL, 2019) and the London Cycling Standards (TfL, 2014) clearly cite the Childs, et al. (2009) research as a basis for their stated standard kerb height advice.

The following sections of this report then broaden discussion, grouped as follows:

- Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location) – **Section 3.5.1.**
- Kerb interface between footway and vehicular carriageway at crossing point – **Section 3.5.2.**
- Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access) – **Section 3.5.3.**
- Kerb interface between segregated footway/footpath and cycle track/cycleway – **Section 3.5.4.**
- Kerb interface between segregated cycle track/cycleway and vehicular carriageway – **Section 3.5.5.**
- Kerbs at raised bus stop boarding areas – **Section 3.5.6.**
- Shared space – **Section 3.5.7.**
- Inclusive design – **Section 3.5.8.**
- Engineering aspects – **Section 3.5.9.**

Table 3.1 References to a specific kerb upstand height or range, according to the interface it demarcates

SCOTLAND

Designing Streets, (Scottish Government, 2010)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	No specific heights or range of heights stated
Kerb interface between segregated footway/footpath and cycle track/cycleway	No specific heights or range of heights stated
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	No specific heights or range of heights stated
Kerb interface at raised bus stop boarding area	No specific heights or range of heights stated

Edinburgh Street Design Guidance, (The City of Edinburgh Council, 2020)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	Standard kerb height is 70 -100mm
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	Not greater than 6mm (Factsheet G4 – Crossings – Uncontrolled Drop Kerb Crossings, page 6)
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	Upstand range between flush and 100mm dependent upon infrastructure arrangement (Factsheet P4 – Vehicle Crossovers on Footways: Residential Footway Crossovers)
Kerb interface between segregated footway/footpath and cycle track/cycleway	50mm min.
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	75mm min.
Kerb interface at raised bus stop boarding area	Standard kerb height at bus stops: 100-120mm (Factsheet PT2, Page 11)

Cycling by Design, (Transport Scotland, 2021)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	No specific heights or range of heights stated
Kerb interface between segregated footway/footpath and cycle track/cycleway	2010: No specific heights or range of heights stated August 2020 Revision: 60mm recommended. Splay kerb recommended. 50mm may be considered as an alternative and avoid the need for splayed kerb (Page 54, Fig. 4.5) September 2021 Revision: 60mm min (Page 113; cites Childs, et al. (2009)
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	2010: No specific heights or range of heights stated

	August 2020 Revision: 60mm recommended. Splay kerb recommended. 50mm may be considered as an alternative and avoid the need for splayed kerb (Page 58, Fig. 4.7) September 2021 Revision: No specific heights or range of heights stated
Kerb interface at raised bus stop boarding area	No specific heights or range of heights stated

National Roads Development Guide (Society of Chief Officers of Transportation in Scotland (SCOTS), 2017)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	125mm
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	0 to 10mm
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	25 to 40mm
Kerb interface between segregated footway/footpath and cycle track/cycleway	40mm
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	No specific heights or range of heights stated
Kerb interface at raised bus stop boarding area	No specific heights or range of heights stated

Roads for all - Good practice guide for roads (Transport Scotland, 2013)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	6mm (4.1.9)
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	25mm (Figure 14)
Kerb interface between segregated footway/footpath and cycle track/cycleway	No specific heights or range of heights stated
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	No specific heights or range of heights stated
Kerb interface at raised bus stop boarding area	No specific heights or range of heights stated

UK (excluding SCOTLAND)

Effective Kerb Heights for Blind and Partially Sighted People (Childs, et al., 2009)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	60mm min. acceptable, 50mm min. potentially acceptable but not verified
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	No specific heights or range of heights stated
Kerb interface between segregated footway/footpath and cycle track/cycleway	No specific heights or range of heights stated
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	No specific heights or range of heights stated

Kerb interface at raised bus stop boarding area	160mm to 220mm to minimise the vertical step required to get on and off the bus from the footway and also minimise the ramp angle for wheelchair users.

Design Manual for Roads & Bridges (DMRB) CD127 (Standards for Highways, 2021)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	100mm urban and 75mm rural
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	0mm (flush) 6mm maximum No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	0mm (flush) 6mm maximum No specific heights or range of heights stated
Kerb interface between segregated footway/footpath and cycle track/cycleway	0mm (flush) 6mm maximum No specific heights or range of heights stated
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	0mm (flush) 6mm maximum No specific heights or range of heights stated
Kerb interface at raised bus stop boarding area	0mm (flush) 6mm maximum No specific heights or range of heights stated

Manual for Streets (DfT, 2007)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	No specific heights or range of heights stated
Kerb interface between segregated footway/footpath and cycle track/cycleway	No specific heights or range of heights stated
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	No specific heights or range of heights stated
Kerb interface at raised bus stop boarding area	Minimum 125mm, but higher kerbs may be desirable

Manual for Streets 2, (The Chartered Institution of Highways & Transportation (CIHT), 2010)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	No specific heights or range of heights stated

Kerb interface between segregated footway/footpath and cycle track/cycleway	No specific heights or range of heights stated
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	No specific heights or range of heights stated
Kerb interface at raised bus stop boarding area	Minimum 125mm, but higher kerbs may be desirable

Streetscape Guidance (Transport for London, (TfL), 2019)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	60mm min; cites (Childs, et al., 2009)
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	0mm (i.e., flush) 6mm maximum
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	25mm
Kerb interface between segregated footway/footpath and cycle track/cycleway	50mm
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	Minimum 125mm
Kerb interface at raised bus stop boarding area	125 to 140mm

Cycling Infrastructure Design (LTN 1/20) (Department for Transport (DfT), 2020)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	60mm min.
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	No specific heights or range of heights stated
Kerb interface between segregated footway/footpath and cycle track/cycleway	50mm min. where kerb segregation is required; in cases of low flow movements of pedestrians or cyclists a raised kerb is not required
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	50mm min.
Kerb interface at raised bus stop boarding area	No specific heights or range of heights stated

Memo. 154/15: Kerb Heights in Public Realm Scheme, (Department for Infrastructure Northern Ireland (DfINI), 2015)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	60mm min. 100 to 125mm in urban situations to 75 to 100mm in rural situations
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	0mm to +6mm
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	25mm
Kerb interface between segregated footway/footpath and cycle track/cycleway	No specific heights or range of heights stated
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	No specific heights or range of heights stated
Kerb interface at raised bus stop boarding area	In public realm schemes it is recommended that the kerb height at any bus stop should be in the range of 125mm to 160mm, and ideally specialised boarding kerbs should be used.

Bus Stop Design Guide (Department for Regional Development Northern Ireland (DRDNI), 2010	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	No specific heights or range of heights stated
Kerb interface between segregated footway/footpath and cycle track/cycleway	No specific heights or range of heights stated
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	
Kerb interface at raised bus stop boarding area	125mm minimum 160mm maximum

London Cycling Design Standards, (TfL, 2014)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	60mm min; cites Childs et al. (2009)
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	Any upstand of greater than 10mm should be avoided as it can destabilise many types of cycle, particularly when approached from an angle; dropped kerbs should be specified as flush within a tolerance of 6mm.
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	No specific heights or range of heights stated
Kerb interface between segregated footway/footpath and cycle track/cycleway	50mm min.
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	50mm min.
Kerb interface at raised bus stop boarding area	No specific heights or range of heights stated

Accessible bus stop design guidance, (TfL, 2017)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	No specific heights or range of heights stated
Kerb interface between segregated footway/footpath and cycle track/cycleway	No specific heights or range of heights stated
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	No specific heights or range of heights stated
Kerb interface at raised bus stop boarding area	100mm min. range 125mm to 140mm preferred

Inclusive Mobility, (DfT, 2005)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	No specific heights or range of heights stated

Kerb interface between footway and vehicular carriageway at pedestrian crossing point	Wherever possible the dropped kerb should be flush with the carriageway (maximum 6mm rounded bullnose upstand if essential)
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	No specific heights or range of heights stated
Kerb interface between segregated footway/footpath and cycle track/cycleway	No specific heights or range of heights stated
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	No specific heights or range of heights stated
Kerb interface at raised bus stop boarding area	125mm to 140mm acceptable but 160mm optimal height; cites Greater Manchester Passenger Transport Executive research

Inclusive Design in Town Centres and Busy Street Areas (WSP, 2021)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	Repeats findings from Childs et al. (2009) 60mm min. acceptable, 50mm min. potentially acceptable but not verified and recommends further research
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	Collates advice from various literature sources but does not make specific kerb height recommendations
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	Collates advice from various literature sources but does not make specific kerb height recommendations
Kerb interface between segregated footway/footpath and cycle track/cycleway	Collates advice from various literature sources but does not make specific kerb height recommendations
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	Collates advice from various literature sources but does not make specific kerb height recommendations
Kerb interface at raised bus stop boarding area	Collates advice from various literature sources but does not make specific kerb height recommendations

INTERNATIONAL (Excluding UK)

Design Manual for Bicycle Traffic (CROW, 2017)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	No specific heights or range of heights stated
Kerb interface between segregated footway/footpath and cycle track/cycleway	Can be up to 110mm with splay kerb. (Design sheet V60)
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	Up to 120mm on carriageway side 50mm on cycle track side but can be up to 70mm if a profile is chosen that prevents pedals catching. (Design sheet V59)
Kerb interface at raised bus stop boarding area	No specific heights or range of heights stated

Geometric Design of Highways & Streets 7th Edition (American Association of State Highway Transportation Officials (AASHTO), (2018))	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	Sloping curbs up to 100mm may be considered for use on high-speed facilities where needed due to drainage considerations or restricted right-of-way. Sloping curbs with 150mm heights may be considered for use on high-speed urban/suburban facilities where there is a need for delineation. Vertical curbs: 150 to 200mm.
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	No specific heights or range of heights stated
Kerb interface between segregated footway/footpath and cycle track/cycleway	No specific heights or range of heights stated
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	No specific heights or range of heights stated
Kerb interface at raised bus stop boarding area	No specific heights or range of heights stated

Guide to Road Safety Part 2: Safe Roads (Austroads, 2021)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	Barrier kerbs higher than 100mm should be avoided except in low speed, urban settings
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	No specific heights or range of heights stated
Kerb interface between segregated footway/footpath and cycle track/cycleway	No specific heights or range of heights stated
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	No specific heights or range of heights stated
Kerb interface at raised bus stop boarding area	No specific heights or range of heights stated

Guide to Road Design Part 6A: Paths for Walking and Cycling (Austroads, 2021)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	If the adjacent ground has a steep slope, a kerb between 65mm and 75mm high should be provided to protect prams and wheelchairs and to guide those people with impaired vision. Handrails may also be provided.
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	No specific heights or range of heights stated
Kerb interface between segregated footway/footpath and cycle track/cycleway	75 to 100mm high
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	No specific heights or range of heights stated
Kerb interface at raised bus stop boarding area	No specific heights or range of heights stated

How does the edge height of curb ramps obstruct bicycles? (Hayashi, et al., 2012)	
Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at pedestrian crossing point	No specific heights or range of heights stated
Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)	Identified 50mm as the maximum edge height that prevents cyclists ascending from a road carriageway via a ramp on to a footway.
Kerb interface between segregated footway/footpath and cycle track/cycleway	No specific heights or range of heights stated
Kerb interface between segregated cycle track/cycleway and vehicular carriageway	No specific heights or range of heights stated
Kerb interface at raised bus stop boarding area	No specific heights or range of heights stated

3.5.1 Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)

This is the most common interface and the literature review identified 60mm as the most recommended minimum kerb height in urban areas.

As described in **Section 3.4**, Childs, et al. (2009) provides the most detailed analysis of kerb heights published to date in relation to what constitutes an appropriate upstand for pedestrians with visual impairment. It concludes that a 60mm kerb height with a bull nosed or half battered profile are consistently discernible by blind or partially sighted people.

The London Streetscape Guidance (TfL, 2019), London Cycling Design Standards (TfL, 2014), Cycle Infrastructure Design (LTN 1/20) (DfT, 2020) and Director of Engineering Memorandum 154/15: Kerb Heights in Public Realm Scheme (DfINI, 2015) (see **Table 3.1)** are consistent in that, other than in defined shared use locations, at pedestrian crossing locations (see **Section 3.5.2**) or vehicular accesses/ footway crossovers (see **Section 3.5.3**), the kerb height separation between pedestrians and motor vehicles should not be less than 60mm.

The London Streetscape Guidance (TfL, 2019) and London Cycling Design Standards (TfL, 2014) both state 60mm as an appropriate minimum kerb height, and cite Childs, et al. (2009) as their basis. This specification in guidance errs on the side of caution, as it is important to note Childs, et al. (2009) did not conclude that a 50mm kerb upstand was inappropriate; it recommended that 'epidemiological tests' are undertaken to verify the adequacy of 50mm.

As acknowledged by Childs, et al. (2009), in Warren Street, Stockport, a 50mm kerb height has been implemented, which was supported by the Stockport Disability Alliance, but the literature review did not ascertain whether this installation has been successful or otherwise.

DMRB CD127: Cross-sections and headrooms (Standards for Highways, 2021), in respect of high-speed roads, specifies 75mm as the appropriate kerb upstand, stating, "Limiting the height of the kerb upstand to 75mm minimises the risk of an errant vehicle being projected upwards upon impact". However, the same design standard states that a 100mm kerb height is appropriate for low speed roads in urban areas.

At shared space locations utilised by both pedestrians and vehicles, kerb height separation of modes is not typically incorporated. This topic is discussed further in **Section 3.5.7**.

The consistent advice to adopt a 60mm at this interface, ascertained from the literature review, does, or is likely to, emanate from the Childs, et al. (2009) research, however, it is not yet certain as to whether a 50mm height kerb would be similarly effective or otherwise in this scenario.

3.5.2 Kerb interface between footway and vehicular carriageway at crossing point

For this interface, which occurs at pedestrian crossings, there was a consensus in the literature review that the kerb height should be flush or no higher than 10mm.

Table 3.1 shows that where design guidance dimensions are stated in relation to dropped or raised road crossing points (controlled or uncontrolled), a flush kerb arrangement is recommended. The definition of flush is typically specified in the range 0mm to 6mm.

The 6mm maximum kerb upstand value is stated by:

- Inclusive Mobility (DfT, 2005)
- Roads for all - Good practice guide for roads (Transport Scotland, 2013);
- DMRB CD127 (Standards for Highways, 2021);
- Inclusive Design in Town Centres and Busy Street Areas (WSP, 2021);
- The Edinburgh Street Design Guidance (The City of Edinburgh Council, 2020);
- London Streetscape Guidance (TfL, 2019); and
- Memo. 154/15: Kerb Heights in Public Realm Scheme (DfINI, 2015).

The National Roads Development Guide (SCOTS, 2017) states the maximum upstand should be 10mm.

According to Guidance on the use of Tactile Paving Surfaces (Department for Environment, Transport & Regions, 2007), at such locations, the installation of tactile paving surfaces will assist visually impaired people. This is conveniently summarised in the UK Government's inclusive mobility guidance entitled 'Making transport accessible for passengers and pedestrians' (DfT, 2005).

The Traffic Signs Manual, Chapter 6 (Traffic Control) (DfT, 2019) recognises that a flush crossing is always required at pedestrian crossing locations and that this can be achieved using dropped kerbs, or alternatively by raising the carriageway to the same level as the adjacent footway sections. It states: "The design should be carefully considered to ensure that it does not lead people to assume a priority over traffic that they do not have."

The literature review did not source anything that contradicted Inclusive Design in Town Centres and Busy Street Areas (WSP, 2021) which, based on Disabled Street User Focus Group inputs to research, states "The research has shown that the standard requirement at a crossing should include dropped kerbs, suitable slope / camber, tactile paving in the correct orientation, colour and contrast and a minimal kerb upstand at the dropped kerb (6mm maximum)."

Whilst there is no cited research supporting the heights stated in most of the above documents, it appears generally accepted that a kerb laid with a 6mm maximum upstand is unlikely to represent a significant pedestrian trip hazard and may also assist in retaining surface water flow in the channel space; see also **Section 3.5.9.1**.

3.5.3 Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)

This interface occurs at limited locations and the literature review suggested kerb heights in the range from 10-40mm.

As indicated in **Table 3.1**, where dimensions are stated in design guidance, a number recommend a 25mm upstand.

The 25mm upstand is stated in:

- Roads for all - Good practice guide for roads (Transport Scotland, 2013);
- Inclusive Design in Town Centres and Busy Street Areas (WSP, 2021);
- The Edinburgh Street Design Guidance (The City of Edinburgh Council, 2020);
- Streetscape Guidance (TfL, 2019); and
- Director of Engineering Memorandum 154/15: Kerb Heights in Public Realm Scheme (DfINI, 2015).

The National Roads Development Guide (SCOTS, 2017) states than the upstand should be within range 10mm to 40mm.

There is no indication in these documents of research or rationale supporting these dimensions.

A 25mm upstand is generally formed using dropped kerb units (often with a bullnose profile) that match with material specification and top width dimension of adjacent standard height kerbs.

Hayashi et al. (2012) indicates that ramped access points (from road carriageway onto a footway) with a kerb face upstand height of 50mm or more will be obstructive to cyclists.

The 25mm raised kerb height at footway crossover locations would appear to be a compromise, which allows a vehicle to comfortably traverse between the carriageway and vehicular access or driveway at low speed, whilst maintaining surface water flow in the channel space.

3.5.4 Kerb interface between segregated footway/footpath and cycle track/cycleway

The interface between pedestrians and cyclists is becoming increasingly important, as transport policies move towards more emphasis on active travel.

The literature review identified a range of recommended interface treatments. Whilst some documents gave commentary on the recommended heights, these did not cite any formal research.

As summarised in **Table 3.1**, advice on appropriate interface treatment between pedestrian and cyclist spaces is set out in various guidance documents. In cases of low flow movements of pedestrians and/or cyclists a raised kerb is often not required.

Where a kerb upstand is defined as appropriate, the following design guidance states a minimum value of 50mm:

- Inclusive Design in Town Centres and Busy Street Areas (WSP, 2021);
- Streetscape Guidance (TfL, 2019); and
- The London Cycling Standards (TfL, 2014).

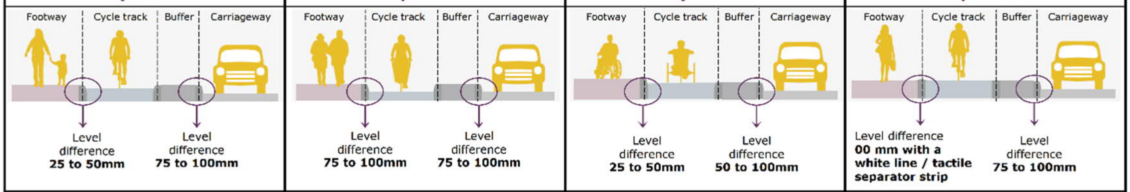
The National Roads Development Guide (SCOTS, 2017) recommends a 40mm minimum kerb upstand.

The Edinburgh Street Design Guidance (The City of Edinburgh Council, 2020) defines values between flush and 100mm dependent upon arrangement, see Figure 3.3

The September 2021 revision of Cycling by Design (Transport Scotland, 2021) states that “Research commissioned by The Guide Dogs for the Blind Association suggests that kerb upstands between cycle tracks and footways should provide a level difference of at least 60mm to be fully detectable by blind and partially sighted users.”, citing Childs, et. al (2009). It is understood that this recommendation is in place until such time as further definitive research is published.

The Dutch Design Manual for Bicycle Traffic (CROW, 2017) states the maximum height of a kerb interface between a pedestrian and a cyclist can be up to 110mm assuming a splay kerb profile is implemented.

Figure 3.3: Cycle track cross sections incorporating kerb segregation



Option 1	Option 2	Option 3	Option 4
Cycle track at intermediate level	**Cycle track at carriageway level**	**Cycle track and buffer at same intermediate level**	**Cycle track at footway level**
Pro's • Relatively easy for pedestrians/loading to cross. Discourages cycle encroachment on to footway • 50mm kerb can be detected by visually impaired users. **Con's** • Potentially complex drainage (consider gaps in the buffer). • Kerb <50mm difficult to detect for visually impaired users.	**Pro's** • Potentially cheaper than Option 1 especially if gaps in buffer for drainage. • Very clear pedestrian/cycle separation. **Con's** • Inconvenient/difficult to cross cycleway.	**Pro's** • Cheaper than Option 1 with raised buffer. • Easier to cross than Option 1 with raised buffer. **Con's** • Lower kerb to carriageway means less disincentive for parking/loading using cycleway.	**Pro's** • Easy to cross cycleway. • Simple drainage. **Con's** • Tactile separation of cycleway/footway takes more space than kerb. • More potential for cyclist encroachment on to footway.
Likely to be preferred for new construction in locations with medium to high pedestrian activity; except where pedestrian crossing movements are highest.	Likely to be preferred in areas of lower pedestrian activity where existing kerb line can be retained.	Likely to be preferred over option 1 for cost reasons where parking/loading pressures are lower.	Likely to be preferred where frequent pedestrian crossing of cycleway is expected. e.g. busy shopping street.

Source: Edinburgh Street Design Guidance Factsheet C4 Segregated Cycle Tracks: Hard Segregation (The City of Edinburgh Council, 2020)

Reasoning supporting the provision of a level difference between pedestrians and cyclists (shown in **Figure 3.4**) is set out in Cycle Infrastructure Design (LTN 1/20) (DfT, 2020): "Cycle tracks in all forms should be clearly distinguishable from the footway. The preference among visually impaired people is for a level difference between the cycle track and footway as this is the most easily detectable form of separation."

Figure 3.4: Stepped cycle track, Gateshead

Source: Cycle Infrastructure Design (LTN 1/20) (DfT, 2020)

Hayashi, et al (2012) supports a view that cyclists find it problematic to travel over a 50mm, or higher, kerb height. This research supports a view that raised kerb separation may also discourage cyclists from encroaching into pedestrian designated space.

The Edinburgh Street Design Guidance (The City of Edinburgh Council, 2020) states that "It will usually be impossible for the designer to fully meet all user needs in designing segregated cycle infrastructure. Even the same user group may have different needs at different times. For example, a blind person will benefit from a clear kerb to a cycleway when walking along a footway, but this same kerb will be a barrier to crossing the cycleway. Overall, the design should aim to balance user needs appropriately, considering the ability of different user groups to adapt as well as relative numbers."

The London Cycling Standards (TfL, 2014) also specifies the 50mm minimum kerb height and asserts that this is appropriate to aid people who are blind or partially sighted and further comments that angled kerbs should be considered to assist cyclists.

Cycle Infrastructure Design (LTN 1/20) (DfT, 2020) provides guidance for the design of cycling infrastructure in support of the Cycling and Walking Investment Strategy. Where significant pedestrian and/or cyclist activity is anticipated, a stepped kerb separation (minimum 50mm) between the footway and cycle track is recommended.

The Edinbrugh Street Design Guidance (The City of Edinburgh Council, 2020) states a kerb height range between 25mm and 50mm as appropriate in such a situation (see **Option 4** in **Figure 3.3**).

Cycle Infrastructure Design (LTN 1/20) (DfT, 2020) acknowledges that raised kerb separation between cyclists and pedestrians is not always essential and is situational; "Shared use routes away from streets may be appropriate in locations such as canal towpaths, paths through housing estates, parks and other green spaces, including in cities."

Janssen et al. (2018) states that "The results show that cyclists moving on the sidewalk is a relatively rare event for all kerb types and no conflicts between cyclists and pedestrians were observed." Suggesting, perhaps arguably, that pedestrians or cyclists are more vulnerable in the presence of motorised traffic than where no motorised transport is involved.

Cycle Infrastructure Design (LTN1/20) (DfT, 2020) advises that physical segregation between pedestrians and cyclists need not always require a stepped kerb interface. A trapezoidal edge form (as shown in Figure 3.5) which incorporates a central peak will provide a visual and tactile reference to the modal dividing line and thus is likely to be more effective than flush surface treatment, such as white line marking, edging strip or contrasting surface colour.

Figure 3.5: Trapezoidal edge strip detail

Source: Cycle Infrastructure Design (LTN 1/20) (DfT, 2020)

The importance of site-specific design considerations and associated consultation with relevant user groups point are well made in the London Cycling Design Standards (TfL, 2014); this would seem particularly relevant for innovative or experimental scheme elements.

Research by Janssen et al. (2018) identified that kerb upstands between cyclist and pedestrian routes have the potential to be a trip hazard for both cyclists and pedestrians and that there is some difference of opinion as to what constitutes an appropriate or optimal kerb separation (upstand height and kerb form) between pedestrian and cyclist paths.

Inclusive Design in Town Centres and Busy Street Areas (WSP, 2021) which, based on Disabled Street User Focus Group inputs to research, states that “if the kerb is too high, the cycle track width would need to be wider, as a cyclist will cycle further away from the kerb. This can result in reduced footway width.”; clearly implying that this is not a desirable outcome.

Kerb upstands, particularly with square or half battered profile, between cyclist and pedestrian routes can be hazardous to cyclists as wheel or pedal strike can cause a cyclist to lose balance and fall. Opinion set out in online grey literature makes a case that an optimal kerb separation arrangement, as is commonly implemented in continental Europe, incorporates a kerb slope face of c. 30° to provide a forgiving profile for cyclists. (The Ranty Highwayman, 2020)

Review of recent published guidance, notably including the Dutch Design manual for bicycle traffic (CROW, 2017), points to essential provision of kerb separation between pedestrians and cyclists only when flows of either or both modes are high and that a ‘forgiving’ kerb profile (splay or chamfered slope profile) which is less likely to catch cyclist pedal or wheel would in such a case be optimal.

There appear to be clear benefits for cyclists through the implementation of chamfered kerbs at track edges, though the suitability of such installations for pedestrians with various forms of disability is less clear, for example, are they reliably detectable by people with sight impairment?

An increasingly important consideration at this interface is provision for wheelchair users and mobility scooters. No specific statements on what would constitute the optimum kerb upstand height for these road user groups were identified during this literature review.

It is evident that a range of kerb forms and upstand heights are commonly used at this interface.

3.5.5 Kerb interface between segregated cycle track/cycleway and vehicular carriageway

As with Section 3.5.4, this interface is becoming more important due to increased investment in active travel infrastructure.

As summarised in **Table 3.1**, advice on appropriate interface treatment between cycle route infrastructure and road carriageways is set out in various guidance documents.

A kerb upstand between cyclists and motorised traffic can take the form of a stepped arrangement between the cycle track and the road carriageway (where the track is situated above the road carriageway and may also incorporate a buffer separation strip) or a raised island section between the cycle track and the road carriageway, whereby the cyclist and motor vehicles are approximately on that same elevation.

Figure 3.3, sourced from the Edinburgh Street Design Guidance (The City of Edinburgh Council, 2020) graphically indicates cross sectional variations acceptable for implementation in Edinburgh.

For stepped arrangements Cycle Infrastructure Design (LTN 1/20) (DfT, 2020), states a value of 50mm (with an upright profile) as appropriate, whilst the National Roads Development Guide (SCOTS, 2017) recommends a 40mm minimum kerb upstand in such a situation.

The Design Manual for Bicycle Traffic (CROW, 2017) states values of up to 120mm on the carriageway side and 50mm on the cycle track side, but this can be up to 70mm if a profile is chosen that prevents pedals catching. Cycling by Design (Transport Scotland, 2021) states 50mm with upright profile and 60mm with splay kerb.

In addition to kerb height separation, buffer strips between cycle tracks and road carriageways are noted as advisable in most situations by both Cycle Infrastructure Design (LTN 1/20) (DfT, 2020) and the Edinburgh Street Design Guidance (The City of Edinburgh Council, 2020).

The literature review shows there are a range of recommended kerb heights. Whilst context is given for some of these, they do not appear to cite research for their recommendations.

3.5.6 Kerbs at raised bus stop boarding areas

Raised bus kerbs are required to achieve a suitable bus ramp gradient intended to inclusively enable passenger access and are becoming increasingly common.

Inclusive Design in Town Centres and Busy Street Areas (WSP, 2021) based on Disabled Street User Focus Group inputs to research, states "Bus stop raised boarding areas were considered very enabling by the mobility impaired group, while visually impaired users suggested that great care was needed in using them.".

As summarised in **Table 3.1**, advice on appropriate kerb interface treatment at bus boarding locations is set out in various guidance documents.

Review of the legislation Bus and coach accessibility and the Public Service Vehicle Accessibility Regulations 2000 (UK Statutory Instruments, 2000), applicable in England, Scotland, and Wales, confirms that all new buses should now comply with low floor requirements to be considered accessible.

This is consistent with the Transport for London (2017) Accessible Bus Stop Design Guidance, which states that a kerb height between 100 and 140mm is acceptable (with a range 125 to 140mm preferable). However, these criteria are not adopted by other UK authorities and there are believed to be many buses and coaches in use nationally that do not comply with the relevant legislation.

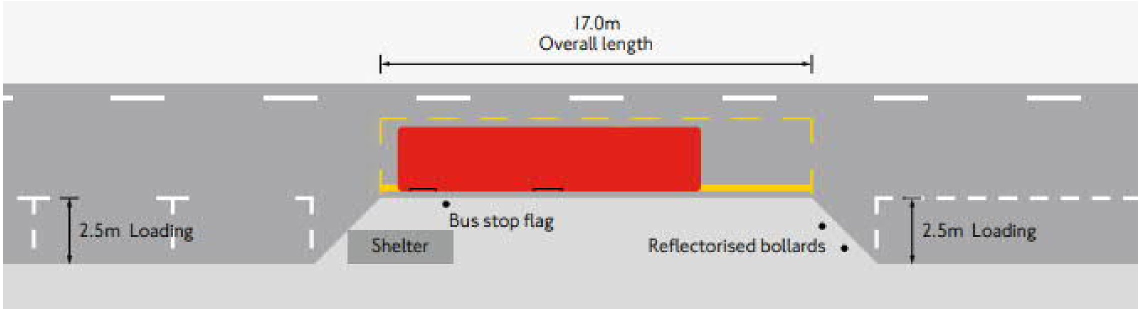
Other design guidance which defines kerb height criteria at bus stop locations include The Edinburgh Streetscape Guidance (The City of Edinburgh Council, 2020) which defines standard kerb height at bus stops in the range 100 to 120mm and the Manual for Streets (DfT, 2007) which defines standard kerb height at bus stops in the range 100 to 120mm and the Northern Ireland Bus Stop Design Guide (DRDNI, 2010) defines an acceptable range as 125mm-160mm.

From the literature review, it is evident that the kerb height is not the only relevant design aspect to achieve appropriate bus stop accessibility. Accessible bus stop design guidance (TfL, 2017) states that for a bus stop to be considered as accessible (including standard kerbside, bus boarder, half width boarder or echelon arrangement bus stop forms), three criteria must be satisfied:

- Bus stop clearway; road markings and signage to support 'no stopping' restriction.
- Access free of impediments; to enable bus to align with boarding zone and deploy its ramp and to provide bus users with an uncluttered footway which is suitably graded.
- Kerb >100mm; to enable the bus to deploy its ramp safely.

A bus boarder incorporates a horizontal offset from the local footway kerb edge (typically full width of c.2m or half width c.1m) and increases the likelihood that a bus will have an unimpeded path to and from the stop location. This is a preferential arrangement where adjacent kerbside loading or waiting activity is required as it will increase the likelihood that a bus will have an unimpeded path to and from the stop location. **Figure 3.6** shows a typical arrangement of a full width bus boarder.

Figure 3.6: Full width bus boarder



Source: Accessible Bus Stop Design Guidance (Figure 15) (TfL, 2017)

Bus stop kerbs (commonly ‘Kassel kerbs’) are installed with upstands in the range 120 to 180mm throughout the UK and local bus stop infrastructure arrangements will often depend upon the bus fleet utilised by local service operators. These kerbs feature tactile features on the top of the kerb to assist bus users who are blind or partially sighted and will align with bus floors to enable step free access via a driver-controlled ramp from the bus.

The high profile of bus stop kerbs means that they are not appropriate for general use, aside from bus stop locations, as the raised kerb will be a barrier to an open car door or potentially a trip hazard for a pedestrian crossing the road. Furthermore, providing acceptable footway crossfall (2.5% is the desirable maximum crossfall gradient stated in Manual for Streets (DfT, 2007) or longitudinal gradient (maximum 5%) adjacent to a raised bus stop kerb can be difficult to achieve.

The literature review suggests that the design of bus stops is a specialist multi-factored area, where kerb heights are not the only factor affecting accessibility.

3.5.7 Shared space

Shared space infrastructure comprises of non-segregated public spaces or streets which allow use by pedestrians, cyclists, and motor vehicles (although the types of vehicles and times of days when vehicles can access the space may be restricted).

At shared space locations, kerb height separation of modes is not typically incorporated. However, at the external boundaries of shared space locations, tactile features are often incorporated. Appropriate surface treatment to cater for the requirements of visually impaired people can be a significant consideration in the design of appropriate shared use infrastructure solutions.

At flush level locations interfacing footways/footpaths and shared areas (available for use by both pedestrians and cyclists), guidance on the most appropriate arrangement of ladder pattern tactile paving is set out in Guidance on the use of Tactile Paving Services (Department for Environment, Transport & Regions, 2007).

The UK Department for Transport withdrew their 2011 published guidance on shared use environments in 2018, however the topic was appraised in Inclusive Design in Town Centres and Busy Street Areas (WSP, 2021), concluding that:

- "The evidence shows that there is still some debate on the need for kerbed edges, however there is consensus that detectable demarcation between motorised traffic and pedestrians in 'shared spaces' is required."
- "Further research is required into collisions associated with existing 'shared space' sites or similar design concepts within the UK. The research needs to include specific reference to vehicle speeds and flows, as well as the form and nature of the design, including consideration of level surfaces and kerbs with associated tactile paving."
- "In the absence of detailed quantitative research, it is suggested that the definition of 'low flow / low speed' locations in Manual for Streets (DfT, 2007) of 100 vph / under 10 mph is adopted. Where these flows / speeds are exceeded, kerb demarcation is required."

Even in shared locations, some pedestrians prefer having an area where vehicles are discouraged or restricted from entering. This is more so the case where significant traffic activity is likely and particularly where speeds exceed 10mph. This 'comfort space' (or 'safe area') is important for all pedestrians but is particularly important for people with disabilities and should be designed with their needs in mind. Appropriate edge demarcation is a key design aspect in this regard.

The literature review suggests that shared space design is complex, and multi factored and associated interface or pedestrian 'comfort space' (or 'safe area') edge design and specification should not be considered in isolation.

3.5.8 Inclusive design

The Equality Act 2010 (UK Public General Acts, 2010) necessitates making reasonable adjustments to remove barriers for disabled people on public roads and other public spaces and covers pedestrians, cyclists, and disabled road users. Mobility impairments are not only restricted to those with physical disabilities; disability should account for those with non-physical impairments such as mental health, age related conditions and certain conditions such as diabetes. Accordingly, authorities must pursue inclusive design, ensuring that everyone, as far as possible, using public roads and spaces are able to participate independently in everyday activities and with confidence, although there will be occasion where different disability types may give rise to conflicting needs.

A Swedish study entitled “Improved Usability of Pedestrian Environments After Dark for People with Vision Impairment: An Intervention Study” (Mattsson , et al., 2020) focused on people with impaired vision (not total sight loss). The study was performed in a city in southern Sweden, along a pedestrian route where observations and structured interviews were conducted before and after an intervention involving installing a new lighting system. The study recorded that people with impaired vision (not total sight loss) use kerbs, grass, and white lines to orientate themselves and that their ability to do so deteriorates significantly when lighting conditions are poor.

A study entitled Step adjustments among young and elderly when walking toward a raised surface (Laessoe & Voigt, 2013) aimed to evaluate whether elderly and young people use different step adjustment strategies during their approach to a raised surface, concluding that “Elderly people use more cautious anticipatory strategies. These strategies allow more time for postural adjustments, but they also result in a loss of forward momentum which may influence the negotiation of a raised surface negatively.”

It is notable that no quantitative research relating to pedestrian trips and falls at kerbs or other forms of upstands was identified through the literature review process.

Inclusive Design in Town Centres and Busy Street Areas (WSP, 2021) sets out evidence-based recommendations on methods and approaches to help deliver inclusive design environments within town centres and busy street areas. The publication concludes:

- “Most aspects of physical design measures are covered to some extent by existing guidance. However, the guidance is spread across multiple documents leading to inconsistency in its application and a perception of a lack of effectiveness of guidance by disabled street users.”
- “For inclusive design there should be consistency in the approach to, and design of, street features in town centres and busy street areas, such that it

supports access for all street users, increasing the confidence of disabled street users and minimising feelings of discomfort and/or feeling unsafe."

Based upon disabled street user focus group inputs, Inclusive Design in Town Centres and Busy Street Areas (WSP, 2021) emphasises the importance of consistency in specification and application:

- "An overriding theme from across the disabled street user focus groups regarding inclusive physical design measures was the importance of consistency in approach and in the application of street design." and
- "From the perspective of disabled street users, 'consistency in approach' supports and improves access. Consistency further improves the confidence of disabled street users that journey can be made and successfully completed in areas that are less familiar to them."

This view is endorsed by a Dutch study by Schepers, et al. (2017) on behalf of the National Safety Council (2017), which states:

- "The risk of obstacles and height differences depends not only on aspects such as visibility but also on the extent to which they fit into pedestrians' expectations." and
- "The central question should be how the road system could be adapted to human capabilities and limitations including those of pedestrians?"

The literature review on inclusive design highlights the legal requirement to be truly inclusive in design and in practice to recognise the importance of consistency and familiarity for disabled street users but does not make any specific references to kerb heights, as these are covered in overlapping report sections.

3.5.9 Engineering aspects

In conjunction with compliance with relevant design standards and guidance there are several civil engineering related aspects to be considered when designing and specifying kerb installations, these include:

- Surface water drainage;
- Vehicular containment;
- Edge restraint;
- Construction safety; and
- Local availability of kerb forms.

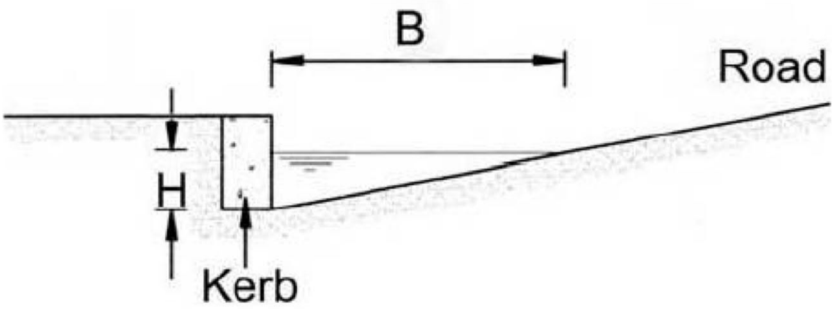
3.5.9.1 Surface water drainage

A key consideration from a civil engineering perspective relates to the role of kerbs in conveying surface water drainage. The requirements and advice relating to the use of kerbs as a drainage feature are provided in DMRB CD 524: Edge of pavement details (Standards for Highways, 2020). This standard is mandated for use when designing all-purpose trunk roads and similar principles will underpin local road design guidance. The document does not specifically mention different requirements for kerbs separating pedestrians from cyclists.

However, according to DMRB CD 526: Spacing of road Gullies Revision 3 (Standards for Highways, 2020), the flow of water parallel to the kerb shall not exceed an ‘allowable flow width’ for a 1 in 5-year storm event for a standard carriageway of 1.0m. Applying basic trigonometry, if the surface water drainage system is designed in accordance with DMRB then to avoid water over topping onto the footway, for a standard carriageway 2.5% crossfall would equate to a kerb height of 25mm minimum.

Figure 3.7 illustrates this scenario and shows H = height of water at kerb, B = allowable width of flow (generally 1.0m maximum). This scenario would also apply to the design of cycling infrastructure, as UK design guidance including Cycling by Design (Table 3.9) (Transport Scotland, 2021) and Cycle Infrastructure Design (LTN 1/20) (Section 5.10.1) (DfT, 2020) both stipulate that crossfalls should not exceed 2.5%.

Figure 3.7: Flow width of water against kerb



Source: DMRB CD 526 Spacing of road Gullies Revision 3 (Standards for Highways, 2020),

The calculation set out above is based upon current design guidance, however it should be noted that design standards are regularly reviewed, and this is particularly pertinent in relation to surface water drainage, with rainfall events predicted to increase in frequency and intensity due to climate change.

Notably, a 25mm maximum kerb upstand is as stated by the Edinburgh Street Design Guidance (The City of Edinburgh Council, 2020), Streetscape Guidance (TfL, 2019) and Director of Engineering Memorandum 154/15: Kerb Heights in Public Realm Scheme (DfINI, 2015) to be applicable at footway crossover locations.

Some authorities require a nominal 6mm upstand at pedestrian crossing locations to allow better throughflow of surface water than a flush (0mm upstand) arrangement. DMRB CD127: Cross-sections and headrooms (Standards for Highways, 2021) states “if it is necessary to lower kerbs, they should be laid flush with the carriageway or with a maximum upstand of 6mm using bullnose kerbs for the purpose of retaining water where the carriageway falls towards the kerb.”.

Kerb placement and form are integral to most surface water drainage systems in urban areas. Kerb height in this respect is not a standalone design element and the local surface water drainage system, which may also incorporate carrier pipes, gullies and/or Sustainable drainage systems (SuDS) features, for new installations should be designed consistent with a requirement to cope with surface water discharge and associated flooding events.

(SuDS) are designed to manage storm water locally (as close to its source as possible), to mimic natural drainage and encourage its infiltration, attenuation, and passive treatment.

3.5.9.2 Vehicular containment

Standard kerb height (up to 125mm) and standard forms of kerb (bullnose, half battered or splay), typically found in urban areas where speed limits up to

30mph are in operation may deflect, but would not fully restrict, movement of an errant vehicle.

No published research was identified specifically addressing the minimum height to eliminate deliberate or accidental overrun of a footway. It is, however, clear from the Trief containment kerb systems product literature (Brett Landscaping, 2010) that the height of the smallest unit (which Brett Landscaping state is applicable for use on roads up to 30 mph i.e., urban or residential areas) comprise units which exceed 300mm and feature a profile that deflects a vehicle back onto the carriageway. Such units have been tested by the Transport Research Laboratory (TRL) and the system is compliant to BS EN 1317-2:2010 Road restraint systems (BSI, 2010).

A UK parking factsheet (DfT, 2010) relating to obstructive footway parking, stated that ‘heightened kerbs’ can be used to manage footway parking. However, no guidance on what constitutes an appropriate height or profile of kerb to limit footway parking was identified in the literature search. London has a longstanding footway parking ban, with associated legislation, which is backed by enforcement. The prospective Transport (Scotland) Act 2019 (Acts of the Scottish Parliament, 2019) is likely to lead to a similar prohibition in Scotland.

Common applications for containment kerbs include traffic islands, site entrances subject to heavy vehicle traffic, locations where the adjacent land feature is not suitably ‘load bearing’ and any other area where it is necessary to improve safety through controlling the movement of heavy vehicles.

The Australian Guide to Road Design Part 3: Geometric Design (Austroads, 2021) states “Given the additional kerb height, high profile barrier kerb is considered to provide a potential tripping hazard for pedestrians and cannot be used where vehicles may be expected to park as it interferes with opening of car doors.” Accordingly, containment kerbs or bus stop kerbs must only be used where they are essentially required.

The design and specification of vehicular restraint systems (which can include containment kerbs) should be developed following established design guidance and British Standards:

- For high-speed roads DMRB CD 377: Requirements for Road Restraint Systems (Standards for Highways, 2021) is applicable.
- For low-speed roads (including 20mph and 30mph speed limit urban roads) Provision of Road Restraint Systems on Local Authority Roads (UK Roads Liaison Group & DfT, 2011) guidance is generally considered applicable.
- Road restraint systems should be compliant to BS EN 1317 (BSI, 2010).

3.5.9.3 Edge restraint

According to the Southwark Streetscape Design Manual (SSDM/DSR Standard DS.603) (Southwark Council, 2019), the fundamental engineering purpose of kerbs and other pavement edge restraints (such as edgings bedded on concrete) is to structurally retain individual areas of pavement at their joints and limits to prevent failure. Insufficient detailing in this respect is amongst the most common reasons for pavement failure – particularly for rigid natural stone sett surfaced carriageway pavements.

3.5.9.4 Construction safety

According to the Health and Safety Executive (HSE) (n.d.) “Kerbs and paving material are common construction products. Regularly lifting, carrying or handling them can present significant risks of developing musculoskeletal problems.” Specification of precast kerbing units which comply with BS EN 1340 (BSI, 2003) should minimise the potential for such injuries occurring, as a competent contractor will be familiar with good practice in lifting and placing such units.

If specifying proprietary, non-standard and/or heavier kerb forms, information on best practice for lifting, handling, and laying should be sourced at design stage. Then, as is standard practice in complying with UK H&S legislation, this guidance should be included with construction information and itemising in the project H&S risk assessment form as a residual risk. Relevant legislation in this respect includes the Manual Handling Operations Regulations (1992) (HSE, 1992) and the Construction (Design and Management) Regulations 2015) (HSE, 2015).

3.5.9.5 Local availability of kerb types

The literature review, in conjunction with professional experience, has not highlighted any significant gaps in the range of available kerb forms, or their general availability in the UK.

All kerb forms that comply with the British Standard (BS) range of kerbs and edgings are commonly available in most UK locations formed from precast concrete. Non-BS kerbs and those formed from materials other than precast concrete, for example high quality local stone products, are often less straightforward to obtain and may require importation, with potentially significant lead time and project cost implications. Further information on common kerb forms is provided in **Appendix A**.

3.5.9.6 Future mobility needs

Development of new technologies is advancing rapidly, from the rise in popularity of electric scooters to future Connected and Automatous Vehicles (CAVs) and in a post pandemic world, autonomous delivery drones. In the near future CAVs will still be required to identify edge delineation of the carriageway via kerbing or road markings to confirm their location, but advances in GPS, radar and camera technology are likely to eventually render this unnecessary.

These developments will likely bring significant opportunities on the way vulnerable road users interact with CAVs and other vehicles, particularly in city spaces, either influencing kerb height and form or even rending kerbs obsolete. For example, FlexKerbs – Roads for the Future - Evolving Streets for a Driverless Future (Arup, 2018) brings in the concept of dynamic pavement spaces - "FlexKerbs could transform fixed kerbsides into dynamic, technologically sophisticated spaces that change function throughout the day and week in response to local policy and user demand. They would directly support the introduction of CAVs onto the UK's urban road networks by maintaining an optimal supply of kerb space for the loading and unloading of people and goods, while prioritising the human scale and placemaking function of city streets".

Such system could operate via the use of ground lighting or other visual cues, supported by smartphone and other such devices. This means pedestrians, cyclists and other vulnerable users are allocated specific road space to CAVs depending on, for example, the time of day, whilst technology allows pedestrians etc including those with disabilities to mingle safely with CAVs to cross the road.

There is also mention of a potential new ISO standard, (ISO/TS4448: Intelligent transport systems - Sidewalk and kerb operations for automated vehicles), which is currently in development and there a number of studies looking at kerbside charging mechanisms to monetise kerb space.

However, these developments remain theoretical at present and may be some time off in realisation. It is worth considering such developments to avoid unnecessary work on defining kerb height and form and to realise any short term potential opportunities, but they are unlikely to affect kerb heights in the immediate timescale.

4 Discussion & Conclusions

This section provides focused discussion of key matters raised through evaluation of the published literature and associated gap analysis.

4.1 Outcomes of literature review

The literature review highlighted useful information contained in published research and guidance. As an integral part of the literature review a gap/opportunities analysis has been undertaken to identify areas where further research is necessary. This will enable resolution of the defined study objectives:

1. What are the fundamental principles that determine current kerb heights?
2. What is the optimum kerb height when considering safety, accessibility, drainage, containment, construction safety and market availability of kerb types?

4.2 Findings

The following key findings emerged during the literature review:

1. Only some of the design standards, policies and guidance considered specified kerb heights and ranges.

For example, Designing Streets: A Policy Statement for Scotland (Scottish Government, 2010) frequently refers to kerbs and discusses their impact on different users, but does not recommend or mandate any specific preferred kerb upstand heights or range of kerb upstand heights.

2. Only two academic papers were identified that specifically researched kerb heights or ranges.

These were:

- the findings of the laboratory study 'Effective Kerb heights for Blind and Partially Sighted People' (Childs, et al., 2009). This appraises several kerb heights, but only two kerb profile forms and did not consider different adjacent surface textures, and
- 'How does the edge height of curb ramps obstruct bicycles?' (Hayashi, et al., 2012) which examines kerb edge height at vehicular access / footway crossover locations which obstruct cyclist movements.

3. Only two design policies, standards or guidance documents, in addition to the September 2021 revision to Cycling by Design (Transport Scotland, 2020), cited academic research.

Both documents identified are part of Transport for London's Streets Toolkit, namely Streetscape Guidance (TfL, 2019) and the London Cycling Standards (TfL, 2014). Both documents cite only Childs et al. (2009).

4. There are multiple instances where standards, policies, proprietary products or guidelines specify kerb upstand heights and ranges without citing supporting evidence.

Examples include DMRB CD127 Cross sections and headrooms (Standards for Highways, 2021) which states kerb heights to be used on all purpose roads, and Cycle Infrastructure Design, Local Transport Note (or LTN) 1/20 (DfT, 2020), which states a minimum kerb height separation in different scenarios but does not provide detailed reasoning in support of the recommendations.

5. Specified kerb heights and ranges often dependent on kerb profile and adjacent features. Road Authorities regularly specify short lengths of kerbing to match existing adjacent kerb features and suppliers often brand new products to suit specific opportunities, hence the vast range of market kerb types available (eg Charcon's 'Cycle Kerb') (Aggregate Industries, 2017).

It is clear from this literature review that balancing the needs and safety of all road users with differing purposes and requirements of kerbs when specifying an optimally safe and practical kerb arrangement is site and purpose specific and in some cases complex. For example, Childs et al. (2009) was focussed on the interface between pedestrians and vehicular traffic whilst Hayashi, et al. (2012) noted the height at which kerb edges at vehicular access / footway crossover locations obstruct bicycle incursion.

6. Grey literature (Informal websites and blogs) indicates user views on accessibility.

A review of grey literature identified two posts on the rantyhighwayman blog and a guidance document posted on cityinfinity.co.uk. These grey literature sources present some logically developed opinions and ideas, but they do not inform a definitive optimum kerb height.

These 6 key findings demonstrate significant gaps in knowledge. Sections **4.3** and **4.4** give more detail relating to each objective.

4.3 Fundamental principles that determine kerb heights

Vertical segregation between pedestrian street users and vehicles, including pedal cycles, is generally required in an urban centre / busy street environment to support access for all road users, including pedestrians with a range of individual physical and mental abilities / impairments.

Only Childs et al. (2009) has tested kerb heights for pedestrians in laboratory conditions. In all other literature identified, there was no other evidence to back up the recommended standard kerb heights.

In summary, segregation by kerbs:

- Ensures vehicles are in predictable positions and provides a level of comfort to pedestrians.
- Can be achieved by a 'step off' level change that informs the pedestrian they have entered a different street space.

Factors to be considered when specifying a kerb installation include:

- Compliance with legislation, design standards or guidance; notably including a requirement to design and implement inclusively.
- Types of road users on either side of kerb separation; The most appropriate form of kerb installation will depend upon the types of road user requiring separation.
- Bus stop locations.
- Containment requirement; including the deterrence of footway parking.
- Requirement to channel surface water flow.
- Local availability of kerb forms.
- Construction safety.
- Future mobility needs, e.g. autonomous vehicles

4.4 Optimum kerb height when considering safety, accessibility, drainage, and issues associated with construction

Specific heights and ranges stated in some design guidance and standards are dependent on the kerb profile and adjacent features (e.g., form of surfacing) and can also have the potential to influence road user behaviour. It is clear from this literature review that balancing the needs and safety of all road users, each with differing requirements from kerbs, is site- and purpose-specific and, in some cases, complex.

Key points from the literature review and evaluation which relate to these design factors and scenarios are set out in **Table 4.1**.

Table 4.1: Kerb design factors and scenarios

Ref.	Design factor or scenario
1	Kerb interface between footway and vehicular carriageway (not at a crossing or footway crossover location)
	In relation to what constitutes an inclusively appropriate standard kerb height only one relevant research study has been identified, Effective Kerb Heights for Blind and Partially Sighted People Childs et al. (2009) this study focused only on pedestrians with sight impairment and concluded that a 60mm kerb height was appropriate but acknowledged that further research in relation to effectiveness of 50mm kerb heights would be warranted, in the form of “epidemiological tests”. • In review of Childs et al. (2009), the following conclusions as set out in Inclusive Design in Town Centres and Busy Street Areas (WSP, 2021) are considered relevant and well founded: • “The recommended research could be supplemented with consideration of a monitoring and evaluation study of known sites where a kerb has been implemented, categorised by street type, street features, dimensions, pedestrian / cyclist / vehicular demand, and vehicle speeds.” • “Further quantitative research is recommended to define the kerb height provision with and without tactile demarcation, taking into consideration all types of disabled street users. The research approach should consider the level and type of disability, the level of personal adaptation and degree of personal assistance as well as street conditions. The research should seek to identify the kerb height that supports access for most users (i.e., 85th percentile of street users).” Conclusion

Ref.	Design factor or scenario
	This is the most common interface and to address gaps, further research into standard kerb heights, profiles and adjacent tactile surface features, considering the needs of an inclusive societal representation, is recommended as part of a Phase 2 study. It is considered notable that (Childs, et al., 2009) only considered sight impairment and no other form of disability and furthermore only tested two kerb profiles (half batter and bullnose). Accordingly, future research could beneficially appraise sites which feature other profiles of kerb including a splay kerb. Subsequent research could usefully appraise established kerb installations across the UK consistent with conclusions drawn from a review of Childs et al. (2009) as documented by Inclusive Design in Town Centres and Busy Street Areas (WSP, 2021)
2	Kerb interface between footway and vehicular carriageway at crossing point
	For dropped kerb crossings a flush kerb arrangement with a 6mm construction tolerance is generally accepted as suitable, although no research basis was identified to support this. Any kerb upstand above 6mm could therefore represent a pedestrian trip hazard and is not appropriate for a crossing location. <u>Conclusion</u> Further research relating to dropped kerb installations at crossing points is not required.
3	Kerb interface between footway and vehicular carriageway at footway crossover (driveway or vehicular access)
	Although no research basis is cited, it is evident from the majority of design guidance, where dimensions are stated (published by Inclusive Design in Town Centres and Busy Street Areas (WSP, 2021), Streetscape Guidance (TfL, 2019) and The Edinburgh Street Design Guidance (The City of Edinburgh Council, 2020), the upstand is recommended to be 25mm, whilst the National Roads Development Guide (SCOTS, 2017) recommended 10-40mm. <u>Conclusion</u> Given the limited nature of this interface and the minor difference in recommended heights, further research into kerb installations at footway crossovers is not required.

Ref.	Design factor or scenario
4	Kerb interface between segregated footway/footpath and cycle track/cycleway
	Where a kerb upstand is defined as appropriate, then design guidance typically states a minimum value of 50mm as appropriate. The Dutch Design Manual for Bicycle Traffic (CROW, 2017) states a preference for use of a splay kerb profile on the cyclist side of the kerb. According to Cycle Infrastructure Design (LTN 1/20) (DfT, 2020) the kerb height separation between the footway and cycle track is provided to enhance amenity and the facility of visually impaired pedestrians. It may also encourage both user groups to remain in their designated space. No research basis is cited for the specified kerb upstand values stated in any of the design guidance reviewed. Splay kerbs are commonly utilised at interfaces between pedestrian and cyclist spaces, and it is significant that this profile was not tested by Childs et al. (2009). <u>Conclusion</u> To address gaps, further research into standard kerb heights and profiles at interfaces between pedestrians and cyclists is recommended. This could be undertaken as part of a next phase study, which could usefully appraise established kerb installations across the UK.
5	Kerb interface between segregated cycle track/cycleway and vehicular carriageway
	Advice on appropriate interface treatment between cycle route infrastructure and road carriageways is set out in various guidance documents. For a stepped arrangement between the cycle track and the road carriageway (where the track is situated above the road carriageway and may also incorporate a buffer separation strip) or a raised island section between the cycle track and the road carriageway, whereby the cyclist and motor vehicles are approximately on that same elevation. Guidance on stepped cycle track when the cycle facility is situated at a higher grade than the road carriageway is generally consistent that 50mm is a minimum kerb height. For island form arrangement, where there is a raised kerb on the cyclist side Cycle Infrastructure Design (LTN 1/20) (Department for Transport, 2020) states 50mm with an upright profile. The Dutch Design Manual for Bicycle Traffic (CROW, 2017) suggests that up to 70mm is appropriate if a splay profile kerb is utilised. No research basis is cited for the specified kerb upstand values stated in any of the design guidance reviewed.

Ref.	Design factor or scenario
	Conclusion To address gaps, further research into standard kerb heights and kerb profiles at interfaces between cyclists and vehicles is recommended as part of a next phase study, which could usefully appraise established kerb installations across the UK.
6	Kerb interface at raised bus stop boarding area
	Kerb height is not the only factor in facilitating an accessible bus service. Other factors include: • the types of bus utilising stops (whether they comply with low floor accessibility legislation or not), • the designation of bus stop clearways through appropriate signs and road markings to enable enforcement of 'no stopping' restriction, • provision of clear access and egress manoeuvring space for buses, and • provision of an uncluttered footway adjacent to the boarding zone. The high vertical profile of commonly installed bus stop kerbs means that that they are not appropriate for use elsewhere, because the high kerb will be a barrier to an open car door or potentially a trip hazard for a pedestrian crossing the road. Bus stops, by definition, are not locations which should be used for car parking and are typically protected with clearway or waiting and loading restrictions. It is also established good practice to provide suitable crossing points adjacent to rather than directly on bus stop locations. Conclusion Bus stop design is multi factored and the kerb height specification should not be considered in isolation. Accordingly, research into bus stop infrastructure is considered beyond the scope of this study.
7	Shared space locations
	The UK DfT withdrew its 2011 published guidance on this topic in 2018. The literature search and evaluation did not draw out any definitive advice as to what constitutes appropriate kerb edge treatment at shared use or pedestrian comfort space boundaries or indeed when such is even necessary. Conclusion Shared space design is complex, and multi factored and associated interface or pedestrian comfort space edge design and specification

Ref.	Design factor or scenario
	should not be considered in isolation. Accordingly, research into shared use infrastructure is considered beyond the scope of this study.
8	Inclusive design
	Inclusive Design in Town Centres and Busy Street Areas' (WSP, 2021) suitably and comprehensively sets out evidence-based recommendations on methods and approaches to help deliver inclusive design environments within town centres and busy street areas. Disabled street user focus groups inputs to the WSP 2021 research clarified the importance of consistency in street design specification. Matters which related to kerb specification overlap with other design factors and scenarios appraised as part of this literature review. <u>Conclusion</u> Established good practice inclusive design should be replicated consistently.
9	Engineering aspects
	In conjunction with compliance with relevant design standards and guidance there are several civil engineering related aspects to be considered when designing and specifying kerb installations. These are discussed below.
9a	Surface water drainage
	In urban situations, the kerb height (which generally exceeds 50mm aside from at dropped crossings and vehicular access locations), surface water drainage is unlikely to be critically impacted by kerb type to the extent that this may affect amenity and safety of active travel modes. It is anticipated that further research and experimentation would confirm this conclusion. <u>Conclusion</u> Further research into surface water drainage in respect to kerb installations is not required.
9b	Vehicular containment
	Containment kerbs should only be used where essentially required to prevent vehicular overrun. Obstructive footway parking in Scotland is proposed to be managed through legislation and enforcement. The design and specification of vehicular restraint systems including containment kerbs should be developed following established design

Ref.	Design factor or scenario
	guidance (by road type) with specification in accord with relevant British Standards. Conclusion The design and specification of appropriate vehicular restraint systems, including where appropriate containment kerbing, is suitably covered by existing design guidance and standards. Further research in this respect is not required.
9c	Edge restraint
	Kerbs and edgings structurally retain individual areas of pavement at their joints and extents. However, kerb height is not a primary or standalone aspect in respect of edge restraint design and specification. Conclusion Further research into kerb edge restraint is not required.
9d	Construction safety
	Specification of precast concrete standard kerbs units complying with BS EN 1340 (BSI, 2003) minimises potential of injury as competent contractor will be familiar with handling and laying them. Relevant existing legislation covers design and construction including the Manual Handling Regulations (HSE, 1992) and the CDM regulations (HSE, 2015) Conclusion Construction safety is well covered by existing legislation and standards. Further research into kerb edge restraint is not required.
9e	Local availability of kerb forms
	A review of literature in conjunction with professional experience has not highlighted any significant gaps in the range of available kerb forms or their general availability in the UK. Conclusion Further research into available kerbs forms and their availability in the UK is not required.
9f	Future Mobility Needs
	The presence of carriageway edge definition could be an important element of road infrastructure required to operate autonomous

Ref.	Design factor or scenario
	vehicles, either as kerbs or road markings. However, it is more likely development in Connected and Autonomous Vehicles (CAV) will ultimately render the kerb obsolete, other than for limited purposes such as drainage. Research in this area is widespread and developing very quickly and is likely to provide new opportunities for pedestrian, cyclist and CAV interactions, including for those with disabilities or mobility impairment. <u>Conclusion</u> There is already a wide range of research activities into future mobility technology in progress and, therefore, it is not necessary for this study to include specific investigation. However, further research into the effects of future mobility needs, particularly CAVs, should focus on how likely rapid development in technology can benefit vulnerable road users, and thus its impact on medium term kerbing requirements.

5 Recommendations

This section provides recommendations for a potential Phase 2 of this study.

5.1 Key Interfaces

Areas recommended for further research are the kerb interfaces between:

- Footway and vehicular carriageway (not at a crossing or footway crossover location)
- Segregated footway/footpath and cycle track/cycleway, and
- Segregated cycle track/cycleway and vehicular carriageway

5.2 Scoping

The first stage of a potential Phase 2 should involve the development of a refined and appropriate study scoping, methodology and delivery programme, through structured dialogue with stakeholders.

Potentially this could be achieved through a structured workshop and/or using appropriate data analysis, during which:

- the findings of Phase 1 would be reviewed,
- precise objectives set, and
- agreement is reached as to the scope of specific issues to be addressed, based on risk, i.e., to identify key user types and physical engineering scenarios to be studied.

The format of potential stakeholder/user interviews and consultations, likely to consist of face-to-face surveys and online questionnaires, should also be discussed. Agreement should be reached as to a definitive list of stakeholders that will be invited to participate in any such process.

5.3 Examining mobility and cycling infrastructure

In Phase 2 it is recommended to further investigate the findings of this literature review, including the conclusions drawn by both Childs, et al. (2009) and related recommendations set out in Inclusive Design in Town Centres and Busy Street Areas (WSP, 2021). Potential qualitative and quantitative research activities should focus on key disability user types and location factors determined from data analysis or workshops, i.e., activities should consider the level and type of disability, the level of personal adaptation and degree of personal assistance as well as environmental conditions. Activities could include:

- Undertaking study visits to existing locations with standard kerb upstand heights at and below 60mm; these are evident across the UK. Study visits could incorporate recording an inventory of local conditions, precise geometry, and materials, interviews and surveys with a broad spectrum of disabled street users as possible to observe how they interact with the infrastructure and subsequently interviews to ascertain their perceptions of the suitability of the local infrastructure. A review of historical collision data by an experienced road safety professional could usefully be undertaken at all test sites in conjunction.
- Undertaking study visits to assess existing locations with a variety of kerb upstands and profiles delineating a boundary between pedestrian and cyclist spaces; a range of interface treatments are evident across the UK. Study visits could incorporate recording an inventory of local conditions, precise geometry, and materials, interviews and surveys with a broad spectrum of disabled street users as possible and cyclists of different ages and experience levels, to observe how they interact with the infrastructure and subsequently interviews to ascertain their perceptions of the suitability of the local infrastructure. A review of historical collision data by an experienced road safety professional could usefully be undertaken at all test sites in conjunction.
- Undertaking study visits to assess existing locations with a variety of kerb upstands and profiles and other treatments delineating a boundary between cycle tracks and road carriageways; a range of interface treatments are evident across the UK. Study visits could incorporate recording an inventory of local conditions, precise geometry, and materials, surveys of cyclists of different ages and experience levels, to observe how they interact with the infrastructure and subsequently interviews to ascertain their perceptions of the suitability of the local infrastructure. A review of historical collision data by an experienced road safety professional could usefully be undertaken at all test sites in conjunction.

- Develop and scope a further stage 3 (subject to funding) either a lab test or in-situ experimentation to appraise different kerb heights and profiles, with and without different forms of adjacent surface textured/coloured treatment. Outputs of such research would assist in defining the most appropriate pedestrian infrastructure edge treatment advice for Scotland. It is important that research is inclusive and considers the requirements of all road users (not just those who are visually impaired) and may need to include a form of epidemiological input. Any research undertaken would need to recognise prevailing Covid-19 pandemic restrictions.

The research should seek to identify interface treatments, including kerb height and kerb profile specifications, that support access for most users, but recognise that due to the limitations of any on site interviews, surveys and observations undertaken it may not be possible to make generalisations that can then be applied to the population as a whole. If a robust generalisation cannot be made any recommendation to inform national standards will need to be made with caution.

6 References

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Appendices

A. Kerb Types

This Appendix section describes common types and forms of kerbing adopted throughout the UK.

A.1 British Standard Kerb Product Information

Figure A.1shows dimensional information for kerbs and edgings per BS EN 1340.

Figure A.1: British Standard Kerb Product Information

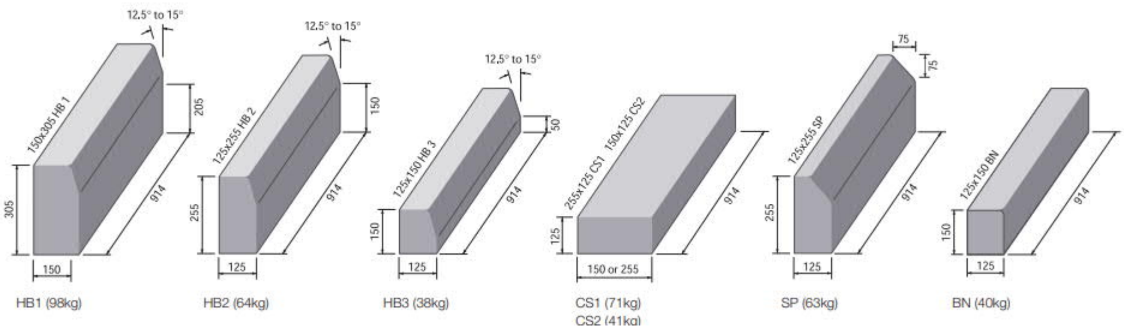
British Standard kerb

Dimensions (mm)	HB1	HB2	HB2	HB3	BN1	BN2	BN2	BN3	BN3	SP2	SP2	SP3
Length	914	914	609	914	914	914	609	914	609	914	609	914
Height	305	255	255	150	305	255	255	150	150	255	255	150
Width	150	125	125	125	150	125	125	125	125	125	125	125
Weight (kg)	100	70	40	40	100	70	40	40	30	60	40	30
Units/m (approx)	1.09	1.09	1.64	1.09	1.09	1.09	1.64	1.09	1.64	1.09	1.64	1.09
No. per pack	14	18/16	18/16	Various	14	18/16	18/16	Various	24	18	18	24
M/pack (approx)	12.84	16.51/	10.98/ 14.68	Various 9.76	12.84	16.51/	10.98/ 14.68	Various 9.76	14.63	16.51	10.98	21.9
Pack weight (T)	1.4	1.26/1.12	0.72/0.64	Various	1.4	1.26/1.12	0.72/0.64	Various	0.72	1.26	0.72	0.72
Colour available	Gy	Gy	Gy	Gy	Gy	Gy	Gy	Gy	Gy	Gy	Gy	Gy

British Standard edging

Dimensions (mm)	Flat top	Flat top	Flat top	Bullnose	Bullnose	Bullnose	Round top	Round top	Round top
Length	914	914	914	914	914	914	914	914	914
Height	150	205	255	150	205	255	150	205	225
Width	50	50	50	50	50	50	50	50	75
Weight (kg)	15	20	30	15	20	30	15	20	40
Units/m (approx)	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
No. per pack	40	20/40	20/40	40	20/40	20/40	60	20	12
M/pack (approx)	36.56	18.28/ 35.56	18.28/ 36.56	36.56	18.28/ 35.56	18.28/ 36.56	55.05	18.28	11.01
Pack weight (T)	0.62	0.45 / 0.90	0.55 / 1.10	0.62	0.45 / 0.90	0.55 / 1.10	0.90	0.45	0.45
Colour available	Gy	Gy	Gy	Gy	Gy	Gy	Gy	Gy	Gy

Gy – Grey
HB – Half batter / BN – Bullnose / SP - Splay



Source: Aggregate Industries UK Limited. May 2011

A.2 Common types of kerbs

For use on public roads in Scotland, kerbs shall be specified in accordance with BS EN 1340 (BSI, 2003) and comply with the minimum requirements of MCHW Series 1100 (Standards for Highways, 2021).

Kerb types are available in a variety of forms and profiles. Those in common use in Scotland are generally in precast concrete units. Stone, plastic compound and asphalt kerbs are also used. Common kerb types include:

- Bus stop kerbs.
- Half-battered.
- Bull-nosed kerbs.
- Containment kerbs.
- Dropper and dropped kerbs.
- Edge restraint kerbs.
- Extruded kerbs.
- Kerb drains.
- Quadrant/angle kerbs.
- Square kerbs.
- Splay kerbs.
- Transition kerbs.

A.2.1 Bus stop kerbs

According to Bus Stop Innovation: A comparison of UK Trials (Unknown, n.d.), usage of bus stop kerbs spread after good experiences with the Kassel Kerb featuring a concave section that allows easier alignment for buses. Bus stop kerbs should provide seamless integration with existing pathways for easy access.

Bus stop kerbs are specifically made for use at bus stops and in bus stations to help drivers dock close to and parallel with the kerb. A well-designed bus stop kerb will enable quicker and safer access to public transport in addition to facilitating easy boarding and alighting for all passengers (NBS Source, n.d.).

Figure A.2: Kassel Kerb

Source: Mott MacDonald

Figure A.3: Marshalls Bus Stop Kerb

Source: https://www.marshalls.co.uk/commercial/product/bus-stop-kerb-system

A.2.2 Half-battered kerbs

Half battered kerbs are the most used road kerbs. They are usually deployed where a footpath is provided adjacent to the carriageway. They have a slanted upper profile providing a safety feature for pedestrians, providing an element of check that is enough to warn motorists that they are close to the kerb. This element also results in vehicles being deflected back into the road should they clip the kerb. A half-battered kerb also allows road rollers to operate close to the edge of the pavement when undertaking surfacing work (Allen Concrete, n.d.).

Figure A.4: Acheson & Glover Half-battered kerb

Source: https://ag.uk.com/kerb/road-kerbs/

Figure A.5: In-situ Half-battered kerb

Source: Mott MacDonald

A.2.3 Bull-nosed kerbs

Bull-nosed kerbs are mostly used where a pedestrian crossing, access point or access to a driveway (footway crossover) is required. They can generally cope with increasing levels of traffic and are designed to be durable and resilient to deliver long term performance. They act similarly to half battered kerbs, whilst providing softer profile edge restraint and ensuring vehicles stay on the carriageway (RPC Paving Solutions, n.d.).

Figure A.6: Greengates Concrete Bullnosed kerb

Source: https://www.greengates.co.uk/kerb

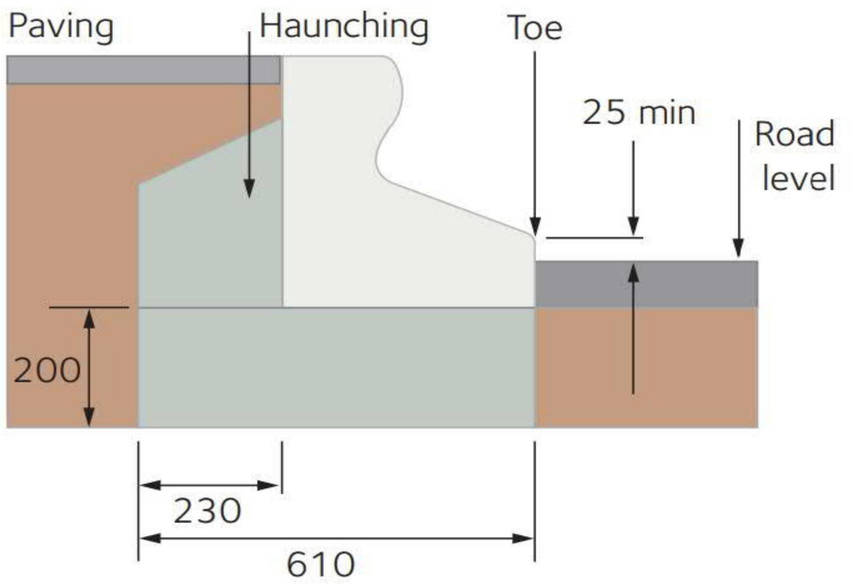
Figure A.7: Marshalls Bullnosed kerb

Source: https://www.marshalls.co.uk/commercial/product/british-standard-kerb

A.2.4 Containment kerbs

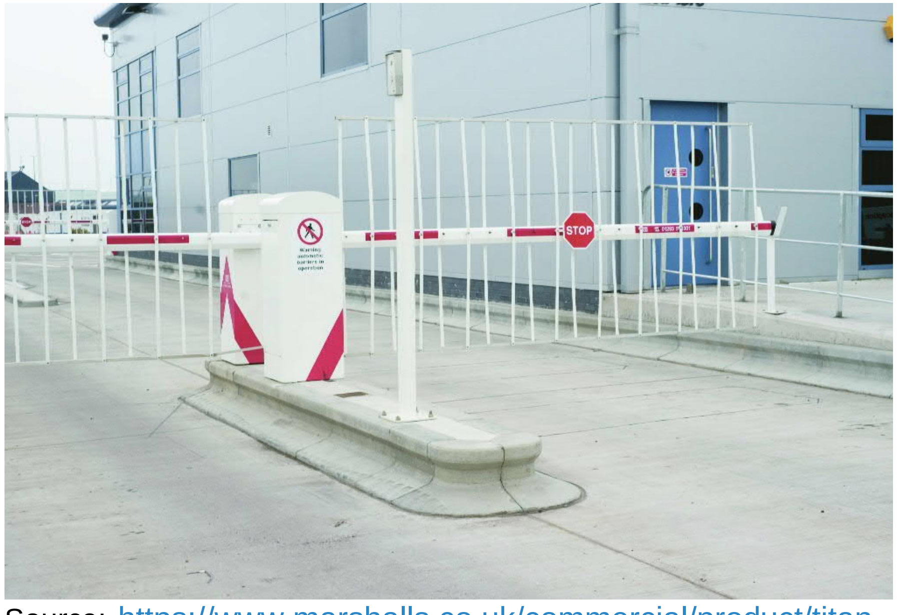
The concept of containment kerbs is to safely redirect vehicles away from danger, (passive traffic control) returning them to their intended route. Unlike crash barriers, containment kerbs remain undamaged and cause no damage to vehicles. Common application includes traffic islands, site entrances subject to heavy vehicle traffic and any area where it is necessary to enhance safety through controlling the movement of heavy vehicles (Marshalls, n.d.).

Figure A.8: Brett Landscaping Trief kerb system



Source: https://cms.esi.info/Media/documents/Brett_Triefcontainkerb_ML.pdf

Figure A.9: Marshalls Titan Containment kerb



Source: https://www.marshalls.co.uk/commercial/product/titan-kerb

A.2.5 Dropper and dropped kerbs

A dropped kerb is also known as a crossover, which is an alteration to the footway. It is a small ramp built into the kerb of a pavement to make it more accessible for people with disabilities. It also involves lowering the kerb and laying new foundations to the paving to enable a car to be driven onto the front area of a property (Ealing Council, n.d.). It enables vehicles to cross the public pavement (footway) to access a private driveway. It allows safe, off-road parking and can add value to properties (Birmingham City Council , n.d.).

Figure A.10: Dropped kerb at crossing point under construction

Source: https://www.pavingexpert.com/edging5

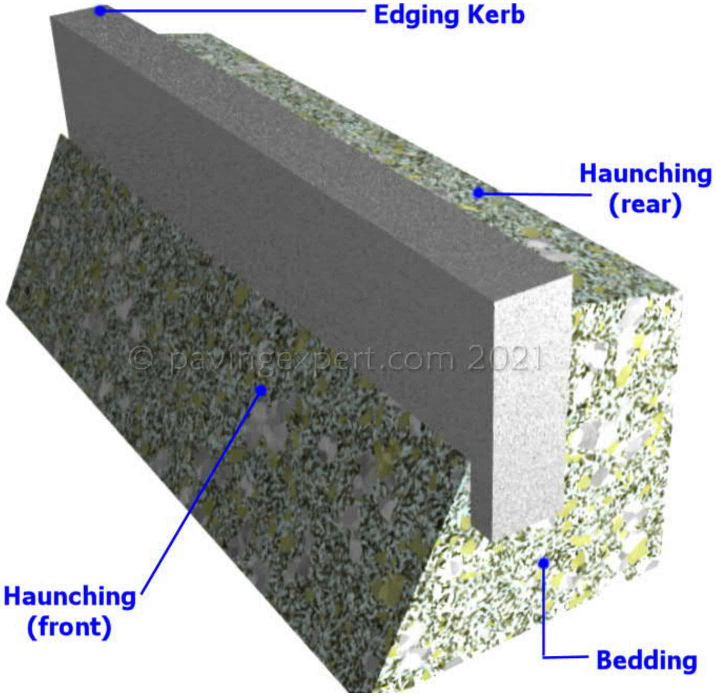
Figure A.11: In-situ dropped kerb

Source: Mott MacDonald

A.2.6 Edge restraint kerbs

Edge restraint kerbs (typically concrete) are used wherever a rigid support or restraint is required at the edge or perimeter of a pavement. They are essential for block paving and tarmacadam driveways. All edgings or kerbs, other than mowing strips, need to be bedded onto a medium strength concrete base (pavingexpert, n.d.).

Figure A.12: Concrete bedded edge restraint schematic



Source: https://www.pavingexpert.com/edging3

Figure A.13: Type EF Edging kerb under construction

Source: https://www.pavingexpert.com/edging3

A.2.7 Extruded kerbs

The extruded asphalt kerb is the most widespread type of machine laid drainage system in the UK. For more than 30 years, extruded asphalt kerbing has been the most prolific type of kerb utilised on the UK's motorway and trunk road network due to its maintenance free nature (Extrudakerb, 2021). Using a laying machine, the kerb is formed of concrete with asphalt bonded to the existing asphalt surface (Designing Buildings Wiki, 2021).

Figure A.14: Extruded asphalt kerb on UK Motorway

Source: https://www.pavingexpert.com/edging5

Figure A.15: Slip-formed concrete kerb on Irish housing estate

Source: https://www.pavingexpert.com/edging5

A.2.8 Drainage kerbs

On kerbed roads with a local gradient of c. 0.5%, the drainage path can be provided by kerbs with integral drainage channels. Kerb drains are kerbs which combine a closed profile hydraulic conduit with slots.

According to DMRB CD 524: Edge of pavement details (Standards for Highways, 2020); Although combined drainage and kerb systems are useful on roads with relatively flat gradients, they are prone to the build-up of sediment and debris which can impede flow into and within the system. Combined drainage and kerb systems are useful in urban areas where there is a high incidence of utility services because they do not need as great a depth of excavation as piped systems.

Kerb drainage systems are generally installed within the standard range of 100 -125mm upstand above carriageway level.

Figure A.16: Combined kerb and drainage unit

Source: https://cityinfinity.files.wordpress.com/2018/04/the-joy-of-kerbs-v1.pdf

Figure A.17: In-situ drainage kerb

Source: Mott MacDonald

A.2.9 Quadrant/angle kerbs

Quadrant and angle kerbs are manufactured to compliment straight and radius kerbs. They come in various angles and sizes and can be cut to create angles of less than 90° (cedstone, n.d.).

Figure A.18: Quadrant kerb

Source: Mott MacDonald

Figure A.19: Angle kerb

Source: https://www.pavingexpert.com/edging5

A.2.10 Square kerbs

Vertical-faced square kerbs are used to discourage motor vehicle drivers from leaving the roadway. The square (90º-edge) or close to square type is often used in towns or cities as it is a straight step down, making it unlikely for pedestrians to trip over and fall (concreteconstruction.net, 1958).

Figure A.20: Square kerb at construction site

Source: Mott MacDonald

Figure A.21: Square kerb at construction site

Source: Mott MacDonald

A.2.11 Splay Kerbs

Splay Kerbs are mainly used on high speed carriageways and where there are no adjacent footpaths. It allows a vehicle to mount the verge in an emergency and keep the carriageway clear (RPC Paving Solutions, n.d.).

Figure A.22: Splay kerb on high speed road

Source: http://www.rpcltd.co.uk/concrete-solutions/downloads/products/bs-kerb-data-sheet.pdf

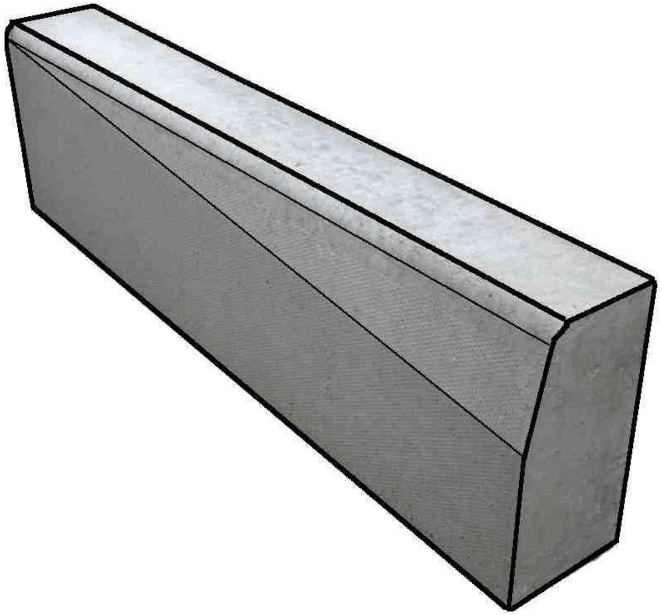
Figure A.23: Splay kerb separating cycle route from footpath

Source: https://therantyhighwayman.blogspot.com/2017/01/

A.2.12 Transition Kerbs

Transition Kerbs are utilised for changing the profile of the kerb face, whilst not changing the overall height or dimensions. They are often used when changing from either Splay profile to Half Battered or from Half Battered to Bullnosed (RPC Paving Solutions, n.d.).

Figure A.24: Bull-nosed to Half-battered Transition kerb



Source: https://www.krmbs.com/125-x-255mm-bn-hb-transition-kerb-right-hand.html

Figure A.25: Splayed to Half-battered Transition kerb

Source: https://www.pavingexpert.com/edging5

B. Additional relevant literature

This Appendix provides a summary of literature reviewed but not cited in this report.

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