Guided Busway

DESIGN HANDBOOK

Guidelines for the design of kerb-guided busway infrastructure in the UK

britpave

The British Cementitious Paving Association

2017 edition

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Design Handbook

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GUIDED BUSWAY DESIGN HANDBOOK: GUIDANCE UPDATE

First published by Britpave in 2004, the Guided Busway Design Handbook provides industry guidance and best practice on the design and implementation of kerb-guided busway systems. It covers relevant design standards, provides busway scheme examples and offer guidance on geometric guideway design, stops and pedestrian crossings plus loading and structures. Both urban bus priority schemes and independent light rapid transit schemes are considered.

This 2017 version of the Guided Busway Design Handbook updates two important chapters, Chapter 3: Geometrical Design of Guideway and Chapter 9: Construction. It has been updated by Arup with the assistance of the Britpave Rail Task Group.

Chapter 3 has been updated to incorporate the various lessons learnt from the Cambridge and Luton busway schemes. There is now a section which deals with the particular issues relating to geometry design for precast busway. Chapter 9 has been updated to include reference to the Leigh to Ellenbrook Guided Busway, Manchester. All chapters are regularly reviewed for currency and are updated as required.

The Guided Busway Design Handbook is not intended to be a specification or prescriptive construction manual. It is intended that the designer shall consider the advice and guidance given herein and evaluate its suitability and applicability to the project being designed. This guidance does not relieve the designer, owner or operator of any responsibilities under the Construction (Design and Management) regulations 2015 or the Health and Safety at Work Act 1974 or other applicable legislation.

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FOREWORD

Although thought of as a relatively modern concept, the guided bus actually has a long and honourable pedigree. Originally conceived in the mid-19th Century, the aim then was to produce a public transport vehicle with the flexibility of the on-highway bus and the greater payload capacity of a railed vehicle with its smooth track.

As road surfaces improved the value of the guided bus concept decreased – that is until the massive growth in traffic in the second half of the 20th Century resulted in severe congestion and unpredictable delays to buses, particularly in urban areas. The current ability to use a smooth designated track for fast, longer-distance bus operation has resulted in a re-appearance of guided buses.

Congestion usually occurs where there is little space to do anything about it; so it may often be impossible to provide public transport segregation. The chance of such segregation will be materially increased if a narrower path than usual can be found – and this is exactly what the guided busway can provide.

Recent years have also seen greater awareness of the need to allow all potential travellers access to public transport systems. This requires level and close boarding between stop platform and vehicle, and lateral guidance allows that to take place very effectively.

Finally comes the issue of enforcement. Sad to relate, far too many selfish road users will violate transit lanes if they think they can gain a few seconds on their journey without being caught – to the obvious detriment of public transport journeys. The precision of the guided vehicle path encourages a large degree of self-enforcement.

Amongst the new generation of bus guidance systems, the kerb-guided bus is not the oldest but is the most mature, having been in proven, reliable, continuous operation since 1980. It is not perfect; for example its kerbs rule out its use in flush pedestrian areas.

Nevertheless it is robust and effective for short and medium distance transport up to speeds of around 100 kph. It is inherently fail-safe as the guide kerbs themselves act as an effective secondary containment measure in the rare event of any guide wheel failure.

It has also been demonstrated to attract passengers in significant numbers. For a cost base of less than 20% of that for rail-based systems, more than 80% of the latter's patronage potential can be realised.

Twenty-five years of public operation is still a relatively short span in transport system development terms. Implementers of kerb-guided busways are still on the learning curve (though well up on it!) and fresh developments and ideas are still emerging.

I commend this publication to anyone implementing a kerb-guided busway system. It contains the essence of all the theoretical and practical development work, and the experience of continuous day-to-day operation, over that quarter-century, which should, if followed, enable an effective and useful kerb-guided bus system to be designed, built and operated.

Other guidance systems, usually more technologically based, are appearing. They sometimes offer different guidance opportunities. In due course they may even mirror the roles for which kerb guidance is presently ideally suited – but the beauty of the kerb-guided busway infrastructure is that it is intrinsically usable (without significant alteration) subsequently by those emerging technologies.

Thus any investment in kerb-guided busways now is robust for the future.

Dr Bob Tebb
Fellow of the Chartered Institute of Logistics and Transport (UK)

Introduction

1

This handbook aims to set out best practice based on recent experience with construction of kerb-guided busways in the UK. It covers relevant design standards for the design of kerb-guided busway infrastructure in the UK, gives examples of existing schemes and provides guidance for the geometric design of the guideway, stops and pedestrian crossings. Guidance is given on loading to the guideway and structures, and pavement design and safety issues are addressed.

Consideration is given to the application of guided busways in a street environment as part of urban bus priority schemes. Consideration is also given to the development of guided bus as an independent light rapid transit system such as that which operates in Adelaide, Australia.

1.1 GUIDED BUS SYSTEMS

Guided bus technology has been developed as a means of utilising the benefits and flexibility of road vehicle technology, but with the advantages of a fixed infrastructure system.

Guided bus systems are seen as a less expensive and more flexible alternative to light rail and metro systems as a means of providing a high-speed, reliable and comfortable public transport service. Traditionally, buses have been subject to problems where there is, or is likely to be, traffic congestion, even where bus lanes are provided. The provision of segregated guided busways removes the buses from the general road network, and can therefore provide a significant contribution to dealing with urban traffic congestion.

Bus transit has the following advantages over other public transport systems:

- High accessibility with through services using the ordinary road network.
- Flexibility to respond to social change and urban development.
- Cost effective with low development costs.

However, there are disadvantages with traditional bus systems including congestion on urban roads, low average speed, customer perception, condition of vehicles, lack of identifying infrastructure, structure of services and varying fares.

Guided bus systems seek to address some of these issues, providing the following benefits over traditional bus services:

- Segregated running alleviates congestion impact on services;
- No obstruction of guided bus lanes by other vehicles;
- Permanent guideway and stop platforms give customers confidence that the service is operating;
- Bus routes and stops are clearly defined and easily located by passengers;
- Easy access into buses from purpose-built platforms;
- Since buses are guided, the infrastructure typically requires a narrower corridor than conventional highway routes.

1.1.1 Kerb-guided systems

Kerb-guided busways are in operation in Essen (Germany) (the O-Bahn system), Adelaide (Australia), and in Leeds, Bradford, Ipswich and Crawley in the UK. The system consists of two 180 mm high guide kerbs set 2.6 metres apart for each guide lane. Vehicles are provided with two lateral guide wheels connected to the steering mechanism on the front axle of the bus (Figure 1.1). An increase in force on one of the guide wheels, for example on the outer wheel when the bus enters a curve, causes the bus to turn.

Figure 1.1 Guide wheel and arm on FirstGroup bus, Leeds (Scania 3-series chassis)

Buses enter the guideway using a funnel arrangement with asymmetric splayed kerbs allowing the experienced driver to smoothly engage the guide wheels. Once on the guideway with both guide wheels in contact with the kerbs, the bus is guided securely from both sides and the driver can in fact release hold of the steering wheel. On leaving the guideway, both kerbs are terminated equally, releasing the guide wheels simultaneously and requiring the driver to resume steering.

Short breaks in the guide kerbs to allow for manholes or pedestrian crossings can be accommodated without the need for full entry splays. It is however important to ensure that any breaks in the guide kerbs occur equally to reduce the likelihood of unequal side force on the guide wheels causing the vehicle to deviate from its path. A guided bus system can operate effectively with only one guide kerb, if the driver steers to maintain contact with the kerb. This facility can be useful for sections with tight radii, or overtaking lanes.

1.1.2 Central guided systems

Alternative mechanical guidance systems using a central guide rail embedded in the road surface have been developed by the European companies, Bombardier and Lohr Industries.

Examples of the Bombardier system can be found in Nancy and Caen, France. The vehicle is steered by metal guide wheels running in a central groove in the pavement surface

The Translohr system uses two front rollers running on a central guide rail to control steering as shown in Figures 1.2 and 1.3.

Figure 1.2 Translohr central guide slot

Figure 1.3 Translohr vehicle

Both these systems provide a high specification tram-like operation, with the advantage that the vehicles can operate on the open road with manual driver steering. They also provide an easy interface with the public highway, allowing easier access for pedestrians to cross the guideway than kerb-guided systems, although cyclists may experience difficulty crossing the slot. Slow running speeds are also required when entering or leaving the guide slot

However, there have been concerns about safety (when transferring between automatic and manual guidance) and noise from the guide wheel/rail interface; these led to the suspension of the Bombardier systems in Nancy and Caen for a time.

1.1.3 Automatic electronic guidance

In this system, electrified underground cables generate a magnetic field that is detected by antennae under the bus. These antennae are linked to an on-board computer system, which automatically guides the steering mechanism. Test trials on the system have proven successful and it is currently in use in the service bore of the Channel Tunnel.

Electronic guidance has the advantage of not requiring guide kerbs. The infrastructure is flush with the running surface; there are no obstacles to pedestrians or other vehicles crossing. There have been reservations, however, regarding safety and how the system would perform in severe winter weather when roads become slippery.

1.1.4 Optical guidance

Optical guidance involves the use of dashboard-mounted cameras, a video-monitoring system and a road-marking recognition system. In France, an optical guidance system with 40 buses has been in operation in Rouen for over two years, with more than two million successful guided pick-ups to date. There are also plans to implement a test scheme in Las Vegas.

General design issues

2

In addition to the geometric and physical values set out in Section 3, there are a number of general issues that will influence the layout, design and construction of infrastructure for a kerb guided bus system. These include:

- Operational requirements including dwell times, service interval;
- Legal requirements, procurement routes and system approval;
- Vehicle characteristics;
- Governing UK design standards.

These issues are described in more detail below.

2.1 OPERATIONAL ISSUES

2.1.1 Bus stop dwell times

The time taken by passengers to board a bus is an important component of total journey time. This is particularly the case where one person operation (OPO) and cash fare systems are used when, as a rule of thumb, bus dwell times account for approximately 20% of total journey times. If the dwell time due to boarding and alighting is reduced the resultant saving in total journey time will have a beneficial effect on route operation, vehicle requirement and fleet utilisation. It is probable that an improvement will also be obtained through reductions in the variability of dwell times and resultant increase in service reliability.

A bus stopping at a stop has an impact on overall journey time. This comprises several discrete elements, including:

- Deceleration time;
- Door opening time;
- Passenger boarding time (including allowance for ticket purchase/pass checking where appropriate);
- Passenger alighting time (where separate boarding and alighting doors are provided the highest figure should be used in assessments, where a single door is used the sum of the boarding and alighting times should be used);
- Door closing time (this will be influenced by the door closure/handbrake release interlocking);
- Acceleration time.

The main components of bus stop dwell times, as illustrated in Figure 2.1, are:

- A ➢ B: deceleration from operating speed;
- B ➢ C: door opening time;
- C ➢ D: boarding and alighting time;
- D ➢ E: door closing time;
- E ➢ F: acceleration to operating speed.

Further details on calculation of bus stop dwell times can be found in Appendix A.

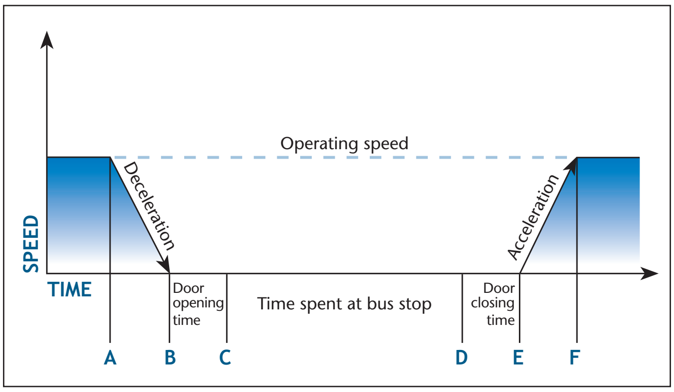

Figure 2.1 Components of bus stop dwell time

2.1.2 Bus lane or transit system?

In theory a busway system enables the development of a network that combines the high accessibility of the ordinary bus system and its ability to penetrate residential areas and city centres, with the rapid line-haul characteristics normally associated with rail-based systems, to provide more attractive journey times.

In the outer areas of the network buses operate conventionally on-street. They switch to the segregated busway over the trunk-haul sections of radial routes, where journey time advantages are greatest and where the combined frequencies of bus services can justify the investment in busway infrastructure.

The advantages of guided busways over conventional bus lanes on the trunk-haul sections of routes include:

- Easier enforcement – segregated busways tend to be more self-enforcing than conventional bus lanes.
- Better access to bus stops – guided busways prevent the illegal parking which occurs in bus lanes and can make it difficult to access bus stop kerb lines with consequent adverse impact on accessibility and dwell times.
- Quality of ride – this can be higher in a busway due to reduced conflict with other vehicles and reduced traffic loading on system.
- Image – segregated busways can generate a better image than conventional bus operations along bus lanes; this can be important in attracting car users to switch transport modes.

The scale of busway operations can be tailored to suit the particular characteristics of the network or individual corridor. In Adelaide, for example, a 12 km guided busway is in operation, with a continuous guideway along which buses operate at up to 100 km/hr. The guideway is accessed only at its outer end and at an intermediate point. It is widened out only at two locations to accommodate bus stations along the route. The bus network is designed to feed bus services into the busway for the fast trunk-haul section of their routes.

In Leeds the guided busway system is less continuous, with guideways being located alongside or within the central reserve of existing dual carriageway roads. The busways are provided to bypass the worst congested sections of road. Operating speed is lower than in the Adelaide example and bus stops are provided along the busway, usually without overtaking facilities (i.e. no lay-bys). This results in a busway system with operating characteristics more similar to conventional bus operations than is the case in Adelaide.

2.1.3 Simulation and modelling

Bus journey times along busways can be modelled using simple runtime simulation models or more complex operational modelling tools. The choice of model will depend on a number of factors including:

- **The stage in the planning process**
  At a pre-feasibility stage a more simple model may be adequate, while at a later stage a more complex simulation model may be required, which takes account of the interaction between service frequency, bus stopping patterns, bus stop design, demand, ticket systems, signals and control, vehicle performance and journey times.
- **The extent of busway operations**
  An extensive, complex and expensive busway system is likely to require more detailed modelling of operations to provide forecasts of journey times to feed into the demand forecasting process and to justify the investment. For less extensive busway proposals, such as short sections of segregated operations within a conventional bus priority corridor, a simpler approach may be all that is required, although the ultimate decision will depend on the precise local circumstances.

In general, buses operate along busways on the basis of line-of-sight operations, i.e. there is no signal control other than at locations where they leave, join or cross other roads, railways or footpaths/cycleways. This is usually acceptable for service frequencies of up to 60 buses per hour (bph) although in theory busways can operate at 120 bph. There have been examples of busway operations where signal systems are provided (e.g. on the section of the Essen guided busway network shared with light rail operations).

The limiting capacity is usually not the busway itself, but the bus stops (including bus stop dwell times) and junctions with other roads. For busways where there is a mix of stopping patterns, e.g. some buses call at all stops while others are limited or non-stop, the interaction between stopping and non-stopping services at bus stops can cause capacity problems. The degree of priority provided for buses at junctions with other roads will also impact on busway capacity.

For busways where high frequency services and/or complex operating patterns are proposed, simulation modelling of busway operations is recommended. Similarly, the operation of busway junctions with the road network should be modelled in order to understand the impact on bus journey times and service reliability.

2.2 LEGAL ISSUES

A guided busway is subject to the requirements of *The Railways and Other Transport Systems (Approval of Works, Plant and Equipment) Regulations 1994* because it corresponds to the criteria for a 'road-based with side guidance' mode as prescribed in Schedule 1 of those Regulations for the purposes of section 41 of the Transport and Works Act 1992.

As a consequence of this, the approval of the Secretary of State is required before any new or altered works, plant or equipment is brought into use. At time of writing, such approvals are given by HMRI (Her Majesty's Railway Inspectorate). Some bus-related approvals will need to be obtained from the relevant staff in the Department for Transport.

[**Note.** The Secretary of State's approving body for guided-bus systems is under review, as a consequence of the *Future of Transport – July 2004* White Paper].

Any connections and alterations to the road network will be subject, in England, to the approval of the Highways Agency (for trunk roads) and/or the Local Authority. In Wales, Scotland and Northern Ireland the organisation corresponding to the Highways Agency in England will need to be consulted for works affecting trunk roads.

The detailed design, construction and operation of works that affect any railway in the vicinity of the work should be submitted for approval to Network Rail (and the owners of any other railway systems in the vicinity).

If any part of the guideway is to be constructed outside the limits of the current highways/roads, the powers for the works are likely to be obtained by means of an Order under the Transport and Works Act 1992, which will give the necessary planning consents, CPO powers and other legal approvals and protections for the construction and operation of the system. If all of the system is within the existing highways/roads, the guideway works would normally be undertaken under the existing powers of the highway/road authority rather than by means of a TWA Order.

A number of permanent and temporary Traffic Regulation Orders (TRO) will be needed for on-road sections of the guideway. These would normally be included in any TWA Order (if applicable), with other TROs being obtained by the relevant highway/road authority.

Any vehicles to be used on the guideway must comply with the Road Vehicles (Construction and Use) Regulations 1986, as amended by the Road Vehicles (Construction and Use) (Amendment) (No.6) Regulations 1995 in respect of permitting wider vehicles, and disregarding the guide arms and the width of any guide wheels fitted to a bus, provided that they do not project more than 75 mm beyond the side of the bus. While the vehicles themselves are subject to the Construction and Use Regulations, approval of the guide arm and guide wheel remains the responsibility of HMRI.

It should be noted that, for any guided bus system in Scotland, the Transport and Works Act 1992 does not apply.

In cases where a TWA Order would otherwise have been sought, the Scottish Private Bill procedure would need to be followed.

A wide range of legal protective measures, such as prevention of trespass, can be incorporated in bylaws to be enacted under the provisions of the TWA Order. Part III of the Transport and Works Act 1992 applies, in respect of offences involving drink or drugs, to any part of a guided busway that is subject to a TWA Order rather than a TRO.

Consideration needs to be given to how policing of the guided busway will be undertaken.

2.3 VEHICLES

Most designs and configurations of buses can be built or adapted to run on kerb guideways. There are various issues to consider when making a choice of vehicle, and these choices may impact on the design of the infrastructure, and vice versa.

For example, the use of redundant railway alignments with a significant number of over bridges may prevent the operation of double-deck buses, at least without significant re-grading work to increase bridge headroom.

Buses in Britain may be built to an overall width (excluding such things as mirrors) of 2.55 metres, though 'midibuses', which are shorter and have a usual overall width of 2.45 metres, are also quite common. There are also even shorter and narrower minibuses. However, because of Construction & Use Regulations, it is not legal to operate a bus narrower than 2.45 metres on a 2.6 metre guideway.

This restriction arises from the requirement that no part of the guidance equipment may extend more than 75 mm beyond the widest part of the bodywork when the steering is in the straight-ahead position.

Generally speaking, single-decker buses are longer than double-deckers and have a longer wheelbase. Articulated buses, though longer overall in the body, generally have shorter wheelbases between the three axles. When running in guideways the wheelbase of the bus is critical as the wheels are so close to the guide kerbs.

When cornering, any vehicle 'cuts in' its rear wheels and it will be appreciated that the narrow space between kerb and rear tyre can soon disappear as the radius reduces. (This is the prime reason for the recommended minimum curve radii given in this handbook, and the associated need for other measures when tight radii are unavoidable.)

Systems used abroad, such as that in Essen, incorporate rear 'nudge' wheels, set within track gauge but positioned to nudge the rear axle(s) away from the inside kerb on a sharp bend. However these place high forces on the rear chassis members.

A further aspect, which requires most careful attention, is bus alignment. All road vehicles run 'crabbed' to some slight extent and this usually causes no real problems. However the small gap between kerbs and rear tyres means that a 'crabbed' bus is likely to scrub a rear tyrewall against that kerb – in extreme circumstances this could even happen on a straight run. Furthermore such a bus may drift off-line at a crossing gap, resulting in unpleasant lateral bumping on funnel re-entry. For such reasons, all buses operating on British guideways are required to be checked regularly to ensure that the rear axle(s) are not more than 25 mm out of alignment with the front axle.

Each manufacturer designs and supplies their own guidance equipment, including guide arms and guide wheels. The design of the arms in particular is likely to be influenced by the geometry and layout of the steering mechanism. There are, in practice, two basic layouts.

The old MCW double-decker and the recent Volvo chassis feature extended track-rod arms functioning as guide arms. Thus, part-way between the guide wheel and the front wheel hub, there will be a take-off on the guide arm to the steering box of the bus. This means that, as the bus enters a curve, turn 'signals' from the guide wheel will be transmitted to the steering box before that message reaches the road wheel hub directly.

The Mercedes-Benz and Scania designs feature entirely separate guide arms, directly linking guide wheel and road wheel hub. Thus the turn 'signal' goes first to the road wheel hub and thence back down the track-rod arm to the steering box.

Both arrangements work perfectly well and have been in successful use on their respective manufacturers' vehicles for many years. Drivers may detect a slight difference in handling as the extended track-rod arrangement puts more 'feel' into the steering wheel, whilst the separate arm damps out small changes in alignment.

2.3.1 Single-decker buses

Most single-deckers are of the order of 12 metres long, with a wheelbase of around 6 metres. For the guideway radii quoted in this handbook such buses will generally operate without problems. Even here, however, slight differences can affect running when near the minimum radii. For example, comparable bus chassis by Scania and Volvo will show a slightly longer wheelbase for the Scania product, but as the rear wheeltrack of the Volvo is slightly greater, this effectively cancels out any cornering differences.

Existing British kerb-guided bus systems have successfully operated the following single-deck designs:

- Dennis Dart 2.4 metre width (used only on Ipswich 2.5-metre narrow gauge guideway)
- Scania 3-series
- Scania 4-series
- Volvo B10
- Volvo B7
- Mercedes-Benz O405

A Transbus 300 vehicle has also been tested.

2.3.2 Double-decker buses

Double-deckers were used for the inaugural kerb-guided bus operation in Britain in the early 1980s with the 'Tracline 65' system in Birmingham using MCW Metrobus vehicles. More recently the extensive East Leeds and Bradford Manchester Road schemes have used Volvo double-deckers as their primary vehicles.

No significant differences in ride quality, operational performance or wear-and-tear characteristics have been detected between double and single-deckers in current operation. However the employment of double-deckers in exposed locations where strong or gusting cross-winds might be encountered should be considered carefully before allowing such operation.

Existing British kerb-guided bus systems have successfully operated the following double-deck designs:

- MCW Metrobus;
- Volvo B7 double-decker.

A Dennis Trident low-floor double-decker has also been successfully tested.

2.3.3 Articulated buses and multiple unit vehicles

There is extensive overseas experience of use of articulated buses on guideways and they have been operated to a limited extent in the UK. It is likely that such usage will increase substantially in future years as guided buses are employed for rapid transit systems.

With articulated buses the curve radii of guideways are particularly critical, as is vehicle alignment. Although each part-wheelbase is generally shorter than will be found with a conventional single-decker, the third axle will inevitably cut-in further since the second axle is itself already on a cut-in alignment.

Most articulated buses are currently 'pushers' i.e. the third axle is powered; this means it cannot easily be made a steering axle. When low-floor 'puller' articulated buses develop (whereby the second axle is powered), this will allow the third axle to steer, reducing the minimum guideway radius that the bus can negotiate.

Existing British systems have successfully operated the following articulated designs:

- Mercedes-Benz O405G;
- Volvo B10 articulated.

In addition it should be noted that MAN and low-floor Mercedes-Benz articulated buses have been used extensively abroad.

Several overseas systems featuring alternative guidance technologies such as rail and optical guidance have used multiple-section vehicles. However no such use on kerb-guided systems, other than on research tracks, has yet taken place.

2.3.4 Recovery vehicles

The characteristics of the guided system will have a significant influence on the recovery and maintenance vehicles to be employed. A lengthy, wholly-segregated alignment, such as may be found on a former railway corridor, may require the provision of guided recovery vehicles to permit fast access to the site of an incident.

However, where the alignment is generally alongside or close to existing highway lanes, the need for specialised vehicles will be much reduced. For example, on the existing Ipswich, Leeds and Bradford systems, no special recovery vehicle is provided. As these systems employ short guideway sections, with frequent breaks where access is possible for service vehicles, it has been found that any reasonable recovery vehicle driver can manoeuvre it backwards or forwards in the guideway over the relatively short distances involved.

In contrast is the Adelaide system with only two possible intermediate entry points in its 12 km length. Here a special recovery vehicle, with guide wheels for both directions of operation – and even two cabs for the same purpose – is used.

It is suggested that guided maintenance vehicles are unlikely to be required on present or planned British systems if vehicles with a narrow wheelbase (such as the 'Unimog') are considered.

2.3.5 Maintenance vehicles

There are two maintenance vehicles commonly required; these are for cleaning on and adjacent to the guideway and for such things as gritting and snow clearance.

For cleaning, this is usually performed at relatively low speed and in such circumstances a steered vehicle will perform satisfactorily.

For gritting, the same principles apply as those for recovery. For snow-clearing it is important to appreciate that a conventional plough cannot be used in a guideway. The only solution is to use salt, or similar chemical, to suppress the amount of snow present. However, in such extreme circumstances, it is unlikely that buses could reach the guideway sections because of roads blocked either by snow or stranded vehicles.

2.3.6 Kinematic profile and swept path

Guided buses, unlike rail vehicles, generally run within the envelope of the guidance infrastructure. As already noted, a guided bus may not exceed 2.55 metres in width (other than over its guide wheels and its mirrors) for use in a 2.6 metre guideway.

When negotiating a curve, it is likely that the front and rear sections of a bus beyond the outer axles may overhang the outer kerb face, and similarly the mid-section of the bus may overhang the inner kerb face. With guideway minimum radii as large as they are, the amount of overhang will be small.

Thus in designing any infrastructure higher than the top surface of the guide kerb (generally 185 mm) account must be taken of such potential overhangs by any bus type that may be expected to operate there. In order to avoid future problems, it is suggested that more than adequate clearances should be provided where doubt exists.

Where a guideway is employed for full guidance (i.e. the vehicle is wholly guided on both sides) the clearances which should be adopted are those indicated by Her Majesty's Railways Inspectorate in their relevant Guidance Notes.

Where superelevation is applied, the designer should ensure that the calculated kinematic profile and swept path takes account of the tilting of the vehicle and the position of the wing mirrors. Particular care should be taken in areas where pedestrian refuges are required and with siting of road signs, street furniture, barriers, etc.

2.3.7 Other characteristics

The overall performance of any guided bus will correspond generally to its equivalent on-highway performance. This is understood by HMRI., who have generally accepted that provided the bus meets the appropriate Construction & Use Regulations, their interest in the vehicle is restricted to the relationship with the infrastructure, the Vehicles Inspectorate being responsible for the 'fitness for purpose' of the vehicle itself.

Buses are generally expected to cope with any road gradient likely to be encountered. In theory, therefore, very severe guideway gradients are feasible. However, in practice, the potential effects of ice and degraded road surfaces from oil etc. suggest lower limits are likely to be used. The steepest guideway used in Britain to date is c. 7% downhill on the Leeds Scott Hall Road system (this section also features a pedestrian crossing burst-through in this length).

There is a discussion in Section 9.2.1 of this handbook on the precision of the guide kerb alignment. Different buses have different body suspension arrangements and these may produce different ride characteristics on poorly-aligned sections. As the infrastructure-provider is unlikely to be able to restrict the vehicle types to be employed, guide kerb alignment should be as precise as possible.

2.3.8 Guide wheels

Although every chassis supplier has developed their own arrangement of guide arms and guide wheels, all kerb-guided bus systems throughout the world use the same Continental-Elastic solid rubber tyre (180/50 – 120 L). This has given satisfactory service on all systems.

The clearance beneath the guide wheel assembly (the lowest point generally being the steel scuff-plate beneath the guide tyre) is usually taken as around 95 mm. If lower, there is a risk of grounding the guide wheel, with serious risk of steering snatch, whilst if higher there is a risk of losing guidance if the road wheels run over an obstruction in the guideway.

2.4 DESIGN STANDARDS

The design and construction of the infrastructure should comply with the following documentation:

- *Design Manual for Roads and Bridges* (DMRB) as published by TSO.
- *The Specification for Highway Works* (SHW).
- Notes for Guidance (NG) to the *Specification for Highway Works*, published by TSO as Volume 2 of the *Model Contract Document for Highway Works*.
- *Highway Construction Details* (HCD) published by TSO as Volume 3 of the *Manual of Contract Documents*.
- The design of the alignment should comply with the requirements of the *Design Manual for Roads and Bridges* and *Manual Contract Documents for Highway Works* in respect of non-guided sections.
- Relevant sections of the *HMRI Railway safety principles and guidance.*
- *Thickness design of concrete roads* (RR87), published by the Transport and Road Research Laboratory (due to be replaced in December 2004 by TRL 630: *CRCP new materials and designs*).
- Local Transport Note 2/95: *The design of pedestrian crossings*. published by TSO.
- *Inclusive mobility: a guide to best practice on access to pedestrian and transport infrastructure*, published by the Department of Transport.
- Statutory Instrument 2002 No. 3113, *The traffic signs regulations and general directions 2002*, published by TSO.
- Statutory Instrument 2000 No. 1970, *The public service vehicles accessibility regulations 2000*, published by TSO.

This list is not intended to be exhaustive or exclusive; other relevant standards may apply. Designers should ensure that they reference the latest version.

2.5 LOADING

The guideway, formation and structures should be designed to allow for the legal maximum axle weights for buses applicable in the UK, in accordance with the DMRB standards where applicable. However, it should be noted that the load is applied repetitively in the same place, presenting more onerous design criteria than for all-purpose roads.

For design of the guideway, the design loads should allow for the following loading:

Vertical axle load on running surface	120 kN
Lateral load on guide kerb	15 kN

This loading assumption is based on the design of the Essen O-Bahn and will accommodate the use of articulated **single-decker** buses. If operation of double-decker buses on the guideway is required, then the designer should ensure that appropriate design loads are used.

The above design loads are given for general running on the guideway. At entry splays and breaks in the guide kerb, e.g. pedestrian crossings, where the vehicle may not enter the guideway smoothly, design of guide rails and guide kerbs should take account of additional requirements for impact loading. Layout and design of entry splays is discussed further in Section 5.

3 2017 UPDATE Geometrical design of guideway

The guidance presented in this section is given to inform the designer about the design methodology and approach that can be used to deliver a guided busway alignment. This document is not intended to be a specification or prescriptive standard. It is intended that the designer should consider the advice and guidance given herein and evaluate its suitability and applicability to the project being designed. This guidance does not relieve the designer, owner or operator of any responsibilities under the Construction (Design and Management) Regulations 2015 or the Health and Safety at Work Act 1974 or other applicable legislation.

This section contains discussion of appropriate design methodology and parameters for the design of the guideway infrastructure. The design parameters given here have been developed for operation of single decker buses and articulated buses. If use of double decker buses on the guideway is required, then the designer should ensure that the parameters are appropriate. Double decker buses are operational on a UK guideway at speeds up to 100 km/h. The parameters given cannot cover every vehicle type and designers should check the suitability for the vehicle type to be used on the guideway. The designer should fully consider the location of the guideway and wind forces; it is highly recommended that trials should be undertaken to satisfy the designer and operator that it is safe to operate the proposed vehicles at the chosen speed, and if in any doubt, reduce speed.

In addition to the geometric parameters set out in this handbook, the following general issues should be taken into account in design of infrastructure for the guided bus system:

- Access onto the guideway for emergency vehicles and maintenance vehicles;
- Vehicle types expected to use the guideway;
- Driver error.

3.1 DESIGN SPEED

3.1.1 Independent LRT

For design of the busway as an independent light rapid transit style system it is suggested that the **permissible maximum speed** on the guideway should be as follows:

Guideway	100 km/h
Guideway entry/exit	40 km/h
Discontinuities e.g. pedestrian crossing	50 km/h

except where a safety risk assessment or local circumstances e.g. pedestrian crossings, tight radii, etc. require lower speed restrictions to be imposed. These speeds are given for conditions where all passengers are **seated** in the bus. If the system is to carry **standing** passengers, then it should be considered whether the maximum permissible speed on the guideway should be limited to 60 km/h.

Risk assessment or operating conditions may require restrictions to be imposed on the maximum permissible speed. The designer should communicate any identified risks or restrictions, and the operator should ensure that any speed restrictions identified during the design process are implemented in service.

Recommended **design speeds** for calculation of geometry should be as follows:

Guideway	120 km/h
Guideway entry/exit	50 km/h

These speeds are based on the operation of the system in Adelaide.

3.1.2 Urban on-street

For design of busways in an urban on-street environment, the speed of the buses operating on the guideway should be appropriate to the local traffic speed.

3.2 HORIZONTAL ALIGNMENT

The main factors influencing the engineering design of the guided bus system should be passenger safety and comfort. Sustainability and energy efficiency should also be considered.

The horizontal alignment should consist of circular curves and straight elements connected where necessary by transition curves. Where required, transition curves should be of clothoid form, or comprised of compound curves for precast systems. Horizontal radii should be selected to take account of the vehicles using the guideway and the permissible speed of travel.

Superelevation is not always required for guided busways. For example the Cambridgeshire Guided Busway and Luton & Dunstable Busway are designed to operate without superelevation. Where superelevation is applied to the guideway, this should take account of vehicle type, design/permissible speed, passenger comfort, effect of the weather, structure and passing clearances, lateral forces and loading on guide kerbs and guide wheels, and drainage.

This document illustrates two approaches for the determination of the horizontal alignment in kerb guided busways. Method 1 is based on experience from the design of guided bus systems for Essen and Adelaide. Method 2 is an application of principles from the Design Manual for Roads and Bridges (DMRB) Volume 6 Section 1 Road Geometry Design Part 1 TD9/93 Highway Link Design. Method 2 will lead to a more conservative alignment, so where space constraints dictate, or journey time is paramount, Method 1 may deliver a more efficient solution. The two approaches are covered in more detail in Appendix B.

3.2.1 Method 1

Method 1 of alignment design has been proven by research at TRL and has been developed successfully for the systems operating in Adelaide and Essen. To apply this method, the horizontal alignment should be based on a constant comfort factor with the design speed varying to suit the curve to be negotiated. The passenger comfort factor is a function of the horizontal force (lateral acceleration) applied to passengers as the vehicle travels around the curves.

From experience in Essen and Adelaide the limiting value for passenger comfort is set as a maximum lateral acceleration of 1.0 m/s² (see Table 3.1 and section 3.5.2).

Lateral acceleration is given by the equation:

$$a = \frac{v^2}{R} \qquad \ldots(3.1)$$

Where:
a = lateral acceleration (m/s²)
v = speed (m/s)
R = radius (m)

The coefficient of side friction force (f) developed between the vehicle tyres and the running surface can be found from:

$$f = \frac{v^2}{Rg} \qquad \ldots(3.2)$$

Where:
f = coefficient of side friction force developed between the vehicle tyres and the running surface
g = acceleration due to gravity (m/s²)
v = speed (m/s)
R = radius (m)

Substituting a = 1.0m/s² (equation 1.1), and g = 9.81 m/s² into equation 3.2, gives a limiting value for f:

$$f = \frac{1.0}{9.81} = 0.102$$

For the busways in Cambridgeshire and Luton, the curve radii were selected such that superelevation was not required. However, for any given curve and speed, superelevation may be introduced to enable a component of the vehicle's weight to reduce the frictional need. It can be shown that the general relationship for this effect is:

$$R = \frac{V^2}{127\,(e+f)} \qquad \ldots(3.3)$$

Where:
V = speed of vehicle (km/h)
e = superelevation of surface (m/m)
R = radius (m)
f = coefficient of side friction force developed between the vehicle tyres and the running surface

Using the limiting value of f = 0.102, for a known maximum superelevation and given radius, it is therefore possible to calculate the maximum speed on the curve. Similarly, the minimum radius for the design speed can be found. Note that the speed V appears in this equation in kilometres per hour.

3.2.2 Method 2

The Design Manual for Roads and Bridges (DMRB) Volume 6 Section 1 Road Geometry Design Part 1 TD9/93 Highway Link Design, gives standard design guidelines and parameters for highway link design in the UK. For the purposes of busway geometry design, it is considered reasonable to equate the design of the alignment for a guided busway to that of a single carriageway highway. However, a guided busway does differ significantly from a highway in the following respects:

- Restricted type of vehicle;
- Guided transport system;
- Driver training and system controls;
- Ability to install drainage features between the running tracks (discontinuous running surface).

DMRB Table 3 gives desirable minimum values related to design speed. DMRB Figure 5 shows the appropriate superelevation for the range of Design Speeds. DMRB allows for relaxations against the values in DMRB Table 3. The designer and the technical approval authority should establish at the outset to what extent relaxations and departures are permitted on the project.

For radii less than those in DMRB Table 3, the relationship between radius, speed and superelevation is given by the equation:

$$S = \frac{V^2}{2.828 \times R} \qquad \ldots(3.4)$$

Where:
V = speed of vehicle (km/h)
S = superelevation of surface (%)
R = radius (m)

Busways can be designed to operate successfully without superelevation by careful selection of radii, and provision for surface water runoff. In this case application of Method 1 may be appropriate to allow the designer to optimise the radii for operating speed and simplify construction.

3.2.3 Recommended Limiting values

Recommended limiting parameters for horizontal alignment design are given in the Table 3.1. A normal or desirable design value is given together with a suggested limiting maximum or minimum value. These values are derived from the DMRB or experience from guided bus systems in Essen and Adelaide, where appropriate.

Table 3.1 Recommended limiting values for horizontal alignment design

Parameter		Normal	Limit
Curvature	Minimum radius without guideway widening	500 m	Articulated bus– 350 to 400 m Rigid bus – 250 m
	Minimum radius with guideway widening[1]	120 m	25 m
Superelevation	Maximum	5%	6%
	Variation in grade of edge profile	0.5%	1.0%
	Minimum crossfall on running surface	1.0%	0.5%
Clothoid Transitions	Rate of change of centripetal acceleration	0.3 m/s³	0.6 m/s³
Lateral Acceleration (comfort limit)	Maximum	0.6 m/s²	1.0 m/s²

3.2.4 Transitions

This section describes two alternative approaches that have been used to determine the geometry of transition curves for guided busways:

- Design for clothoid curves;
- Design for compound curves.

3.2.4.1 Clothoid Curve Transitions

For Method 1 and 2, where clothoid curve transitions are to be designed, the transition length should be taken as the greater of the lengths calculated using the following equations 3.5 and 3.6:

$$L = \frac{3wS}{2p} \qquad \text{...(3.5)}$$

Where:
L = transition length (m)
w = rolling width of guideway (m)
S = superelevation (%)
p = variation in grade of edge profile (%)

$$L = \frac{V^3}{46.7qR} \qquad \text{...(3.6)}$$

Where:
L = transition length (m)
R = radius (m)
V = design speed (km/h)
q = rate of increase of centripetal acceleration (m/s³), travelling along curve at constant speed V (km/h)

These equations are based on the DMRB guidelines. The variation in grade of edge profile (p) is subject to a desirable maximum limit of 0.5% and an absolute maximum of 1.0%. Where designing clothoid transitions, for passenger comfort, q should not normally exceed 0.3 m/s³, although it may be increased up to a maximum of 0.6 m/s³. (Note that q is a rate of change of acceleration and the limits for q are not applicable to the method of design described in 3.2.4.2 for compound curves).

3.2.4.2 Compound Curve Transitions

An alternative approach to transitions on guided busways is to use compound curves in place of clothoid geometry. This method is particularly suited to precast construction.

Transition curves for precast guideways are designed as compound curves formed from the standard radii set (Figure 3.1). The designer can estimate the length of compound curve required using equation 3.6. This equation is derived for use with clothoid curves but here can be used to approximate the compound curve length; the compound curve is effectively substituted for the clothoid transition. This allows use of standard precast elements leading to cost effective design. The combination of radii elements used for the compound curve will depend on the corridor constraints.

Where this method of design is adopted, the designer should pay close attention to the instantaneous change in lateral acceleration that occurs at each tangent point. (See Figure 3.2 for a graphical illustration of this effect). Note that the change in lateral force (due to acceleration) is not actually felt instantaneously by the passenger due to the effects of the vehicle's wheelbase and suspension. However, experience from design of busways using compound curve geometry

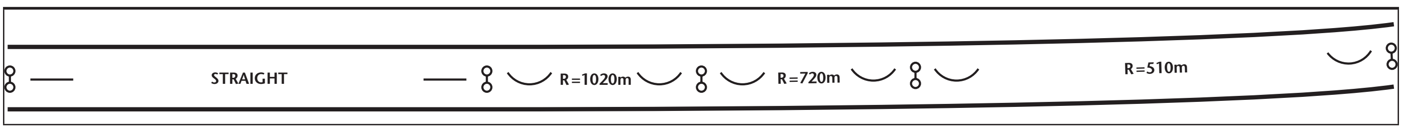

Figure 3.1 Typical compound curve "transition"

***Note:** Departures from standard for the substitution of compound curves as transition curves may need to be accepted by the Employer depending on contract requirements.*

[1] For tight radii (<350m) it may be more cost effective to reduce speed and construct the route as an unguided section, i.e. eliminate upstands, e.g. Cambridgeshire Guided Busway.

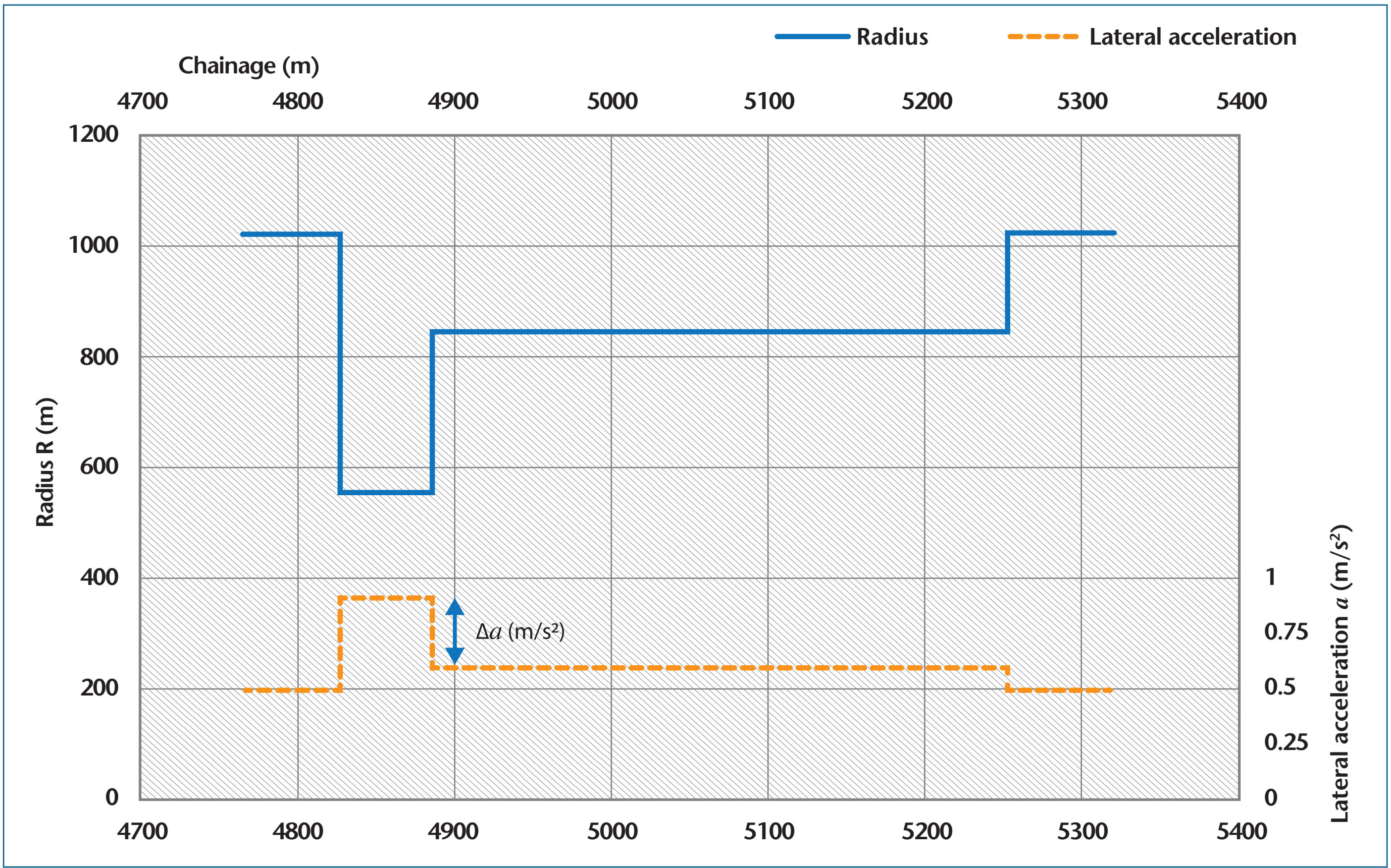

Figure 3.2: Illustration of changes in radius and lateral acceleration through a compound curve

suggests that the magnitude of the change at each tangent point should be limited, and the cumulative effect throughout the curve should be considered.

Based on experience from precast busways constructed in the UK it is recommended that, in general, the magnitude of instantaneous change in lateral acceleration Δa at tangent points should be limited to around 0.6 m/s^2, and this should deliver an acceptable ride quality. Isolated locations with higher change $|\Delta a| \leq 1.0$ m/s^2 have been shown to still deliver acceptable ride quality, but this should be considered on a case-by-case basis in the context of the project.

(Note that the units of Δa are m/s^2 as it is the numerical difference between two acceleration values, and it is not to be confused with any limits given in Table 3.1 and 3.2.4.1 for the ***rate of change*** of acceleration q on clothoid curves).

3.2.5 Application of superelevation

Where required, superelevation should be applied with an s-curve profile on or within the transition length, from the arc end.

3.3 VERTICAL ALIGNMENT

The vertical alignment should consist of lengths of route at constant gradient connected by parabolic vertical curves.

Design of guideway gradients should take into account the braking and acceleration performance of vehicles likely to use the guideway, stopping sight distances, effect of the weather, and the combined effect of gradient and horizontal curvature where the gradient coincides with a small radius curve.

Recommended limiting parameters for **vertical** alignment design are given in Table 3.2. A suggested normal or desirable design value is given together with a limiting maximum or minimum value. These values are derived from the DMRB or experience from guided bus systems in Essen and Adelaide, where appropriate.

Designers of precast busway alignments should note that the running surface comprised of beam elements will approximate the vertical curve as a series of short gradients. It may be necessary to select a larger minimum K value to accommodate the beam elements, depending on the length of the precast unit. Where placing precast elements on gradients consideration should be given to anchorage to prevent slippage.

Table 3.2 Recommended limiting values for vertical alignment design

Parameter		Normal	Limit
Gradient	Maximum vertical gradient	4%	6%
	Minimum vertical gradient	1%	0.5%
Vertical curves	Minimum K values[2]	10	5
Vertical acceleration	Maximum (sag curves)	0.3m/s²	---
	Maximum (crest curves)	0.3m/s²	---

3.4 PHASING

Phasing of the horizontal and vertical curves of the guideway implies their co-ordination so that the line of the guideway appears to flow smoothly, avoiding the creation of hazards and visual discontinuities. It becomes more important with small radius curves than with large, and drainage issues should always be considered.

The designer should consider how the combination of horizontal and vertical elements will affect the overall buildability and ride quality of the guideway.

3.5 PASSENGER COMFORT

Guideway design should consider the impact on passenger comfort and seek to maintain an acceptable ride quality, depending on the project requirements. In particular, the following should be considered:

3.5.1 Speed

The design speed of the guideway will dictate the minimum allowable curvature to maintain an acceptable level of passenger comfort. Speed will also accentuate any tendency to vibration or hunting caused by imperfections in the guide kerb alignment, which are transmitted to the vehicle through the guidewheels, and guideway surfacing.

The guide arms are rigid and the guidewheel tyre is solid. The quality of the guideway surfacing, joints and guide kerb finish and alignment are therefore critical in achieving good ride quality, particularly where high speed operation is required.

3.5.2 Superelevation and transitions

A suggested limiting value for lateral acceleration on curves should be 1.0m/s² to ensure acceptable passenger comfort. This is considered to be the **comfort limit** for standing passengers[3] on a bus. The "normal" value of 0.6m/s² given in section 3.2.3 is derived from the parameters of DMRB.

For high speed operations it may be necessary to introduce superelevation on curves to compensate for centrifugal forces and keep the lateral acceleration experienced by the passenger within the acceptable comfort limit.

For vehicles travelling on a road there is a degree of wheel sideslip which results in the rear axle drifting out as the vehicle corners. On superelevated sections the rear axle will tend to drift in when travelling at slow speed. For guideway running, which is effectively a very narrow road, a limited speed range exists in order to keep the wheels within the running surface and prevent scrubbing of the tyre walls on the guide kerbs.

It is recommended that guideway superelevation is limited to a maximum of 6% to reduce the discomfort experienced by standing passengers if the vehicle has to stop or drive slowly on a superelevated section. A lower value may be appropriate where double decker vehicles are to be used.

3.5.3 Alignment design

Passenger comfort should be considered in the location of vertical and horizontal curves. Wherever possible, the two alignments should be phased. In addition the cumulative effect of sequential maxima/minima in the horizontal and vertical alignments should be considered in light of the effect on ride quality.

There is a degree of sway experienced by the vehicle when travelling through changes in geometry due to roll of the vehicle on its suspension. For guided vehicles there is a time delay between the geometric change and the compensation of the steering mechanism and suspension response.

3.5.4 Guide kerb alignment and running surface

Construction tolerances should be specified to ensure that irregularities in the guide kerb alignment do not adversely affect ride quality. The dynamics of the guide arm chosen will determine to what extent minor variations in kerb alignment will affect ride quality. Guide arms currently in operation are rigid and use solid tyre guide wheels. The imperfections in the guide kerb finish and alignment are therefore transmitted to the vehicle through the steering mechanism.

A more detailed discussion of construction tolerances is presented in Chapter 10.

At guideway entry points it has been found that using a low friction surface for the splays e.g. using steel rails as in Essen, reduces the opposing fiction forces generated when the guide wheel makes contact. The bus therefore makes a smoother entry to the guideway with less jolting experienced by passengers.

3.5.5 Passenger view

When designing the alignment, consideration should be given to the expected view of passengers using the service. Wherever possible, the alignment should ensure that passenger view adds to ride quality rather than detract from it. Careful consideration should be given to sections where the route is in cutting, tunnel or screened with noise barriers and fencing.

[2] Refer to section 3.7.2 for particular considerations for precast busways.

[3] Kluge, B. Adelaide O-Bahn, Technical Constraints and Challenges. Tasks and Issues, Planning Processes, Limitations. 1988.

3.5.6 Driver training

Drivers should be adequately trained to confidently operate the guided bus, ensuring a high standard of passenger comfort and safety. In particular, they should be trained in how to enter and exit the guideway smoothly and also in handling the vehicle at breaks in the guideway such as pedestrian crossings.

Use of coloured "target" kerbs and road markings for optimum alignment at entry splays can assist the driver. For an experienced driver, it is possible for the vehicle to enter the guideway without the passengers being aware that the vehicle has engaged with the guide kerbs.

3.6 STOPPING SIGHT DISTANCE

The Stopping Sight Distance for the guideway should be in accordance with the requirements of the DMRB. At pedestrian and other uncontrolled crossings the Stopping Sight Distance should be based on a deceleration rate of 1.3 m/s^2. In all visibility calculations the following parameters should be adopted:

Driver's eye height	2.00 m
Object height	0.26 m

3.7 SPECIFIC DESIGN CONSIDERATIONS FOR GEOMETRY OF PRECAST CONSTRUCTION

3.7.1 Horizontal geometry

Either Method 1 or Method 2, or a combination of the two, can be used to design a precast guided busway solution.

Precast guideways are constructed from precast concrete beams of set length. The beam length should be determined depending on the horizontal and vertical alignment of the scheme. Tight curves may make the use of long beams unsuitable. Beam length will also be influenced by the contractor's chosen construction methodology.

Precast systems are usually designed from a limited set of standard radii in order to limit the number of different beam elements to be cast. There are two types of beams - straight and curved beams. Curved beams have the face of the upstand constructed as a radius on the horizontal plane; the outer faces remain straight.

Precast systems in the UK have been designed and constructed without superelevation. Using Method 1, design radii can be selected to limit lateral acceleration in curves without the need to apply superelevation. As described in section 3.2.4 transition curves for precast guideways are designed as compound curves formed from the standard radii set.

Depending on the route corridor, it is usually possible to restrict the number of different centreline horizontal radii used to between 4 to 5 number, to streamline the construction process. It is possible to form large radius curves using straight beam elements, and this approach was successfully applied on the Cambridgeshire and Luton busways.

The size and number of radii will vary with each scheme and will depend on the available land and length of the beams the Contractor chooses to use. Shorter beam lengths provide greater flexibility whilst designing horizontal alignment in narrow corridors but will increase the number of joints.

3.7.2 Vertical geometry

There are also specific considerations for vertical alignment where using a pre-cast busway system. Vertical curves are designed as parabolic curves. Table 3.2 suggests values for the limiting K value as 5 and minimum K value as 10. For a pre-cast system the vertical curves are achieved through a series of straight beams. As a result, the centre of the beam is either below the proposed vertical alignment for crest curves or above the proposed vertical alignment at the sag curve locations. The difference between the design alignment and the measured elevation at the midpoint of the beam will depend on the beam length and the vertical curvature. For example, with a beam length of 6 metres the difference in elevation would be 4.5mm for a curve K value of 10, measured using a 3 metre rolling straight edge.

The contract documents should define the surface regularity. If using the Manual of Contract Documents for Highway Works this should be defined in Appendix 7/1. The Employer should define the absolute variation from the vertical alignment permitted, and it may be necessary to increase the minimum K value to 20 to reduce the vertical difference at the centre of the beam and provide an acceptable level of ride quality.

4 Cross sections

4.1 TYPICAL SECTIONS

4.1.1 Dual-lane guideway

A typical cross section for a dual-lane guideway is shown in Figure 4.1. This section applies for straight alignment or non-superelevated sections of curvature greater than 150-metre radius.

Each guideway measures 2.6 metres between the guide kerb faces and the running surface of the guideway is provided by two plinths/slabs 0.7 metres wide. Guide kerbs are provided on the outer edge with an upstand of 180 mm above the guideway running surface. Separation between the two guideways is provided by a central reserve with a desirable minimum width of 0.8 metres between guide kerb faces.

The guide wheels are set with a gauge of 2605 mm (over the face of the guide wheel) ensuring that continuous contact between the guide wheels and guide kerbs is maintained.

The offset from the inside face of the guide kerb to the boundary fence is a desirable minimum of 1.0 metre, allowing a maintenance walkway to be incorporated between the guideway and the fence on each side of the route. This walkway also serves as an evacuation route in the event of an emergency.

The central channel within a guideway lane may be set 100 mm below the running surface so that, in the event of an accident, pedestrians may be removed from under the bus. A risk assessment should be carried out to determine if this is necessary. This also helps to discourage misuse by unauthorised vehicles.

Figure 4.2 illustrates a typical detail for a dual lane guideway with an adjacent 4-metre maintenance track, separated from the guideway by 0.7 metres.

Figure 4.3 illustrates a typical detail for a dual lane guideway on embankment and in cutting.

4.1.2 Single-lane guideway adjacent to highway

A typical section for a single-lane guideway adjacent to the highway is shown in Figure 4.4. The standard single-lane guideway section follows the same principles as those for the dual guideway described above. The running surface is 0.7 metres wide, with 180 mm guide kerb upstands set at 2.6 metres between guide kerb faces.

The desirable minimum offset between face of guide kerb and highway is shown as 1 metre. This may be reduced to an absolute minimum of 0.7 metres, subject to a risk assessment. Designers should ensure that sufficient clearance is provided to any road signs if they are to be placed in this strip. This strip should also be surfaced with deterrent paving to discourage walking on the guideway, except where specifically required in order to provide emergency egress.

Figure 4.1 Typical at-grade cross section without maintenance track

1. All dimensions in metres.
2. Evacuation strip may be reduced to an absolute minimum of 0.7 m where necessary.
3. Central reserve may be reduced to an absolute minimum of 0.6 m where necessary, except where double-decker buses are to be used on the guideway or where bus mirrors are at a height producing a risk to pedestrians.
4. Verge may be omitted where necessary.
5. All dimensions are subject to HMRI approval.
6. For drainage details refer to Figures 4.6 and 4.7.

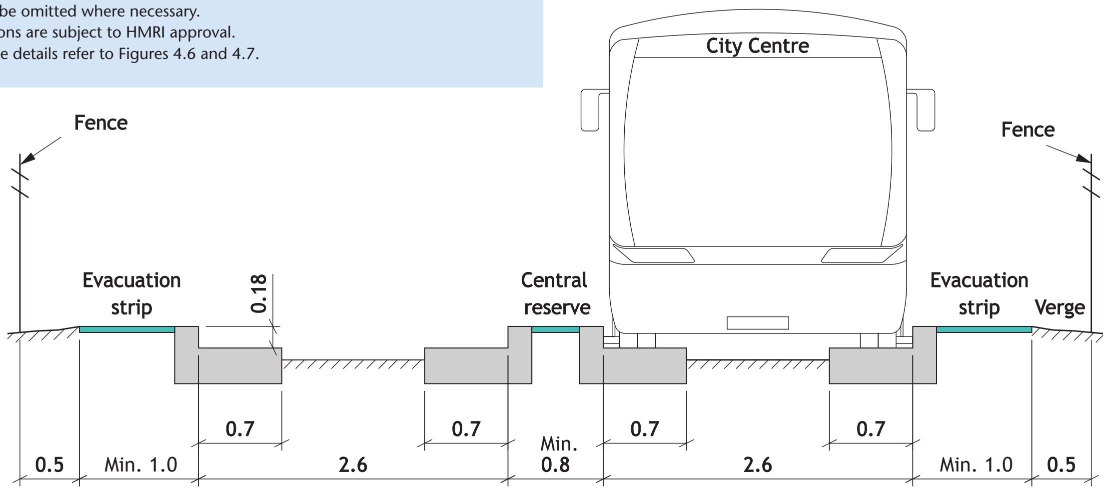

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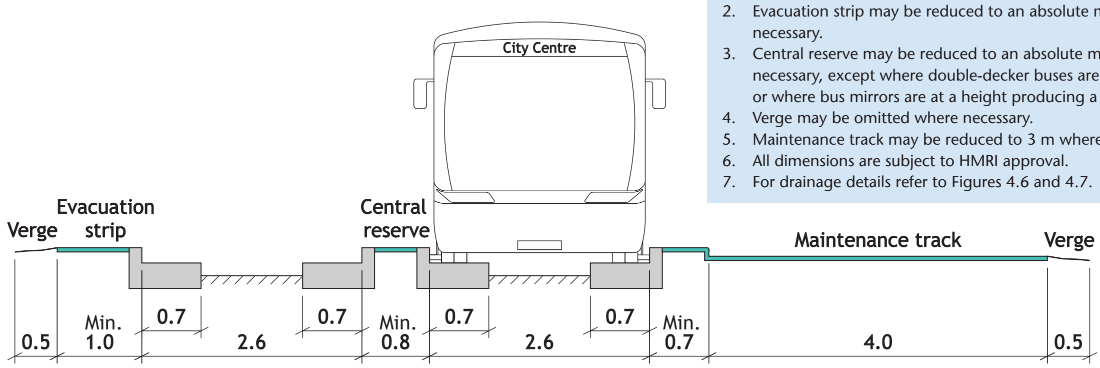
Figure 4.2 Typical at-grade cross section with maintenance track



1. All dimensions in metres.
2. Evacuation strip may be reduced to an absolute minimum of 0.7 m where necessary.
3. Central reserve may be reduced to an absolute minimum of 0.6 m where necessary, except where double-decker buses are to be used on the guideway or where bus mirrors are at a height producing a risk to pedestrians.
4. Verge may be omitted where necessary.
5. Maintenance track may be reduced to 3 m where necessary.
6. All dimensions are subject to HMRI approval.
7. For drainage details refer to Figures 4.6 and 4.7.

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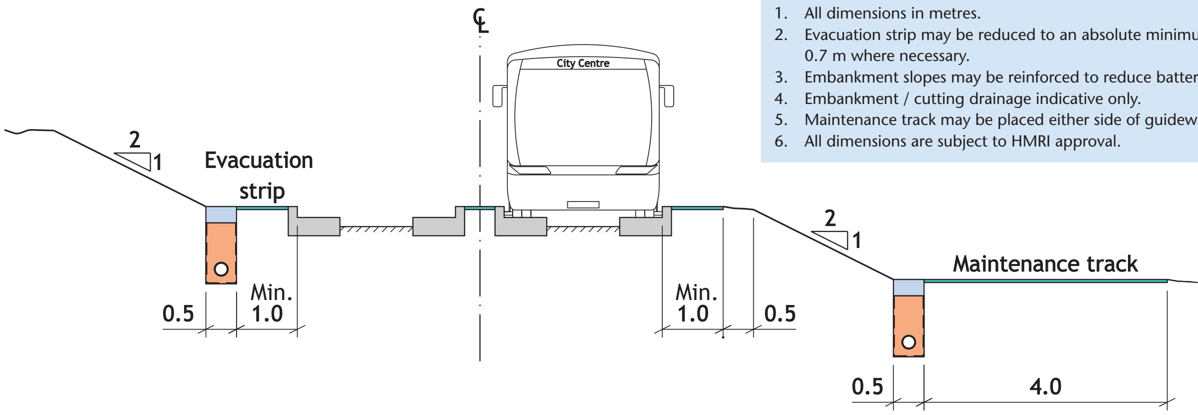
Figure 4.3 Typical section on embankment / in cutting



1. All dimensions in metres.
2. Evacuation strip may be reduced to an absolute minimum of 0.7 m where necessary.
3. Embankment slopes may be reinforced to reduce batter angle.
4. Embankment / cutting drainage indicative only.
5. Maintenance track may be placed either side of guideway.
6. All dimensions are subject to HMRI approval.

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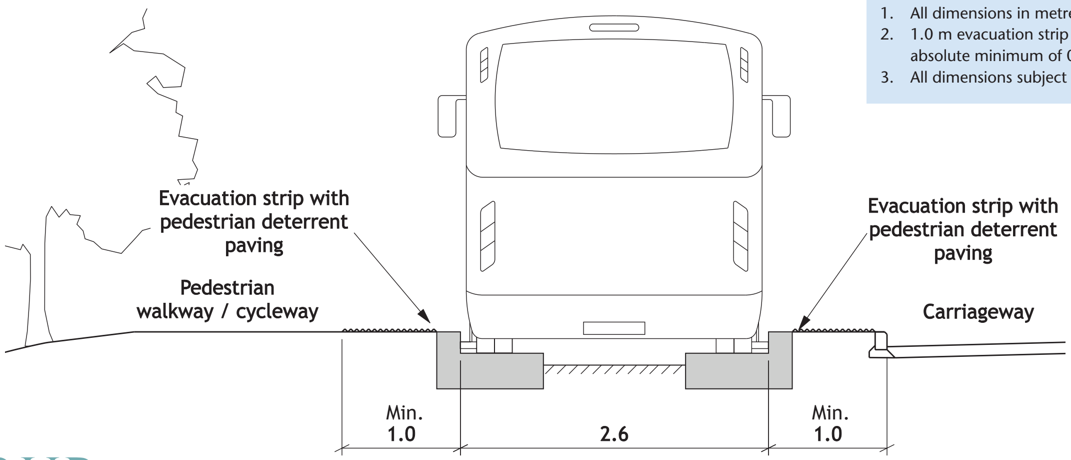
Figure 4.4 Single-lane guideway adjacent to highway



1. All dimensions in metres.
2. 1.0 m evacuation strip may be reduced to an absolute minimum of 0.7 m where necessary.
3. All dimensions subject to HMRI approval.

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4.1.3 Superelevated section

Detailed design should determine whether it is appropriate to apply superelevation either:

- About the centre line of the dual guideway section; or
- About the low side of each guideway independently.

Typical sections with applied superelevation are shown in Figure 4.5. Dimensions and offsets should be maintained as for the standard cross sections.

The superelevated section should take account of drainage requirements and constructability.

Section design for superelevation should also consider the proximity of adjacent guided bus mirrors and ensure that the central reserve is wide enough to prevent collision. On curves where superelevation is applied it is possible that parts of the bus bodywork will overhang the guide kerbs and sufficient clearance must be provided to accommodate this.

4.1.1 Guideway widening

On tight radii, e.g. 150 metres, the guideway should be widened to prevent the rear wheel tyre wall scrubbing on the guide kerb. For very tight radii, e.g. below 90 metres, consideration should be given as to whether the inside guide kerb should be omitted.

The actual extent of guideway widening required should be determined at detailed design stage, once the types of vehicle expected to operate on the route are finalised, by analysis of vehicle and wheel swept paths.

Widened and single-sided guideways require a specialised driving technique in addition to that required for the standard guideway. In each case where this is required a risk assessment should be carried out. It may be preferable to construct an unguided section of busway.

4.1.2 Guideway drainage

Figures 4.6 and 4.7 show two typical drainage options for a guided busway. Wherever possible, a sustainable drainage system is recommended, which preserves and even enhances the surrounding environment, while adequately draining the guideway, as shown in Figure 4.7. However, in urban environments, it may be necessary to provide traditional positive drainage, tying into the existing highway drainage network, as shown in Figure 4.6.

Figure 4.5 Superelevated curve (two options shown)

1. All dimensions in metres.
2. Preferred method of application of superelevation to be determined at detailed design stage.
3. All dimensions are subject to HMRI approval.

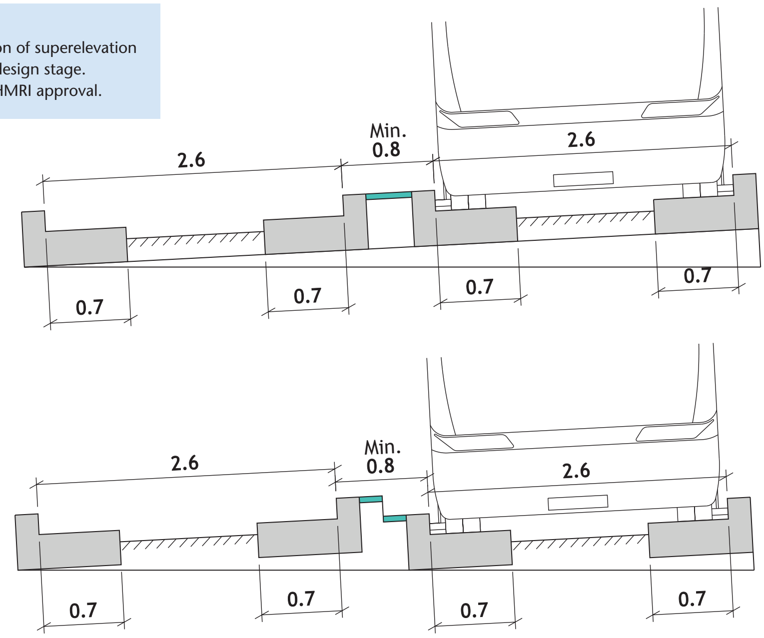

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Figure 4.6 Typical positive drainage details

1. All dimensions in metres.
2. All dimensions are subject to HMRI approval.

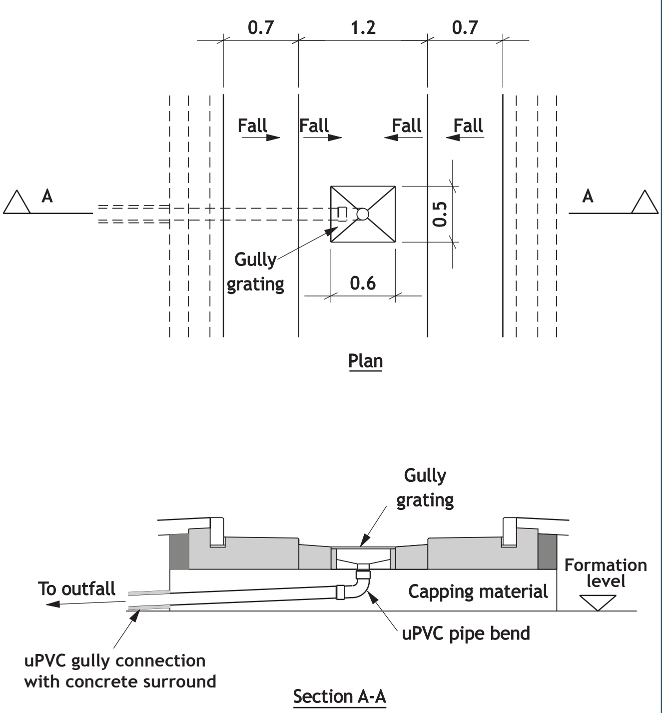

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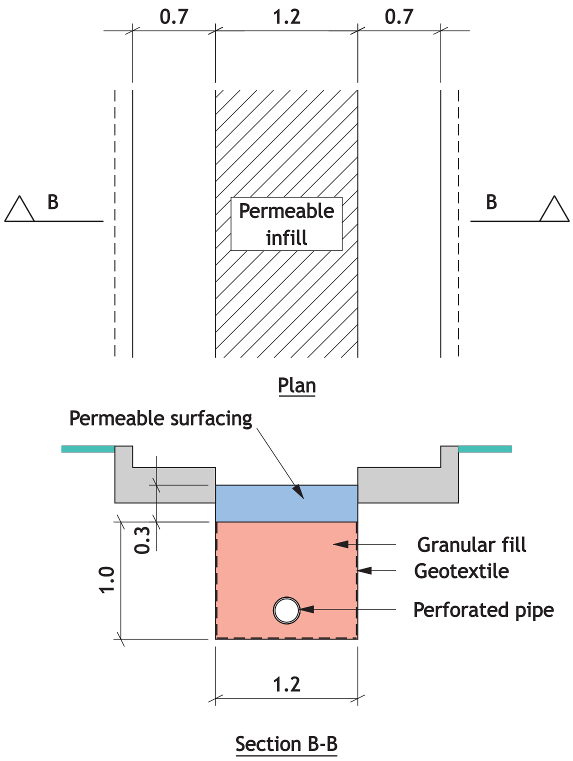
Figure 4.7 Typical sustainable drainage details

1. All dimensions in metres.
2. All dimensions are subject to HMRI approval.



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5 Guideway entry and exit

5.1 GUIDEWAY ENTRY/EXIT SPLAYS

To enter the guideway, a funnel arrangement is provided such that the offside kerb projects beyond the nearside kerb. The driver steers so that the offside guide wheel maintains contact with the guide kerb (see Figure 5.1). When the nearside guide wheel meets the nearside guide kerb, the bus is guided securely from both sides and the driver can in fact release hold of the steering wheel. On leaving the guideway, both kerbs are splayed out equally, releasing the guide wheels simultaneously and requiring the driver to resume steering.

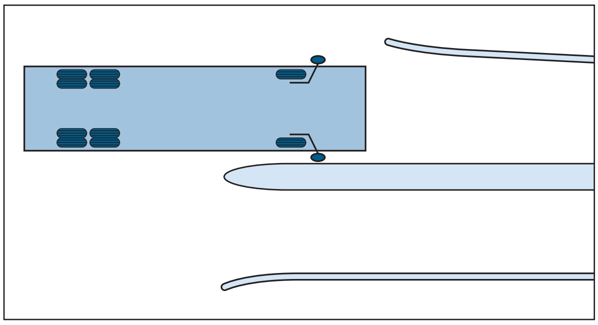


Figure 5.1 Guided bus engaging offside kerb first

The entry splay should be designed to allow a smooth transition from unguided to guided running. Consistency in layout of splays and driver training are important in order to ensure that buses enter the guideway as smoothly as possible to avoid jolting passengers and damaging the kerbs and/or guide wheels.

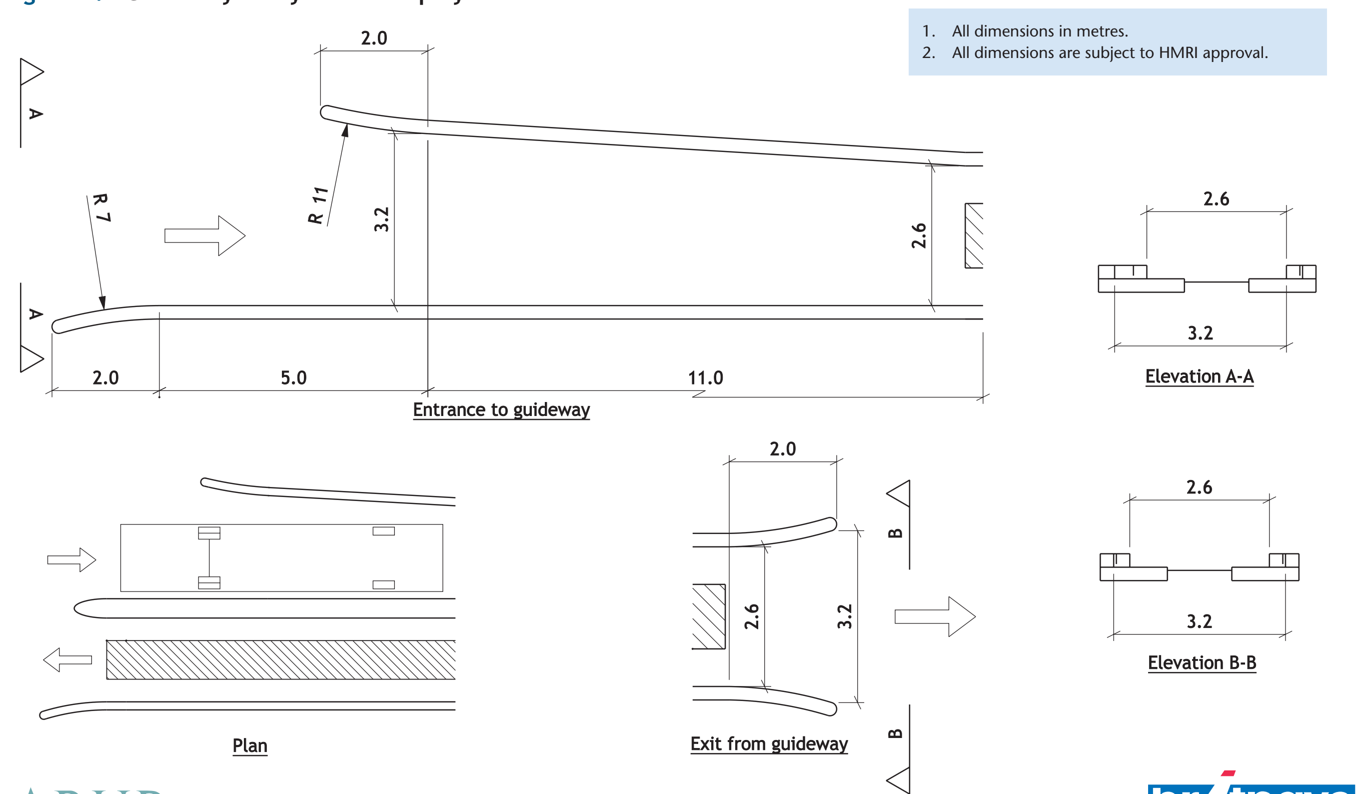
In some instances it may be necessary to hand the entry splay, (i.e. to provide nearside pick-up) depending on the position of the guideway in relation to the adjacent non-guided section of route or highway from which the vehicle is entering. In such cases, the following should be considered in determining the alignment of the splay:

- Consistency across the network for safety reasons;
- The approach angle of the vehicle i.e. running in line or turning onto guideway;
- Proximity of stops on the approach to the guideway;
- Single- or dual-lane guideway.

For safety reasons it is recommended that every effort is made to provide all entry splays with offside pick-up.

In determining the layout of entry and exit splays, consideration should be given to the appearance and overall layout of the guideway and not just the entry/exit splay itself.

Figure 5.2 Guideway entry and exit splays



Use of coloured kerbs and markings can assist drivers in determining which kerb to engage first as well as highlight the optimum contact point to achieve a smooth entry into the guideway and reduce the risk of damage to kerbs and guide wheels. A route line may also be marked on the guideway, suggesting to drivers the optimum approach path.

Use of steel guide rails at entry splays has been found to reduce the opposing friction forces generated on the guide wheel at point of contact and assist a smooth entry into the guideway.

Guideway entry and exit points should be clearly signed in accordance with The Traffic Signs Regulations and General Directions 2002. It should be noted that 'Guided Buses Only' is a non-standard sign. Appropriate road markings should be provided to clearly demarcate the guideway.

5.1.1 Typical splay geometry

Typical entry and exit splays are shown on Figure 5.2.

At the entry splay, the offside kerb projects 5 metres beyond the nearside kerb. The driver over steers to bring the offside guide wheel into contact with the offside guide kerb. This leads the bus into the guideway until the point where the nearside kerb commences.

The nearside kerb is offset 3.2 metres from the offside at the tangent of the entry curve, and tapers in to a width of 2.6 metres typically over a distance of 11 m. When the nearside guide wheel comes into contact with the nearside kerb, the vehicle is then fully guided from both sides.

The guideway alignment should be straight over the length of a splay. Where manoeuvring space is tight, use of 75 mm high kerbs on the approach to the entry funnel will prevent damage to the kerbs and guide wheels.

At the point where the kerb height changes to 180 mm, at the start of the guideway, a 180 mm 'quadrant' or 'cheesecake' kerb stone should be provided on the nearside, directing buses into the guideway, as shown in Figure 5.3. The change to 180 mm kerbs at the start of the guideway should be stepped rather than ramped to prevent buses from riding up the kerb and exiting the guideway.

Figure 5.3 Quadrant kerbstone at step change in kerb height, Leeds

Containment bollards, and if necessary, containment beams, should be provided if there is any risk of the vehicle unexpectedly leaving the guideway in the vicinity of a pedestrian crossing or a stop. A risk assessment is recommended at each site where a change in kerb height is necessary.

The splay kerbs should be laid out to facilitate the smooth transition from unguided to guided operation. The aim should be to ensure that the bus does not deviate unnecessarily from a straight path in order to engage the guide wheels.

At exits from the guideway, the kerbs should be widened out equally allowing the driver to resume full steering and to minimise the likelihood of deviation from the vehicle path. The guideway should be straight for a minimum of 10 metres on approach to an exit funnel to ensure that there are no lateral forces acting on the bus as it becomes unguided.

At entry and exit points, the local alignment should generally be consistent with the standards on adjacent lengths of road. If not, this should be indicated to operators by the use of traffic signs.

5.1.2 Pedestrian crossings

Pedestrian crossings should be designed and constructed in accordance with Local Transport Note 2/95: *The design of pedestrian crossings* as well as the Department for Transport's *Inclusive mobility: a guide to best practice on access to pedestrian and transport infrastructure*. Typical arrangements for pedestrian crossings are shown in Figures 5.4 and 5.5.

Siting and layout of pedestrian crossings should consider the alignment, stopping sight distance, speed and direction of travel. Consideration should be given to the provision of central pedestrian refuges and locally imposed speed restrictions. Where the public have access to the guideway, the location of pedestrian crossings should give due regard to reasonable requirements for crossing,

In order to reduce the length of unguided route, pedestrian crossings should be situated where possible at the location where breaks in the guide kerbs are required for other purposes e.g. road junctions. The number of breaks in the guide kerb should be minimised.

Pavement and pedestrian kerb details should be designed so as to avoid creating any trip hazards or potential locations for the build up of rubbish.

5.1.2.1 'Burst-through' crossings (≤ 3 metres)

Where short breaks in the guide kerbs occur on straight track, full entry and exit splays are not utilised. For breaks of less than 3 metres, a simplified exit splay, with straight parallel guide rails, rather than a funnel arrangement, enables the bus to be 'fired' across the gap in a perfectly straight line. This is generally called a 'burst through' crossing (Figure 5.6). The use of straight guide rails on exit also allows the bus to remain guided for as long as possible before running unguided at the crossing point. A symmetric funnel entry splay then ensures that the bus re-enters guided mode smoothly.

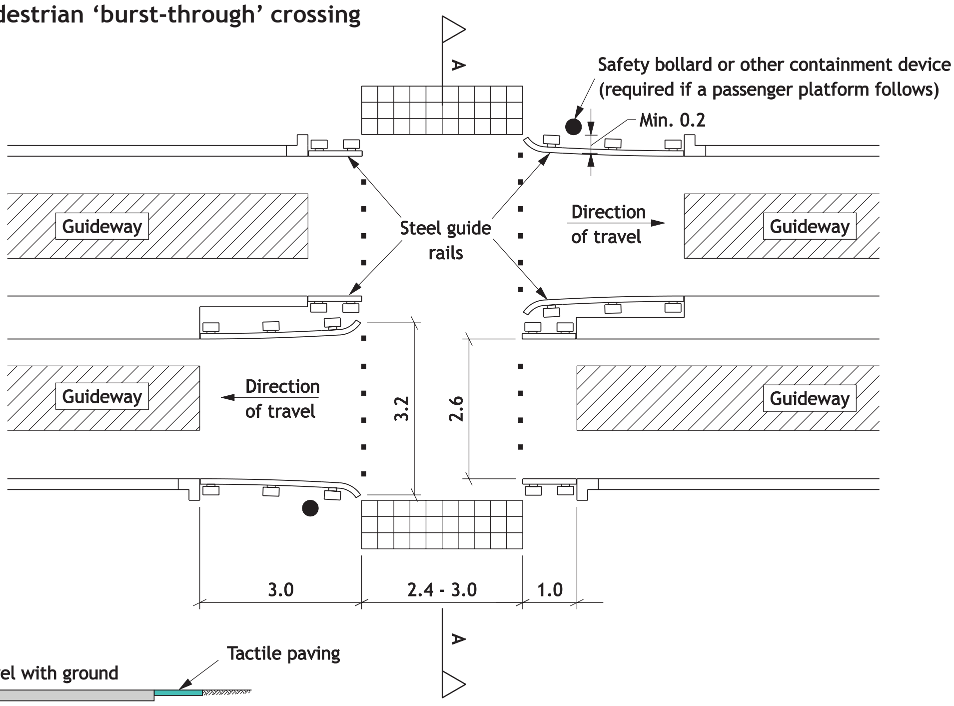
It is recommended that maximum operational speed at discontinuities should be limited to 50 kph. It is important to ensure that both kerbs are broken equally. Use of steel guide rails (Figure 5.7) at discontinuities allows the kerb alignment to be fine tuned by the use of shims and packing in order to ensure straight running of the bus when momentarily unguided. It is also recommended that a low-friction surface be applied to the steel rails on re-entry to reduce lateral jolting caused by friction forces acting on the guide wheels.

A minimum straight of 10 metres is recommended on approach to and following short breaks in the guideway.

To ensure straight running across the gap, vehicles must not brake at the discontinuity during general operation, except

Figure 5.4 Typical uncontrolled pedestrian 'burst-through' crossing

1. All dimensions in metres.
2. For details of steel guide rails, refer to Figure 5.7.
3. Minimum crossing width of 2.4 m in accordance with Local Transport Note 2/95: *The design of pedestrian crossings* and the Department for Transport's *Inclusive mobility: A guide to best practice on access to pedestrian and transport infrastructure.*
4. Pavement and pedestrian kerb edge details omitted for clarity.
5. Crossing studs must not be placed in any bus wheel path.
6. All dimensions are subject to HMRI approval.



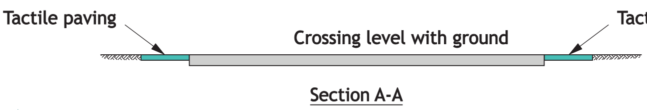


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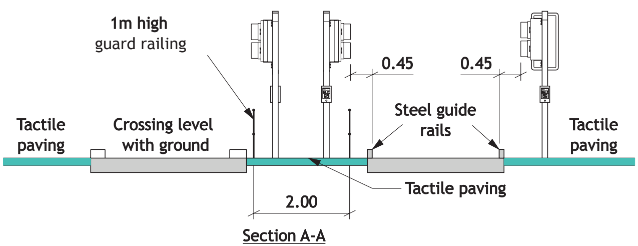
Figure 5.5 Typical controlled pedestrian crossing with central refuge and 'burst-through' crossing

1. All dimensions in metres.
2. Central reserve widened from 0.8 m to 3 m for 10 metres before and after crossing. Distance over which widening occurs to be determined by vehicle swept path analysis.
3. Pedestrian crossing dimensions based on Local Transport Note 2/95: *The design of pedestrian crossings* and the Department for Transport's *Inclusive mobility: A guide to best practice on access to pedestrian and transport infrastructure.*
4. Steel guide rail shims omitted for clarity. For details of steel guide rails, refer to Figure 5.7.
5. Pavement and pedestrian kerb edge details omitted for clarity.
6. Crossing studs must not be placed in any bus wheel path.
7. All dimensions are subject to HMRI approval.



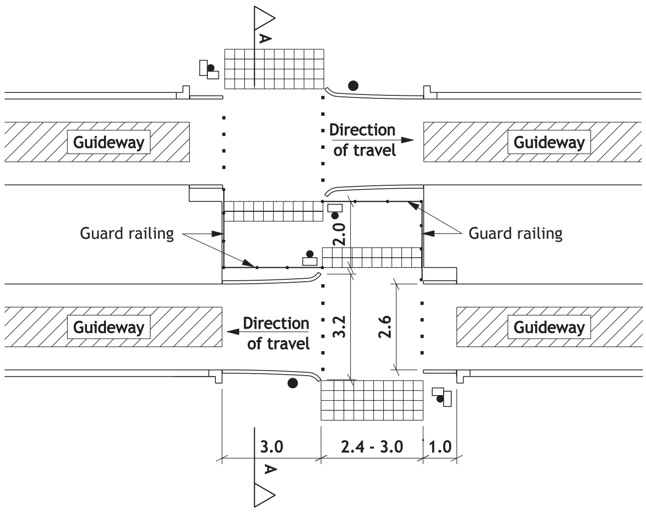


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Figure 5.6 Guideway crossing, Essen.

in an emergency situation. Where braking to control speed is unavoidable, for example if the pedestrian crossing is located on a downward gradient, the bus should brake on the approach and then 'coast' across the discontinuity. The driver should not attempt to steer across the gap; it should be traversed 'hands off' or with hands rested on the wheel without gripping. The designer should minimise the number of 'burst through' crossings on the guideway.

5.1.2.2 Crossings wider than 3 metres

For breaks in the guide kerbs greater than 9 metres, a full entry and exit splay arrangement is required. Breaks between 3 and 9 metres in length should be assessed to determine the most appropriate splay layout. For clarity to drivers, designers should specify either short burst-through gaps or long gaps with appropriate road markings and coloured surfacing. Intermediate length breaks in the guideway should be avoided.

5.1.2.3 Containment features

Where containment bollards are provided to prevent buses from moving sideways from the guideway path at breaks in the guide kerbs, these should be as shown in Figure 5.4. Bollards should be set back a minimum of 200 mm from the kerb upstand and should be provided on the nearside of re-entry splays. In some instances, containment beams or barriers may also be required. A full risk assessment should be carried out to determine the most appropriate and adequate containment measures for each crossing.

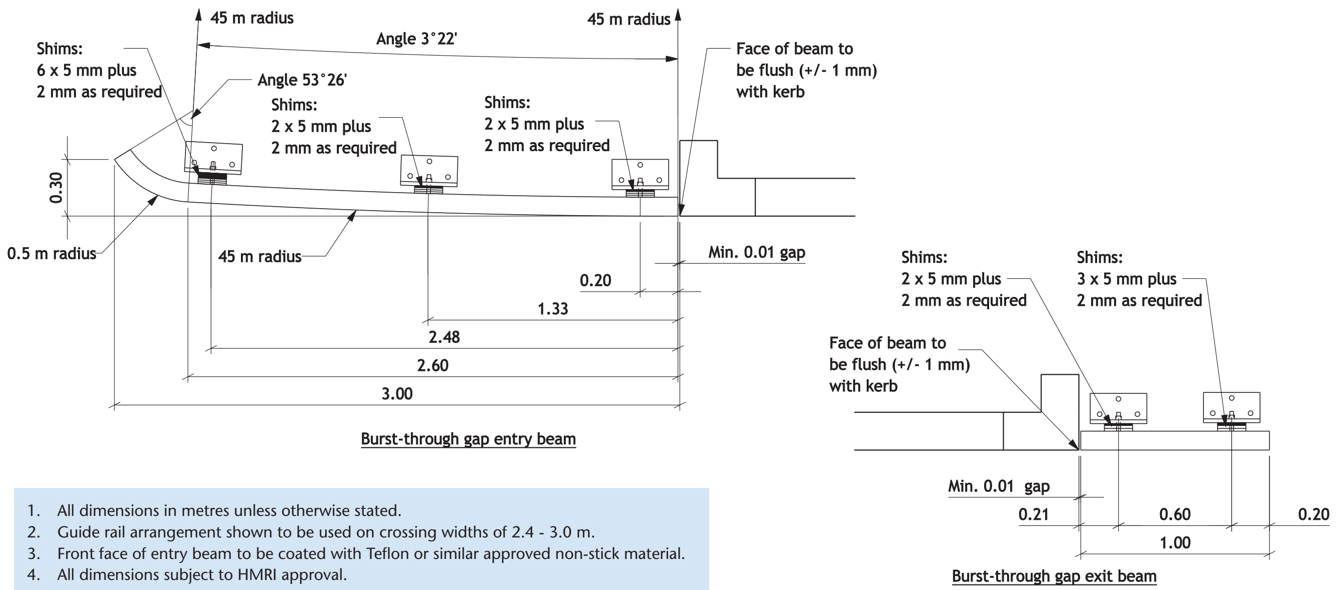
5.1.3 Road junctions and crossings

At road junctions or side road crossings where the break in the guide kerbs is greater than 9 metres, an exit splay is required on leaving the guideway and a full entry funnel is required for the vehicle to re-enter the kerb guidance. For breaks of less than 3 metres, the simplified 'burst-through' arrangement described under Section 5.1.2.1 is adequate. Breaks between 3 and 9 metres in length should be assessed to determine whether full splays are required. These intermediate length breaks in the guide kerb should be avoided wherever possible.

Provision of signal-controlled side road crossings and junctions should be in accordance with DMRB guidelines.

Work has been carried out by Mercedes Benz to develop mechanised switched junctions where the vehicles are fully guided throughout. However, these remain very much a prototype concept. In practice, kerb-guided junctions require high land take due to the large radii necessary to avoid the rear wheels scrubbing on the kerb. A more practical approach has been found to be to introduce short unguided sections using traditional junctions designed in accordance with DMRB.

Figure 5.7 'Burst-through' pedestrian crossing guide rail details



1. All dimensions in metres unless otherwise stated.
2. Guide rail arrangement shown to be used on crossing widths of 2.4 - 3.0 m.
3. Front face of entry beam to be coated with Teflon or similar approved non-stick material.
4. All dimensions subject to HMRI approval.

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6 Stops

In design of stops, passenger and pedestrian facilities, the following general issues should be considered:

- Number of people expected to use platforms, crossings and facilities;
- Location, number and frequency of pedestrian crossings at stops;
- Bus floor heights and door positions;
- Service patterns;
- Accessibility for disabled users.

6.1 GUIDED STOPS

6.1.1 Platform height

Stops can be located within the guideway system with platform heights of 300 mm to facilitate level boarding. A typical stop layout is shown in Figure 6.1.

The Public Service Vehicles Accessibility Regulations 2000 (Statutory Instrument No. 1970) require a maximum kneeled step height of 250 mm to allow for disabled access to buses. Railway Vehicle Accessibility Regulations (1998) require a boarding device between the doorway and platform unless the distance between the doorway and platform is not more than 75 mm measured horizontally and 50 mm measured vertically. It is possible for buses with a first step that is 300 mm high to achieve perfectly level boarding at guided stops, complying with all standards and removing the need for access ramps.

The point of increase from a 180 mm guide kerb to a 300 mm high platform kerb should be stepped and appropriate containment bollards provided.

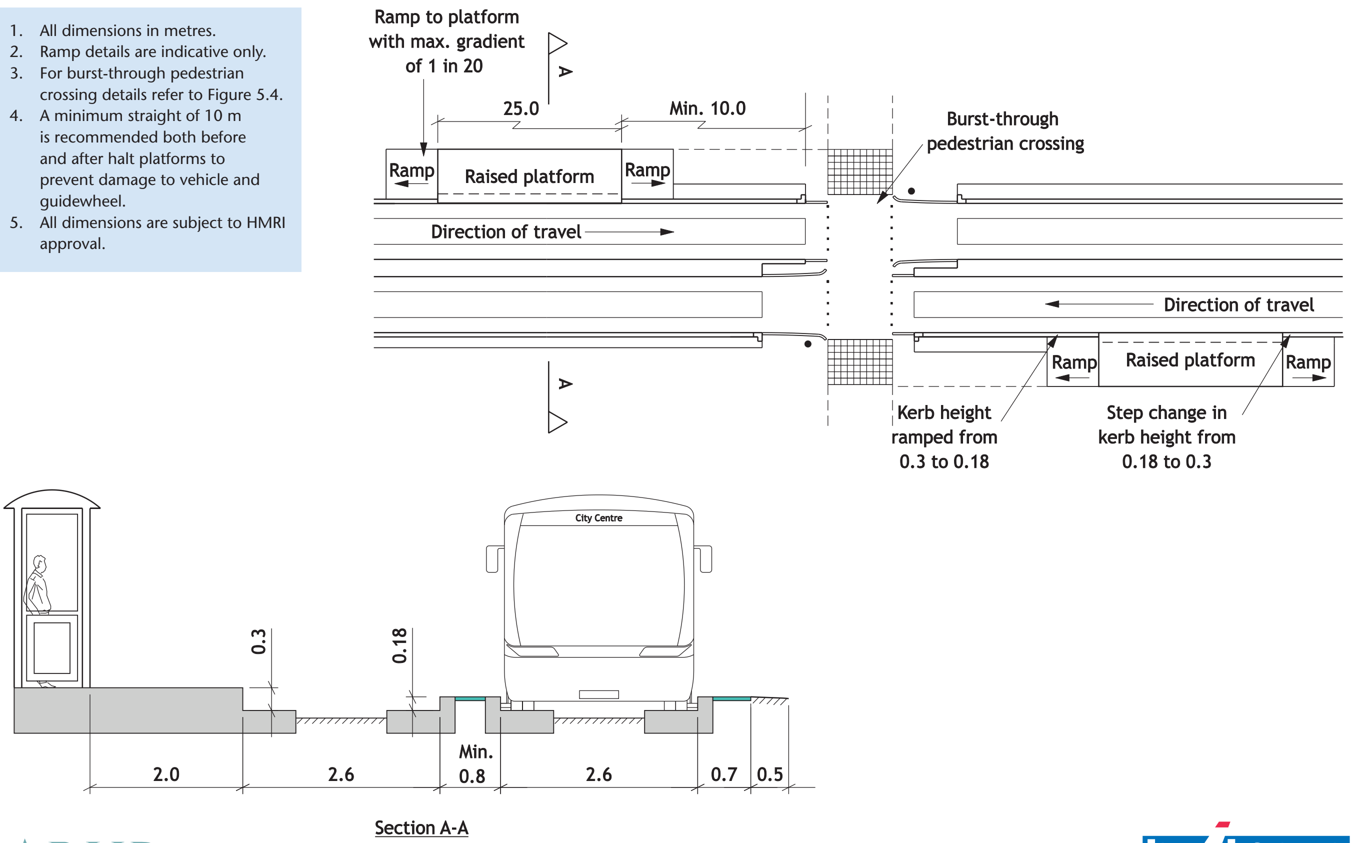
6.1.2 Platform layout

Stops should be situated on straight sections of alignment. A minimum of 10 metres of straight alignment is recommended before and after stops to prevent damage to the vehicle and guide wheel.

A typical stop has two platforms situated on the outer sides of the two running guide tracks. Unless buses with doors opening on both sides of the vehicle are expected to operate on the route, a single island platform is impractical.

Figure 6.1 Typical guided stop layout

1. All dimensions in metres.
2. Ramp details are indicative only.
3. For burst-through pedestrian crossing details refer to Figure 5.4.
4. A minimum straight of 10 m is recommended both before and after halt platforms to prevent damage to vehicle and guidewheel.
5. All dimensions are subject to HMRI approval.



The platform edge may be set back 15 mm from the 180 mm guide kerb edge to prevent bodywork damage due to scraping against the platform.

The platforms shown in Figure 6.1 are 25 metres long. These will accommodate either two standard buses, one behind the other, or one articulated bus. Platform length should include a stopping allowance, as vehicles cannot reverse on the guideway.

There are several available types of platform layouts. An open-fronted shelter is recommended in Figure 6.1. The Department for Transport's 'Inclusive Mobility' guidance requires that platform furniture and shelters should be located to provide an unobstructed footway width of at least 2 metres, preferably 3 metres for new construction, to facilitate disabled access. This may be provided either to the rear of the shelter or in front of it as shown in Figure 6.1. For existing infrastructure or where there are physical constraints, this dimension may be reduced to 1.5 metres. In addition, HMRI guidance on tramways requires that the minimum width between the platform edge and any structure on the platform, except for roofs of shelters, should not be less than 1.5 metres.

Designers should ensure that any stop arrangement chosen complies with the Department for Transport's *Inclusive mobility: a guide to best practice on access to pedestrian and transport infrastructure* as well as the section on tramstops in HMRI's *Railway safety principles and guidance: guidance on tramways*.

Painted lines and signs should advise passengers to stay away from the platform edge on stops, particularly on raised platforms where bus external rear-view mirrors may be at passenger head height for a significant proportion of passengers. A distance of 450 mm from the platform edge is recommended to accommodate bus mirrors. Tactile paving with the on-street warning surface for visually impaired passengers will be required by HMRI.

A pedestrian crossing should be provided at either or both ends of the stop with ramps up to the platforms, allowing pedestrians and the mobility-impaired direct access to the stops. Ideally, the platforms should be staggered with respect to the crossing to ensure that the crossing is upstream of the stop and in the line of sight of the driver, as shown in Figure 6.2.

Figure 6.2 Staggered stop and pedestrian crossing, Essen

6.2 DOCKING STOPS

The principles of guided busway design can also be applied to docking stops on otherwise unguided routes, providing the opportunity for precise alignment of buses parallel to the kerb. A guide wheel is fitted to the nearside front axle of the bus and runs against a 180 mm upstand/kerb. This system has been found to be effective where the stop has a straight kerb of 8 to 12 metres in length.

The raised kerb height also allows level boarding onto the buses, particularly for mobility-impaired passengers. These can be combined with bus boarders (platforms extended out into the carriageway) resulting in a quick and precise parallel alignment with smooth boarding.

6.2.1 Platform height

Guide kerbs at docking stops should be 180 mm high. Kerbs higher than 185 mm increase the risk of body-platform collisions. Buses whose kneeled height is greater than 230 mm would need to be fitted with access ramps for wheelchair users.

6.2.2 Platform layout

As with guided stops, docking stops should be situated on straight sections of alignment, with a desirable minimum straight of 10 metres recommended before and after the stop to prevent damage to buses and guide wheels and to facilitate docking as the vehicles run in from unguided routes. This assumes a 12-metre bus with 6-metre axle spacing. A longer straight approach may be required for other vehicle configurations. Lay-bys, because of their concave kerb shape, usually prevent a parallel approach to docking kerbs. However, docking stops have been used on convex and concave curved alignments. Designers should check, via swept path analysis, that the bus can align itself adequately with the platform, providing the required minimum horizontal clearance at all doors.

At the point of increase from regular highway kerbs to 180 mm docking stop kerbs, a stepped vertical-face quadrant kerb stone (Figure 5.3) should be provided with appropriate containment bollards, as discussed in Section 5.1.2.3.

All other characteristics related to guided stops, as discussed under Section 6.1, are also applicable for docking stops. For further details on docking stop design refer to the London Bus Priority Network Steering Group's *Guidelines for the design of bus bays and bus stops to accommodate the European standard (12 metre) length bus*.

As vehicles are not fully guided at docking stops, their approval does not come within the remit of HMRI.

7 Safety issues

This section describes the following safety issues which influence the design of the guideway:

- Trespass;
- Maintenance and emergency access;
- Special provisions at crossing points and bus stops;

Operational safety of the busway system is not discussed.

7.1 TRESPASS PREVENTION

Measures should be taken to deter unauthorised entry onto the guideway by pedestrians, animals, cyclists and other vehicles. These measures should discourage both unintentional entry onto the guideway and malicious trespass.

The busway should be clearly demarcated to ensure that it is readily identifiable and that other road users and pedestrians do not stray onto the guideway. Warning signs and road markings should be provided at all guideway entry and exit points, pedestrian and side road crossings, and any other discontinuities in the guideway.

Signs should be provided in accordance with The Traffic Signs Regulations and General Directions 2002. It should be noted that 'Guided Buses Only' is a non-standard sign. When locating signs, it may be necessary to cantilever signs above the guideway in order to achieve the required clearances, or increase the width of the central reserve.

Physical deterrent systems such as car traps at busway entry and exit points could be considered, and/or systems which use automatic bollards which lower on approach of the bus or emergency vehicle. An example of a car trap is shown below in Figure 7.1.

Figure 7.1 Example of a car trap at guideway entrance, Ipswich

Pedestrian-unfriendly surfacing can be applied to discourage pedestrians from walking down or crossing the guideway, except at designated pedestrian crossings.

A risk assessment should be carried out to determine if fencing or planting is required along the route. Use of spiny shrubs such as Berberis can be an effective and attractive alternative to fencing and pedestrian deterrent paving. Designers should ensure that no possible areas of concealment are provided by safety fencing or planting, particularly at bridge abutments, as driver and pedestrian visibility should be ensured at all times.

Provision of a footpath, bridleway or cycle track alongside the busway will discourage pedestrians and cyclists from using the guideway itself by providing an easier alternative route.

It is accepted that these measures will be unlikely to prevent the determined trespasser. A full risk assessment should be carried out at each location where there is a potential safety risk.

7.2 MAINTENANCE ACCESS

Safety and maintenance of the guideway must be considered when determining the cross section of the guideway. A minimum evacuation strip of 0.7 metres (desirable minimum 1.0 metres) is required adjacent to the guideway for use in times of emergency (Figure 4.1). This strip may also serve as a maintenance walkway, enabling inspection of the guideway and providing a safe walking area for maintenance staff during normal operation.

Consideration should be given to providing a wider maintenance track (4 metres) alongside the guideway, particularly in rural environments where space is available (Figure 4.2). Maintenance tracks can also serve as public footpaths and bridleways, provided they are adequately segregated from the guideway. If no maintenance track is to be provided, maintenance will have to be carried out online using special maintenance vehicles.

It is also essential to consider the evacuation route to be taken by passengers should there be an incident on the guideway. A clear unobstructed path should be available for passengers to leave the scene as swiftly as possible. The Police, Fire Brigade and other emergency services should be included in consultations regarding the provision of emergency access to the guideway and stops.

7.3 CROSSINGS AND STOPS

Any break in the guideway kerb provides a potential risk and so their occurrence should be minimised. Where breaks are necessary, such as at pedestrian crossings, a risk assessment should be carried out to determine all potential hazards and their appropriate mitigation.

At 'burst-through' crossings, a concrete-filled steel bollard, guide beam or other containment barrier should be provided on the nearside of the re-entry beam to prevent injury to pedestrians in the event of a bus leaving the guideway.

At changes in kerb height, the change should be stepped rather than ramped to prevent the guide wheel mounting the higher kerb and exiting the guideway. In addition, at points where a 75 mm-kerb entry flare meets a 180 mm guide kerb, a quadrant kerbstone (Figure 5.3) should be provided to steer vehicles into the guideway, preventing them from exiting accidentally. Where there is a drop in kerb height, such as after a stop, the transition may be ramped, as there is no opportunity for the guide wheel to ride the kerb and exit the guideway.

Platform edges at stops should be marked to indicate to passengers that, in the interest of their safety, they should remain away from the platform edge, especially as approaching buses are unable to steer away to avoid a collision. It is recommended that a 100 mm yellow line be provided on the platform, offset at 450 mm from the kerb to the outer edge of the line. For the visually impaired, tactile paving with the on-street warning surface should be provided.

The 300 mm platform edge may also be set back 15 mm from the 180 mm kerb to prevent damage to the bus bodywork. Further description of provisions at stops can be found in Section 6.

Consideration should be given as to whether automatic warning beacons should be provided to alert the driver on the approach to discontinuities in the guideway, such as pedestrian crossings and exits from the guideway. HMRI prefers use of passive measures such as rumble strips and road markings.

8 Pavements and surfaces

For design of the pavement, it should be remembered that on the guided busway, the wheels will always run in the same position on the running surface. It is therefore recommended that the guideway running surface be constructed from concrete.

The pavement of the busway should be designed to comply with DMRB Volume 7 for the type of loading anticipated.

In the selection of paving and infill materials, consideration should be given to the use of materials with noise-reducing properties, for both air-borne (wayside) noise and ground-borne noise and vibration.

8.1 DESIGN PHILOSOPHY

There are two possible approaches to designing the concrete running surfaces of the guideway. The guideway may be designed and constructed as a concrete pavement. Alternatively the guideway may be designed as a concrete beam.

Current thinking in UK guideway design prefers the 'pavement' approach, which has a greatly reduced volume of reinforcement, compared with that required for the structural beam. The design philosophy adopted should consider:

- Foundations and geotechnical conditions;
- Length of guideway on structure;
- Urban on-street or segregated applications;
- Drainage requirements.

The guideway may be designed as a continuous cross section or as two independent running plinths. For independent running plinths, ties or sleepers may be required at regular intervals to provide lateral stability and ensure gauge between the guide kerb faces is maintained to within the required tolerance.

Capping layer thickness and material will vary locally, depending on the results of detailed site investigations.

Typical section construction details are shown in Figure 8.1.

8.1.1 Design as running beam

This is the approach adopted for the O-Bahn systems constructed in Essen and Adelaide where precast running beams are fitted together supported by sleepers on a piled foundation. Each running beam effectively acts as a bridge between the sleepers.

For Leeds the running beams were supported directly on the subbase layer with no lateral ties between the two running beams.

8.1.2 Design as pavement

It is recommended that the running surface should be designed as a pavement in accordance with TRRL Research Report RR87 *Thickness design of concrete roads* (due to be replaced in December 2004 by TRL 630: *CRCP new materials and designs*). For a continuous guideway cross section, the upstands may be considered to have a stiffening effect; when designing independent running strips, an edge-load condition should be applied. RR87 provides for both unbound and cement-bound subbases.

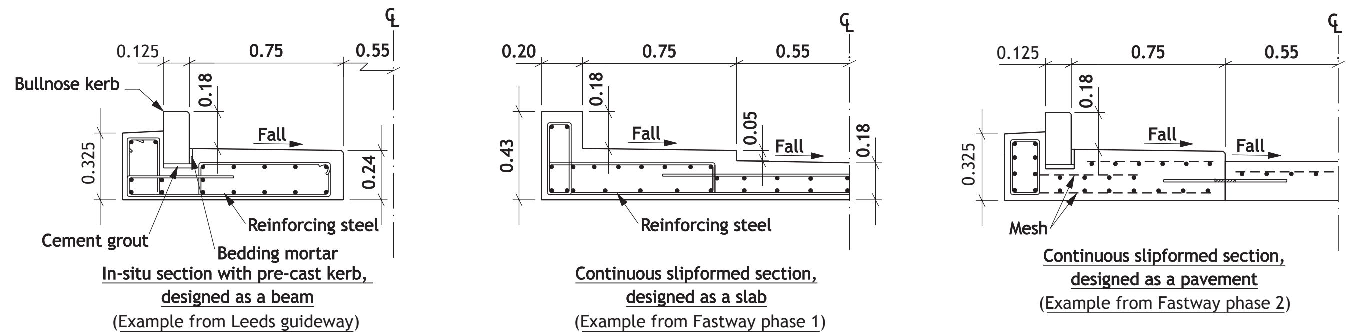
The following approaches could be considered for the pavement design:

- CRCP – continuous reinforced concrete pavement;
- Jointed unreinforced concrete pavement;
- Jointed reinforced pavement.

It is recommended that jointed systems be avoided as the joints can lead to issues with ride quality and noise and vibration over

Figure 8.1 Typical section construction details

1. All dimensions in metres.
2. Reinforcement details are indicative only.
3. Sections are based on previous examples of guideway construction and subject to detailed design checks.
4. All dimensions are subject to HMRI approval.



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time. However these problems are often associated with use of a granular subbase. Laying jointed unreinforced pavement on a cement-bound subbase will reduce the problems of uneven ride arising at the joints. Use of jointed reinforced slab on a cement-bound subbase will further reduce the number of joints.

Use of CRCP will require careful consideration of the movement at the end of the slab.

It should be noted that in order to achieve the required construction tolerances on the guideway upstands, it may be necessary to anchor the reinforcement cage to prevent movement during the slip forming process. This should be allowed for in design. Figure 8.2 shows the reinforcement cage (anchored into the base slab) for the slip-formed guideway, West Edinburgh Busway.

Figure 8.2: Reinforcement cage anchored into base slab, Edinburgh

8.2 RUNNING SURFACE

The finish of the running surface should be specified in accordance with the requirements of *Specification for highway works,* Volume 1; the designer should assess the number of standard axles that will pass during the lifetime of the guideway.

Texturing of the running surface may be achieved by:

- Transverse brushing;
- Exposed aggregate;
- Imprinting techniques.

Tranverse brushing of the running surface of the guideway is shown in Figure 8.3.

Figure 8.3: Transverse texturing on slip-formed guideway, Edinburgh

In other countries longitudinal texturing has been applied to concrete pavements but this does not currently meet UK skid resistance criteria, as outlined in the DMRB Volume 7.

8.3 FORMATION

The formation to support the guideway should be designed on a site-specific basis to accommodate local ground conditions and required loading characteristics. Thorough geotechnical information and site investigation is therefore essential.

For construction of the guideway as a pavement, the formation should be designed in accordance with HD25 from the DMRB with an allowance for granular subbase beneath CRCP options.

8.4 CENTRAL CHANNEL

The central channel may be paved or left void and infilled with suitable material. If paved, the channel should have an appropriate cross fall to allow for adequate drainage. The effects of discolouration from fuel and oil spillage should be considered when choosing the surfacing finish.

Infill material should be visually attractive and capable of being kept clean and weed-free with low maintenance, while discouraging use of the guideway by cars and other unauthorised vehicles. It should also be able to resist the effects of fuel and oil spillage and should provide adequate drainage.

The use of two separate concrete plinths with an infill section is beneficial in rural environments as it allows for the planting of vegetation between the running surfaces, thereby reducing the intrusive image of the concrete guideway. Vegetation is well established on the Essen system (Figure 8.4), providing an overall green landscaped appearance. Such planting also reduces the external noise profile of a moving bus because it absorbs engine noise.

The infilled channel provides an opportunity for the use of sustainable drainage solutions. Urban environments may dictate the use of a paved channel with grills at regular intervals for drainage purposes.

Figure 8.4 Guideway in Essen with central channel planting and landscaping

The central channel should be regularly maintained to prevent the build-up of leaves and rubbish. Particular care should be taken in design of the channel at the ends of the guideway in order to prevent accumulation of litter and debris. A practical solution is to slope the channel up to meet the road level so that the draught from the passing vehicles clears debris from the channel.

9 2017 UPDATE Construction

The guidance presented in this section is given to inform the designer about the construction techniques and processes that can be used to deliver a guided busway. This document is not intended to be a specification or prescriptive construction manual. It is intended that the designer should consider the advice and guidance given herein and evaluate its suitability and applicability to the project being designed. This guidance does not relieve the designer, owner or operator of any responsibilities under the Construction (Design and Management) Regulations 2015 or the Health and Safety at Work Act 1974 or other applicable legislation.

In the construction of existing kerb guided bus systems three approaches have been adopted:

a) Precast running beams on concrete sleepers – *Essen and Adelaide* (Züblin O-Bahn system), *Cambridgeshire* Guided Busway, *Luton & Dunstable* Busway;

b) In situ / slip formed concrete with hand laid pre-cast kerbs – *Leeds, Bradford and Crawley*;

c) Slip formed complete cross section – Leigh to Ellenbrook

9.1 CONSTRUCTION METHODS

9.1.1 Precast sections

The Züblin O-Bahn system (Essen and Adelaide), the Cambridgeshire Guided Busway and Luton & Dunstable Busway are pre-cast. The use of precast running beam sections gives a high degree of control over finish and lateral tolerance between the guide kerb faces. Ride quality is good, even for high speed operation. Fine adjustment of the beam elements for line, level and gauge can be carried out following construction.

Because the guideway elements are precast, they may be formed offsite and delivered to site as needed. On major projects, an on-site or local factory for the precasting of beams and foundation pads should be the preferred option. The number of curve variations along the alignment should be limited to reduce the cost of the precast elements.

In Cambridgeshire, Essen and Luton the track has been in-filled between the guideway running beams allowing growth of vegetation and producing an overall landscaped effect as shown in Figure 9.1.

Figure 9.1 Buried precast concrete beams with infill, Cambridgeshire

Precast guideways can be designed to allow for maintenance, whereby sections of the guideway can be lifted out to allow access to underlying services and utilities and adjusted to ensure that the as-built constructed tolerance is retained.

9.1.2 In-situ concrete with precast kerbs

The busways in Leeds, Bradford and Crawley use pre-cast concrete kerbs hand-laid into the reinforced concrete running slab in order to form the guide kerbs.

Manual kerb laying is becoming increasingly problematic due to HSE guidance. In order to lay 914mm long precast kerb units kerb-lifting equipment will be required. The precast kerbs are also a long term maintenance issue since they could become loose over time with continual running of the guide wheel.

The laying of straight 914mm long kerbs around a tight radius curve may also give problems with ride quality and tolerance between guide kerb faces.

This method is suitable for short lengths or where difficult access means it is impractical to use slip forming equipment. It is not considered that this form of construction is well suited to high speed operation due to ride quality and tolerance issues.

Figure 9.2 In situ concrete beams with precast kerbs, Leeds

9.1.3 Slip-formed guideways

Constructing the guideway in a continuous process by slip-form plant has been shown in the UK to be an economic alternative to in situ and precast construction techniques for lengths typically greater than 600 metres. The slip-form construction process integrates the running slab and kerb form within the single pass of the paver.

The guideway can be formed either as a one-piece slab or as two separate running surfaces. i.e. independent nearside and offside guideways. Recent UK experience suggests that a one-piece slab is preferable to two separate running surfaces; the guideway is constructed in one pass to ensure the required gauge and level tolerances between guide kerb faces are maintained as shown in Figure 9.6, showing construction of the Leigh to Ellenbrook Guided Busway. This technique still allows installation of SuDS drainage features in the central recess (Figure 9.7).

Figure 9.3 Slip-forming the Leigh to Ellenbrook Guided Busway

Figure 9.4 Leigh & Ellenbrook guideway with SuDS channels

Any starter bars for cross ties should not project above the level of the slip-form mould. Care should be taken to maintain cover to steel and avoid deformation of the rebar cage, particularly in the kerb upstands. Figure 9.8 shows the rebar cage prior to slip-form paving.

Figure 9.5 Leigh and Ellenbrook reinforcement cage

On site fabrication of the rebar cages should be considered to avoid any distortion during transit. As discussed in Section 8.1.2, it may be necessary to anchor the reinforcement cage in order to achieve the required construction tolerances in the upstands, ensuring that no movement of the cage occurs under the paver. If anchoring of the reinforcement is required, the design of the pavement must allow for this.

Access for supply of concrete to the slip-form paver and manoeuvrability during construction should be considered early in the design of the guideway. For dual guideway sections, one guideway can be used as a haul road when slipforming the other. Care should be taken to prevent risk of damage to the completed busway from construction vehicles travelling on the guideway. The slip-form paver tracks can run in the space between the guideways or, if necessary, in the adjacent guideway. If slip-forming as a continuous reinforced concrete pavement (CRCP), an I-beam anchor is recommended rather than an anchor slab.

Experience from slip-forming UK guideways has shown that concrete supply is critical to achieving the required tolerances, surface regularity and quality of finish. Dedicated on-site batching with in-transit monitoring and control of concrete consistency is recommended. A second paver used as a delivery system ahead of the guideway slip-form paver will reduce load on the main paver and allow a regular rate of paving to be maintained, improving surface regularity and smoothness.

A typical construction rate for slip-form paving of a single guideway (one-piece slab) on a good day is estimated at between 200m and 250m per ten-hour shift. However, it should be noted that the slip form paving operation is susceptible to weather conditions. For example, even with tenting, it is impractical to slip-form in the rain due to run-off from completed guideway sections behind the paver.

Due to potential variations in the concrete mix, it is recommended that off-site trials are completed using the preferred supply source before the commencement of the main works. This would allow the concrete mix to be tailored to the method of construction and equipment. It is also advisable that the mould is built with some adjustability to allow some adjustment to the to slip-formed gauge width.

It is recommended that the integral kerb is slip-formed to a gauge of between 8 to 15 mm tighter than design gauge and then the kerb face concrete is subsequently ground back to the required gauge for the project. This method was successfully implemented on the Leigh to Ellenbrook Guided Busway (Figures 9.9 and 9.10).

Figure 9.6 Leigh to Ellenbrook: Grinding the kerb

Figure 9.7 Grinding on Leigh & Ellenbrook busway

9.2 Steel entry & exit rails

The O-Bahn system (Essen and Adelaide), Cambridgeshire Guided Busway, Luton & Dunstable Busway and Leigh to Ellenbrook Guided Busway projects all use steel guiderails for entry and exit splays, and at pedestrian and lightly trafficked vehicular crossings.

A risk based approach to make use of 'burst through' for pedestrian, cyclist, equestrian and vehicular access along a guideway must be adopted prior to implementing breaks in the guide kerbs (refer to Chapters 5 and 7).

Steel guide rails can also be applied on structures, mounted on the concrete running slab as shown in figure 9.14.

Figure 9.8 Cambridgeshire Guided Busway - steel guiderails for entry and exit splays

Figure 9.9 Burst through steel guiderails for entry and exit splays, Cambridgeshire

Figure 9.10 Burst through guide rail (Leigh & Ellenbrook)

Figure 9.11 Steel guide rails mounted on concrete slab over structure, Essen (A40 route section)

9.3 Construction and Tolerances

This section represents the findings and conclusions from the latest research and experience gained across the industry.

The main topics discussed are the in-situ tolerances required to deliver good ride quality and the interaction between the bus and the guideway. There are many variables that will affect the performance of the system, including the guideway itself, the vehicle, the skill of the driver and even the weather conditions.

9.3.1 Speed of operation/ride quality

The tolerances required for a given scheme depend upon the performance required of the system. The ride quality sought from the system must be considered and balanced against the construction time and cost implications.

9.3.2 Slip-formed sections

It is advisable to build adjustability into the paver mould. The guideway should be slip-formed narrower than the required gauge and then the face of the kerbs ground back to the required design gauge.

9.3.3 Gauge

Gauge tolerances has traditionally been the main site measurement used to control construction quality. Close care should also be given to the tolerances of other measurements, e.g. horizontal and vertical alignment, and surface regularity.

The lateral tolerances and alignment to which the guide kerbs are constructed will have a direct impact on the ride quality experienced by the bus passengers. Rigid guide arm systems have only the compressibility of the rubber guide wheel tyre in which to accommodate lateral deviations in the kerb face. It is therefore critical that the finish and alignment of the kerbs is within tolerance.

Lateral tolerance can have safety implications; widening or poor alignment of the guide kerbs on the approach to a crossing gap could have potentially serious consequences if the hunting throws the bus sideways in the gap itself.

The high speed systems in Essen and Adelaide are quoted to have a construction tolerance of ±1mm. However, a detailed survey of the Essen system revealed that parts of the system are operating with a gauge tolerance of up to -12+4mm. Work was carried out in 2006 to correlate ride quality in operation against gauge, which revealed that ride is improved where gauge is “tight” i.e. the gauge should not exceed 2600mm. It was concluded that wide gauge should be avoided as this leads to hunting, while tight gauge will ensure the guidewheels remain in contact with both kerb faces. It has been shown in Essen that tight gauge does not cause damage or excessive wear to the guidewheels.

The following construction tolerances are recommended:

High speed and light rapid transit (>70kph)	2600	-5/+0mm
Low speed operations	2600	-7/+3mm

Since 2006, developments in the UK to construct higher speed busways have led to site improvements delivering gauge closer to the aspirational 2600mm ±1mm. This tolerance was specified as a project requirement for Cambridgeshire, Luton & Dunstable and Leigh & Ellenbrook. In the case of the first two of these, a precast construction was used allowing adjustment on site. For Leigh & Ellenbrook a two-stage process was used with the guideway slip-formed to a narrower gauge and then ground back to achieve the ±1mm tolerance.

It has now been demonstrated that in-situ construction tolerances can be compatible with a specification of 2600±1mm. To achieve this, it is recommended that the integral kerb is slip-formed to a gauge of between 2585mm and 2592mm and subsequently ground back to the required 2600mm ±1mm gauge. This method was successfully implemented on the Leigh and Ellenbrook Guided Busway (Figure 9.15).

Figure 9.15 Gauge Readout from 2-stage grinding machine (Leigh & Ellenbrook busway) – Extrudakerb

9.3.4 Horizontal alignment tolerance

The reliable measurement of horizontal alignment is realistically limited to a standard deviation of 2.0-2.5mm measured at 2m centres using existing equipment. Until a

tool is available to measure to a greater accuracy it is not advisable to specify a standard deviation for horizontal alignment of less than 2mm.

The secondary grinding process used on the slip-formed guideway at Leigh and Ellenbrook allowed the kerb faces to be ground to an optimised alignment.

For precast guideways formed of a limited set of curved and straight elements, the alignment tolerance specified by the project should take account of the proposed construction method and use of standard deviation may not be appropriate.

9.3.5 Surface levels and surface regularity

The guideway should be designed with a surface levels tolerance in accordance with Series 700 of Specification for Highway Works Table 7/1.

Models that predict ride quality in relation to surface regularity, such as the international roughness index (IRI), principally consider longitudinal defects with wavelengths between 1.2 and 30 metres. While wavelengths outside this range are also included in the calculation of IRI, it is this band that has the greatest influence on the ride quality experienced by the passenger travelling in the vehicle.

Surface regularity for highways is currently specified in the UK by the 3 metre rolling straight edge (RSE) test. However, this has limitations when applied to guided busways:

- The RSE detects defects over a length of 3 metres; by comparison, the wheelbase of a rigid bus is approximately 6 to 8 metres;
- Research from the USA indicates that defects influencing ride quality typically range between 1.2 metres and 30 metres in wavelength.

The guideway running surface could therefore meet the 3 metre RSE specifications, yet still exhibit poor ride characteristics for the bus.

It is recommended that a trial section corresponding to one day's work (typically 500 metres) should be constructed prior to commencement of paving works to test the paving mould and concrete supply chain. Construction of a pavement which meets the 3 metres RSE, yet still delivers a poor ride quality, may meet the requirements of the contract, but will not meet the aspirations of the client, or the expectations of the passenger.

At the Leigh and Ellenbrook Guided Busway an IRI index of 2.2m/km was achieved and the ride quality is considered to be good. The use of design software such as ProVal should be considered by the designer to check the theoretical IRI expected from the design; the vertical and horizontal alignment will influence the IRI index reading and impact overall ride quality.

Where IRI is specified for a busway the specifier should consider whether IRI is a suitable method of measurement for the surface regularity. Depending on the design of cross section, the profile of the busway may not lend itself to the use of oscillating floats and super smoother which are used on flat pavements to guarantee a much tighter IRI index.

9.3.6 Texturing and smoothness

Both surface macrotexture and smoothness, or surface regularity, impact on the ride quality of a guided busway, but in different ways:

- Surface texture produces high frequency vibrations, which do not activate the suspension. However, noise is generated at the tyre/concrete interface.
- Smoothness or regularity of the surface has a direct mechanical influence on the ride quality; irregularities such as bumps, troughs and steps will excite the suspension of the bus and are transmitted to the passengers as vertical accelerations.

It should be noted that a noisy road surface is not necessarily an indication of a rough ride.

It is recommended that transverse texturing of the surface should not be provided as it is likely to increase the level of noise generated at the wheel-road interface. It is also difficult to apply without risk of damage or deformation of the kerb upstand.

This aspect is discussed in greater detail in the Guided Busway Construction Handbook available from Britpave.

The busways at Cambridgeshire, Luton & Dunstable and Leigh & Ellenbrook have all had surface texture applied to the running strips by shot-blasting to deliver a texture depth of 0.4mm +/- 0.2mm. If greater texture depth is desired, the use of longitudinal grinding/grooving should be considered.

A risk-based approach should be used to determine the required texture depth and where high friction anti-skid surfacing should be applied e.g. on the approach to junctions or pedestrian burst-throughs.

Longitudinal grinding is recognised in the United States as suitable for provision of highways surface texture and has undergone trials for Highways England. This has not yet been applied on busways in the UK.

9.3.7 Height of the guide kerb

For safety reasons, the upstands should be designed so that 100% of the guidewheel vertical face remains in contact with the guide kerb at all time. The height of the upstand should be designed to allow for debris or obstructions lying on the guideway running surface and longitudinal oscillation of the vehicle on its suspension.

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10

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A selection of the above titles has been reviewed in the preparation of this handbook and a summary is provided in Appendix C.

Calculation of bus stop dwell time

A

A1 VEHICLE DECELERATION/ ACCELERATION TIME

The time spent decelerating to or accelerating from a stop is not always considered when assessing the effects of bus stops on overall journey time. However, it does have an effect on the additional journey time imposed by a bus stop. In particular there are differences between the deceleration and acceleration times of buses operating on segregated busways and those operating in general traffic.

When operating in general traffic the time taken for a bus to decelerate to a stop will not be a simple component of vehicle braking performance as the direct route to the kerb at the bus stop may be impeded by parked cars and other vehicles. In addition, drivers have to guide buses as close to the kerb as feasible to provide as level access as possible for passengers. This increases the deceleration time element.

Before accelerating away from a stop a driver will have to check traffic and may have to wait for a break in the traffic. Research in London has shown that a time penalty of 30 seconds should be applied to allow for buses decelerating to and accelerating from a stop located in a general traffic lane. These are split 15 seconds for each element. However, these times relate to deceleration from a maximum speed of 48 km/hr not the 80 km/hr often assumed for guided busway systems.

On segregated busways with adequate kerbline capacity at bus stops there is no need for drivers to negotiate other vehicles when accessing the bus stop. With a guidance system in place the driver has no need to position the vehicle for ‘docking’ with the bus stop platform. In this situation the deceleration time is largely dependent upon the braking capabilities of the vehicle. This is similar to the situation on segregated sections of light rail systems where line of sight operation is used.

As a rule of thumb it is assumed that the vehicles used on guided busways have an average deceleration rate of 0.9 m/s^2. The time taken to decelerate to a stop from 80 km/hr would be approximately 30 seconds.

The acceleration time from a bus stop on a segregated busway will be influenced by the layout of the bus stop. Where no bus stop lay-by is provided the time taken to return to operating speed will be dependent upon the acceleration capability of the bus. For the purposes of assessing busway operations it is often assumed that the average acceleration rate of a bus will be 0.7 m/s^2. The time taken to accelerate from stop to 80 km/hr would be approximately 40 seconds.

Where a lay-by is provided the driver may have to give way to overtaking buses (unless an alternative priority arrangement is operated on the busway). A reduced wait time is likely in comparison with the situation in general traffic. However a lay-by will have an impact on the running time of non-stopping buses.

A2 BUS DOOR OPENING AND CLOSING TIMES

For reasons of passenger safety the doors on modern buses are interlocked (by various means) to the vehicle drive train. This is to ensure that the doors are not open when the vehicle is moving and generally applies to all doorways other than the one immediately adjacent to the driver.

The time taken for a door to open after the wheels have stopped is a function of the operation of the interlocking mechanism for that particular design of bus and is irreducible. Similarly, the time between the driver activating the door closing button/switch and the bus being able to move off is also a function of the interlocking system.

Research undertaken in London has shown that the typical irreducible door closing and opening times are 3 and 4 seconds, respectively. Thus even with no passengers boarding or alighting the minimum bus stop dwell time is 7 seconds. This figure is based on data for the following vehicle types:

- Metrobus, Olympian and Scania two door double deck buses;
- Optare Excel two door single deck bus;
- Dennis Dart single door single deck midibus.

A3 PASSENGER BOARDING TIME

The marginal time taken for an additional passenger to board a bus comprises the following broad elements:

- Time taken to step from the bus stop platform onto the bus;
- Time taken to request a fare (if applicable), pay the driver (or machine) and collect the ticket and change (if applicable).

The time taken to step from the bus stop platform to the bus will be influenced by the distance between the platform and the bus and the number and height of any internal steps. On unguided systems operating in general traffic the ability of drivers to reliably stop adjacent to the bus stop platform, thereby minimising the step distance, may be compromised by the presence of parked cars (illegally or otherwise). The use of measures such as bus stop boarders and bus lanes can help improve vehicle access to the kerb side but cannot provide as reliable a ‘docking’ mechanism as a guided bus system operating on a segregated busway.

Research undertaken by the Transport Research Laboratory has shown that the provision of level boarding between the bus stop platform and the bus with no internal steps within the vehicle can reduce boarding times per passenger by up to:

- 8% for mobile adults;
- 1.5% for mobile OAPs;
- 21% for mobility impaired passengers;
- 49% for adults with pushchairs.

These are significant reductions. However, these reductions in times are likely to be realisable on a regular basis only when there is reliable 'docking' between buses and bus stop platform. This is only likely to be achievable with a guided bus system.

The process of buying tickets using cash is known to extend boarding times and be the major determinant. Use of simple well understood fare scales can help reduce ticket purchase time as can exact fare only/no change systems. However, the most effective way of reducing boarding time is to increase the proportion of passengers using pre-paid/off-bus tickets.

The total boarding time for all passengers is the sum of each marginal boarding time plus what is known as a 'dead time'. The latter relates to the response time of the first passenger to board the bus after the bus doors open (or after the last alighting passenger is clear of the doors on a single door bus) and the delay between the last passenger boarding and the driver pressing the door close button/switch.

Research undertaken in London has shown that the average boarding time for passengers, inclusive of an allowance for 'dead time' is 3.5 seconds per passenger. It should be noted that data for London will be strongly influenced by the widespread use of Travelcards which have only to be shown to the driver when boarding. Between 60% and 70% of London bus passengers use Travelcards. This has the effect of reducing the average boarding time in comparison with operations with a higher percentage of cash fares.

Evidence from Yorkshire suggests that a passenger buying a ticket from a driver for cash takes an average of around 6 to 8 seconds per transaction, but only 2 seconds to show the driver a Travelcard.

The data for the passenger boarding times for the Routemaster buses (rear boarding with separate conductor) provide a useful measure of boarding time where passengers neither purchase a ticket nor show a Travelcard. The average boarding time in this case is 1.5 seconds per passenger. This time allows for the need for some passengers to board from road rather than bus stop platform level when drivers are unable for whatever reason to pull up adjacent to the kerb.

Tables A3.1 and A3.2 summarise the results of our review of available survey data on bus boarding times for cash fare paying and off-bus ticket passengers.

Table A3.1 shows the benefit of passengers not paying on entry to the vehicle. With a second crew member employed to issue and check tickets the average boarding time, inclusive of 'dead time' varied between 1.5 and 1.8 seconds per passenger. When passengers pay cash for tickets on boarding the bus the average time increases to between 2.6 and 5.6 seconds per passenger.

Table A3.1 Bus boarding times

Location	Vehicle type & no. of doors	No. of crew	Fare system	Average boarding time (seconds)
London	Routemaster, 1 Door	2	Cash Fare & Travelcard	1.5
Reading	Full size bus, 1 door	2	Cash fare	1.6
Sunderland	Full size bus, 1 door	2	Cash fare	1.8
Watford	Full size bus, 1 door	1	Exact fare machine	2.6
Hull	Full size bus, 1 and 2 doors	1	Remote ticket issue	2.6
West Midlands	Full size bus, 1 door	1	Exact fare machine	2.8
London	Full size bus, 2 doors	1	Flat fare, no change	2.9
London	Full size bus, 2 doors	1	Flat fare, 27% require change	4.1
London	Full size bus, 2 doors	1	Standard fares, all require change	4.5
London	Full size bus, 2 doors	1	All require change	5.6

Table A3.2 Bus boarding times, pre-paid tickets

Location	Vehicle type &no. of doors	No. of crew	Average boarding time (seconds)
Lille	1 door, 2 channels	1	1.3
Cologne	2 or more doors	1	1.6
Copenhagen	1 door, 2 channels	1	1.9
Stockholm	1 door, 1 channel	1	2.6
Amsterdam	2 door	1	3.4

APPENDIX A
Calculation of bus stop dwell time

The boarding times for pre-paid tickets are generally lower, even with one-person operation. The average boarding times range between a minimum of 1.3 seconds to a maximum of 3.4 seconds with the average being 2.2 seconds per passenger. The boarding times for pre-paid ticket holders are strongly influenced by the number of doors and the number of channels per door.

On a segregated guided busway with guaranteed 'docking' between bus and bus stop platform, 100% off-bus ticketing and separate entry and exit doors on the buses an average boarding time of 1.5 seconds per passenger per boarding channel is reasonable. An entry with a minimum width of 1200 mm will have two boarding channels, although the effectiveness of the channels will be influenced by the width of the gangway within the bus. Any narrowing of the gangway, in particular close to the doors, e.g. from presence of wheel arches, will reduce the use and/or throughput of the channels.

On high-volume bus operations it is important that in the bus the area adjacent to the doors is as wide as possible and kept clear of obstacles such as luggage racks, which will inhibit the passage of passengers down the vehicle. It is important that the interior design of the bus follows the principles used on high-capacity light rail systems where passenger throughput is maximised to reduce dwell times.

A4 PASSENGER ALIGHTING TIME

Alighting times per passenger tend to be lower than those for boarding as there is no ticket purchase or validation. Generally the alighting time per passenger increases with the number of steps, but is inversely related to the size of the bus, possibly because the door widths are related to vehicle length. Alighting times also increase with bus occupancy because on full buses passengers may have to wait for the bus to stop before vacating their seat and are slower than normal in reaching the door. The provision of additional doors along the length of a bus will help in this respect.

At bus stops where total alighting time is lower than total boarding time, the bus dwell time calculation will use the latter time. The exception is where a single door bus is used when the sum of the alighting and boarding times is used in the calculation of the dwell time.

Where the same doorway is used for boarding and alighting the theoretical alighting capacity is often reduced by the obstruction of the doorway by boarding passengers.

Research data on passenger alighting times is more scarce than for boarding times. However, research in London has shown that the average alighting time is 1.25 seconds per passenger. A figure as low as 0.99 seconds has been recorded for Routemaster vehicles. For segregated guided busways it is recommended that a time of 1.25 seconds per passenger per channel be used.

A5 COMBINING ALIGHTING AND BOARDING TIMES

Care must be taken when using alighting and boarding times to calculate this element of bus dwell time. How these times are used in the calculation of dwell times will depend on the number and design of the bus doors and the separation of alighting and boarding passengers. The following rules should be applied:

- Where alighting and boarding passengers use a common door or doors, the alighting and boarding times should be summed.
- Where alighting and boarding passengers use separate doors the longer time should be used.
- Where multi-channel doors are used the boarding time per passenger per channel should be used (care must be taken to include the appropriate number of channels in this calculation).

Table A5.1 summarises the components of dwell times, the range of values identified in this research and the value we think most appropriate for segregated busway systems. These data can be used to assess dwell times at individual stops on such systems for which boarding and alighting volume data are available. Note that these times assume 100% off-bus ticket purchase.

Table A5.1 Dwell time calculation summary

Component of stopping time	Range of values (seconds)		Recommended value for busway (seconds)
	Minimum	Maximum	
Deceleration from operating speed	25.00	35.00	30.00
Door opening	Dependent upon vehicle capability		3.00
Boarding time/ passenger/channel	1.30	5.60	1.30
Alighting time/ passenger/channel	0.99	1.25	1.25
Door closing	Dependent upon vehicle capability		4.00
Acceleration to operating speed	35.00	45.00	40.00

B 2017 UPDATE
Horizontal alignment design methodology

B1. METHOD 1

To apply this method, the horizontal alignment should be based on a constant comfort factor with the design speed varying to suit the curve to be negotiated. The passenger comfort factor is a function of the change of horizontal force (lateral acceleration) applied to passengers as the vehicle travels around the curves.

From experience in Essen and Adelaide the limiting value for passenger comfort is set as a maximum lateral acceleration of 1.0 m/s².

Lateral acceleration is given by the equation:

$$a = \frac{v^2}{R} \qquad \text{...(B1)}$$

Where:
a = lateral acceleration (m/s²)
v = speed (m/s)
R = radius (m)

The coefficient of side friction force (f) developed between the vehicle tyres and the running surface can be found from:

$$f = \frac{v^2}{Rg} \qquad \text{...(B2)}$$

Where:
f = coefficient of side friction force developed between the vehicle tyres and the running surface
g = acceleration due to gravity (m/s²)
v = speed (m/s)
R = radius (m)

Substituting a = 1.0m/s² (equation B1), and g = 9.81 m/s² into equation B2, gives a limiting value for f:

$$f = \frac{1.0}{9.81} = 0.102$$

For any given curve and speed, superelevation may be introduced to enable a component of the vehicle's weight to reduce the frictional need. It can be shown that the general relationship for this effect is:

$$R = \frac{V^2}{127\,(e+f)} \qquad \text{...(B3)}$$

Where:
V = speed of vehicle (km/h)
e = superelevation of surface (m/m)
R = radius (m)
f = coefficient of side friction force developed between the vehicle tyres and the running surface

Using the limiting value of f = 0.102, for a known maximum superelevation and given radius, it is therefore possible to calculate the maximum speed on the curve. Similarly, the minimum radius for the design speed can be found. Note that the speed V appears in this equation in kilometres per hour.

Example 1:

Using a design speed V = 120km/h and assuming zero superelevation (0%), the minimum radius for this speed is found using equation B3 as:

$$R = \frac{100^2}{127\,(0 + 0.102)} = 771 \text{ metres}$$

Example 2:

For a 510 metre radius with superelevation of 2.5%, the maximum design speed is:

$$R = \sqrt{510 \times 127(0.025{+}0.102)} = 90.7\text{km/h}$$

Example 3:

For a 300 metre radius with maximum superelevation of 5%, the maximum design speed is:

$$V = \sqrt{300 \times 127(0.05{+}0.102)} = 76.1\text{km/h}$$

B2. METHOD 2

The *Design Manual for Roads and Bridges (DMRB)* Volume 6 Section 1 *Road Geometry Design* Part 1 *TD9/93 Highway Link Design*, gives standard design guidelines and parameters for highway link design in the UK. It is considered reasonable to equate the design of the alignment for a guided busway to that of a single carriageway highway.

Table 3 gives desirable minimum values related to design speed. Figure 5 shows the appropriate superelevation for the range of Design Speeds. Busways in the UK have been designed successfully to operate without superelevation. This can yield benefits in simplified construction. DMRB allows for relaxations against the values in Table 3. The designer should establish at the outset to what extent relaxations are permitted on the project.

For radii less than those in table 3, the relationship between radius, speed and superelevation is given by the equation:

$$S = \frac{V^2}{2.828 \times R} \qquad \text{...(3.4) B4}$$

Where:
V = speed of vehicle (km/h)
S = superelevation of surface (%)
R = radius (m)

The values in the DMRB are more conservative than those obtained by Method 1. This is not surprising as the parameters in DMRB cater for a variety of vehicle types.

Example 4:

Using a design speed V = 100 km/h and zero superelevation (0%), the desirable minimum radius for this speed is found using Table 3 as:

$$R = 2040 \text{ metres}$$

Example 5:

For a 510 metre radius with maximum superelevation of 2.5%, the desirable maximum design speed is found using Table 3 as:

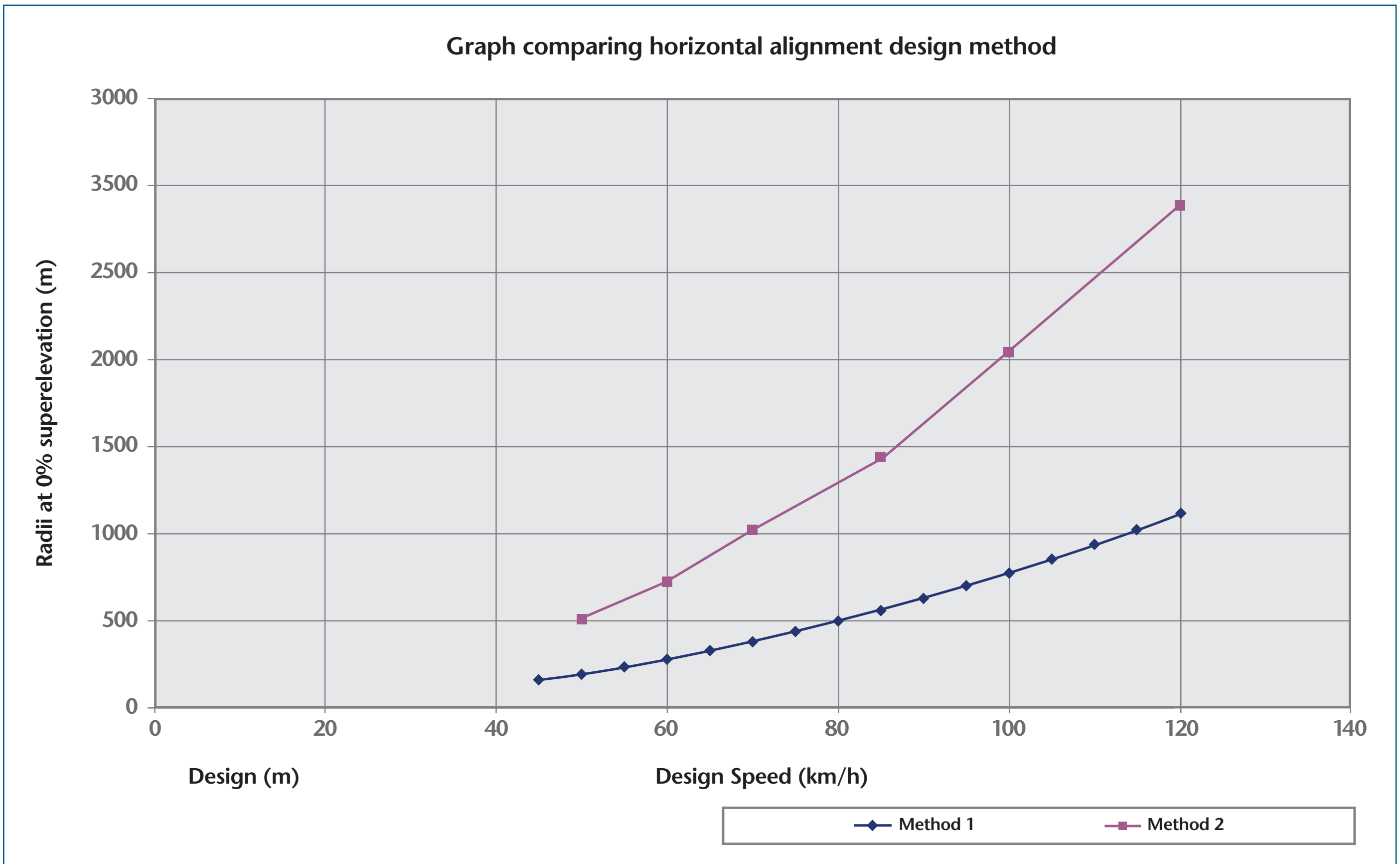
$$V = 60 \text{ km/h}$$

Example 6:

For a 300 metre radius with maximum superelevation of 5%, the maximum design speed can be found using equation A4 as:

$$V = \sqrt{300 \times 2.828 \times 5} = 65.1 \text{ km/h}$$

B3. GRAPH COMPARING HORIZONTAL ALIGNMENT DESIGN METHODS



C Literature review

The reviews in this appendix are a selection from the *Further reading* list (Section 10), presented in date order.

1) RUPRECHT, G F AND ENGLISHER, L S (1983)

***Bus guidance technology: a review of current development*. US Department for Transportation, Washington, DC.**

Written in the early 'eighties, this presents a comprehensive overview of the then emerging technology of guided buses with case studies of experiences in Germany, Adelaide, and Sweden. The report traces the technological development of guided bus systems in Germany with particular emphasis on the Essen experiment and the then unfinished Adelaide scheme (which utilised German technology), and in Sweden with emphasis on Volvo's electronic guidance system. The report concludes with a summary of proposed developments in the UK and America.

The account of Germany's development of guided bus technology begins with initial research into the use of both mechanical and electronic guidance from as early as 1975. Mechanical guidance research was pioneered by Daimler-Benz and MAN, the two largest bus chassis builders in West Germany at the time. Together, they developed the now standard rigid arm guide wheel to be fitted to conventional buses. It is interesting to note that designs involving the use of hydraulic dampers and hinges to cushion lateral impacts were developed and tested but ultimately discarded in favour of the greater stability offered by the rigid arm.

Differences between the Daimler-Benz and MAN systems are also explored including variations in vehicle specifications, bus stops, exhaust extraction and switches. Daimler Benz developed both lifting edge and moving blade steel switches that actively guide buses at crossover points, whereas MAN opted for a passive switching technique where vehicle direction at branches is determined by maintaining contact with the guide rail in the appropriate direction.

The Essen experiment is described in detail, including the different phases of design and construction. The Essen guided busway was built in three phases, each one being used to test a different element of the system. Phase one (1980) tested the use of mechanical kerb guidance as well as an automatic (headway control) safety system, while phase two demonstrated the capability of operating a guideway in an existing tram right of way, including the use of a lifting edge switch and the use of Duo-Buses with both diesel engines and electric motors, with electricity being supplied by pantograph. Phase three, then yet to start, was to test the operation of the Duo-Buses in a tramway tunnel. All reports indicated that the tests were successful. The Essen guideway was built using a beam and sleeper method of construction where precast guideway units were tied together by horizontal sleepers resting on bored piles. Wooden sleepers laid end to end with rails attached were also tested on some sections.

A fully guided busway was chosen for the Adelaide scheme (12 km) over other systems including a dedicated non-guided busway and partial sections of guideway. This choice was made on the basis of savings in structure costs, greater safety, comfort, reduced environmental impact and greater passenger acceptance. The system was designed by German engineers and at the time of print, construction was under way.

In the early 1970s the Volvo Bus Corporation tested a system of electronic guidance at bus stops in Sweden to accompany its low-floor buses with the aim of speeding up boarding times, thereby reducing journey times. The system controlled both the steering and speed of buses at high-level stops. A demonstration was run in Halmstad with eight buses and 26 stops. During implementation, however, drivers mostly overrode the electronic speed system and were uncomfortable with the steering, leading to both systems being abandoned after 2 ½ years.

The paper takes a brief look at a proposed trial of a 720 metres long guided busway in the West Midlands, UK. The system would utilise German technology but be composed of UK-made parts. Modifications to the German system included linking the guide arm to the steering control, unlike the Essen experiment where the guide arm is linked directly to the stub axle and not the steering hardware, The system would also make use of double-decker buses on the West Midlands guideway; these have a higher centre of gravity than single floor buses and could potentially affect vehicle stability.

The final section of the paper reports on research taking place in the USA on automatic guided bus technology. The paper concludes that not much work was being conducted in this field and identified no applications of automatic bus guidance technology in North America. There were expressions of interest in mechanical guidance, however, in Boston, Seattle and Ottawa.

The paper concludes that, overall, electronic guidance has been proven to be technically feasible but its implementation has been hampered by driver reluctance to use it and the need for a 'fail safe' mechanical backup. According to the author, mechanical guidance has been tested in several places; this has provided a wealth of data for evaluation and will become an important mode in the near future.

2) DREHER, G & HIPP, E (1988)

Guided buses: Present and expanded technical development. *Verkehr und Technik*, pp. 405 - 408.

This paper describes the two principal guidance systems under development: electronic guidance systems and kerb guidance. For the kerb-guided system the guide wheel arm and linkage to the vehicle axle and steering mechanism is described. The paper also describes development of switches to automatically route the vehicles at junctions.

3) ACKERMAN, J & SIENEL, W (1990)

Robust control for automatic steering. *Proceedings of the American Control Conference*, *Vol. 1*. pp. 795 - 800. American Automatic Control Council. Green Valley, AZ.

This paper describes vehicle dynamics and development of control systems for automatically steered vehicles. The principal application considered is electronically guided buses However, all the model data and specifications are taken from the MAN track guided bus. The bus dynamics are modelled and the problem of passenger comfort discussed. The following influencing factors were modelled:

- Transition into a curve;
- Entering narrow bus stop;
- Changeover from manual to automatic steering;
- Side wind.

The study concludes that the addition of a gyro feedback reduces oscillation in the vehicle and improves the ride quality.

4) CRAWFORD, R G (1990)

Practical experience of guided bus operation. *International Journal of Vehicle Design*, Vol. 11, No. 4/5, pp. 483 - 495.

A short 600 metres stretch of twin guideway was introduced in the central reserve of a main carriageway in the West Midlands as part of a wider route improvement scheme. Kerb guidance was chosen above slot guidance or a raised central guideway as it was simpler and provided a segregated busway. Influenced by the short length of the guideway, the track bed was cast in situ and steel guide rails were used. In hindsight, both the guide wheel and the track were found to be over designed. This was due to the tight timescale for development of the system and the lack of experience with guided technology. Overall there were no major problems with operation, although pedestrian crossings were judged to be too wide giving buses more chance to drift prior to re-entry and it was judged that entry splays could have been improved. There were also aesthetic concerns over oil from vehicle leaks, which tended to form unsightly patches at stops.

As deregulation approached, the experiment was viewed as no longer commercially viable and in 1987 the track was demolished.

5) YAPP, C J (1992)

Guided bus: A practical solution to the problem of urban congestion. *Public Transport Planning and Operations*. *Proceedings of Seminar held at the PTRC European Transport*, *Highways and Planning 20th Summer Annual Meeting*, Vol. P356, pp. 105 – 116.

This paper presents a strong argument for the use of guided buses to solve problems of urban congestion. It is written by a consultant who had undertaken feasibility studies for guided buses in Glasgow and Cambridge. The advantages of guideways are outlined but caution is encouraged when dealing with the advantage of flexibility. Benefits gained by segregated operation on the guideway must not be lost through delays in mixed traffic or on-street running areas. Articulated single buses are recommended as the vehicle of choice to use the guideway, and attributes such as ease of boarding, ride comfort, comfortable seating, minimal reliance on standing and low raised stop platforms are stressed.

The powers for implementation of guided buses in the UK are discussed with mention of highway authority powers being the obvious choice where guideways are being built in central reserves or adjacent to existing highways. Where a guideway is proposed outside of highway land on a new alignment, on a disused railway line or near railway infrastructure, the Transport and Works Act Order procedure is recommended.

The paper finishes by taking a look at two proposed guided bus schemes in the UK, one in Glasgow and one in Cambridge, with details of their proposed routes.

6) TEBB, R (1993)

Possible application of guided bus technology in Britain - Operational design implications. *Proceedings of the Institution of Civil Engineers Transport* 1993, 100, Nov, pp. 203 - 212.

This paper was written by Bob Tebb, who is considered an authority on the design and operation of guided buses in the UK, with experience of operating the busway in Leeds.

It introduces the concept of guided buses, citing the advantages of bus transit and giving comparisons with rail transit. Bus guidance technology (electronic and kerb guidance) is described and the paper gives a history of the development of guided bus systems with examples from Birmingham, Mannheim, Essen and Adelaide.

The paper contains a section on the design of infrastructure for kerb-guided systems. Detailed descriptions of the guideway cross-section and layout for entry/exit splays, pedestrian crossings and stops are given together with design loadings. It also makes comprehensive recommendations for developing the bus guideway system such as location of stops, guideway location relative to other traffic, and interaction with other road users and pedestrians.

The dimensions and criteria in this paper have been used in development of this *Guided busway design handbook*.

7) DEPARTMENT OF TRANSPORT (1995)

***Guided buses: A briefing note*. Buses and Taxis Division of the Department of Transport.**

This document forms the basis for guided bus system design in the UK. Based on experience from the systems in operation in Essen and Adelaide, it describes the basic values and required dimensions for the guideway and infrastructure. This document is the primary source used in preparation of this *Guided busway design handbook*.

8) WOOD, C (1998)

Bus stop innovation: A comparison of UK trials ***The European Transport Conference*****,** ***Proceedings of Seminar J: Traffic Management and Road Safety*****. Association for European Transport, London. www.cilt.dial.pipex.com/comparison.htm**

This paper describes the development of bus and bus stop design in order to make the transport system accessible to the elderly, disabled and mobility impaired. A number of trial schemes around the UK are described with five examples: Birmingham, Liverpool, London. Northampton and Norwich. The paper looks at both vehicle innovation and developments in bus stop design such as hydraulic ramps and kerb/platform heights.

The paper describes the use of guided bus technology to allow vehicles to 'dock' with the kerb, i.e. achieve the correct alignment and guarantee level boarding.

The trial in Northampton using kerb guided docking stops is described[1]; a guide wheel is fitted to the nearside front axle and runs against the 180 mm upstand/kerb at the platform edge. This system has been found to be effective where the stop has a straight kerb of 8 to 12 metres in length. Problems have been encountered with the guide wheel catching on kerbs 140 mm to 150 mm in height. The vehicle manufacturer, Volvo Bus, claims it is possible to position the bus in such a way that the horizontal gap between vehicle and kerb is 10 to 20 mm. The cost of adding the single guide wheel is estimated at £500 to £600 to the cost of the bus.

9) DE BRUIN D, DAMEN, A, POGROMSKY, A & VAN DEN BOSCH, P (2000)

Backstepping control for lateral guidance of all-wheel steered multiple articulated vehicles. ***Proceedings of 2000 IEE Intelligent Transportation Systems*****, pp. 95 - 100. IEEE, Piscataway, NJ.**

This paper looks at the dynamics of articulated and double-articulated buses equipped with all-wheel steering in Eindhoven in the Netherlands. To assist the driver, these buses are to be equipped with an automatic guidance system to steer the vehicle along the bus lanes. The behaviour of the vehicles entering curves of different radii at different speeds is modelled. The paper describes the simulation of a backstepping controller based on a non-linear dynamic vehicle model, for vehicles operating at both high and low speed.

10) BAIN, R (2002)

Kerb guided bus: Is this affordable LRT? ***Traffic Engineering & Control*** **Vol. 43, No. 2, pp. 51 - 55.**

Based on an interview by the author with Dr Bob Tebb, considered a major guided bus authority in the UK, as well as a review of existing guided bus schemes, the author seeks to investigate the viability of guided buses as affordable LRT. Guided buses, according to Dr Tebb, are a more attractive solution to urban traffic congestion than conventional busways not only because of their limited landtake but more so because of their advantages in self-enforcement and accessibility at stops. The author presents an overview of guided bus operations in Leeds (both the first phase opened in 1995 and the second opened in 2001) as well as of the then proposed Fastway scheme in Crawley. Of particular interest is the author's observation that success in schemes of this nature requires partnerships built on goodwill from all sides. The first phase of the Leeds busway was built under a Public Private Partnership (PPP) involving Leeds City Council, Metro, the Passenger Transport Executive and First Leeds, the bus operator. The partnership was subsequently extended to include another bus operator, Arriva. Similarly, the Fastway project near Crawley was carried forward by a consortium including West Sussex County Council, Surrey County Council, Crawley Borough Council, Reigate and Banstead Borough Council, BAA Gatwick, Metrobus and the Go Ahead Group. In addition, the author considered that, given the right financial conditions, private sector contributions can be harnessed for the benefit of bus infrastructure development even in a deregulated operating environment. Cost comparisons between Bus Rapid Transit and Light Rail Transit found that the capital cost associated with bus based systems was significantly less than for rail-based alternatives.

11) ROGERS, L H (2002)

O-Bahn Busway: Adelaide's experience. ***National Transportation Council (US) Transportation Research Boar*****,** ***Proceedings of 81st Annual Meeting*****, Washington, DC.**

Written 16 years after the opening of phase one of the O-Bahn Busway in Adelaide, this paper attempts to assess the Adelaide experience for its potential as a model for the introduction of similar scheme elsewhere. It concludes that the O-Bahn system is safe, popular and effective but questions why it was never exported to other cities worldwide or even extended in South Australia.

An interesting political backdrop to the project is offered, which suggests that it was driven by a marriage of political and commercial needs rather than the best technological solution. The main aim of the project was to increase accessibility to the Central Business District from the city's northeast districts with higher speeds, fewer stops and quicker time, while reducing local congestion by diverting buses onto the guideway.

The guideway was constructed of 12 metres long precast elements. For straight runs and large horizontal radii, the guide kerbs were concrete but for small radii, guide rails were made of steel. The design speed for the guideway was 100 km/h except in the unguided sections near bus stations where it was reduced to 60 km/h. No significant drop in car usage was noticed but this was attributed to a lack of

1 This system has also been installed on the Fastway Project, Crawley.

car spaces at stations. There was a positive uptake in usage of the pedestrian pathways and bike paths built along the guideway. Ride quality was found to be superior to street pavements, in part because of high-quality engineered trackway components. Excluding rolling stock, the O-Bahn busway was found to be more expensive than a standard busway but significantly cheaper than light rail.

The paper ends by asking why the O-Bahn team was disbanded after the Adelaide experience and why there has been no subsequent interest in the technology elsewhere in the world.

12) COLLINS, T (2003)

Concrete keeps guided bus system on track.
***Concrete*, Vol. 37, No. 8, pp. 52 – 53.**

Written by the Fastway Project Director, this paper gives a brief overview of the Fastway project followed by a description of the construction process for the guided busway. This project was devised to combat increasing congestion in and around Gatwick Airport. It is a bus improvement scheme that involves the use of real time passenger information, global positioning system based automatic vehicle location, that grants priority to buses at junctions and on stretches of guided busway. The concrete guideway was slip formed as one complete section, enabling the team to produce 650 metres of guideway in 10 days. The team worked to strict tolerances of +3 mm, -0 mm between the two kerb faces and used a 300 mm layer of recycled concrete as subbase.

13) SMILER, S.

***Special feature on kerb guided buses* (O-Bahn)**
http://www.garden.force9.co.uk/OBahn.htm

Based on several articles written by the author for bus magazines, this site provides a comprehensive summary of guided bus technology across the globe today. It briefly describes all attempts at guided bus systems then gives a more detailed description of guided bus development in the UK.

The origins of O-Bahn technology are traced back to the Essen experiment, where 10 metre long L-shaped precast concrete panels were laid to form the guideway, supported every 1.35 metres by sleepers, to which they were fixed by means of fishplates and clamps. Where buses and trams shared the same guideway, wooden beams were used in place of concrete sections with rails attached. In addition to being fitted with front guide wheels, the Essen buses were also fitted with touch-wheels on the centre and rear wheels which were not in continuous contact with the kerbs but were needed for curves. The Essen system is still in operation apart from sections that were underground. These were discontinued as the experimental wooden track became life-expired and there was no funding to replace it.

Mention is also made of the Mannheim system in Germany which opened in 1992 and is a 800 metre long guideway that allows buses to bypass traffic congestion leading up to a busy signalised junction. The track is wooden and consists of tighter curves than those used in Essen. The result is a bouncing sensation as the bus hits the guide rails, though because the guideway is so short, ride comfort is not severely affected.

In addition, mention is made of Japanese experimentation with guided bus technology. Two systems are being researched. The first is similar to the O-Bahn system except that the kerbs are wider apart so that both sides of the bus do not make contact at the same time. The buses are fitted with stabilisers to improve straight travel stability. The second system features fully automated driverless operation when in guided mode. It uses electric buses fitted with storage batteries for normal street running. Interestingly, when in guided mode, power is collected by means of a terminal which extends sideways from the rear of the vehicle and contacts a power rail located alongside the track just above the guideway, providing an alternative to overhead cables.

The paper then gives a more detailed description of guided bus developments in the UK, beginning with the abandoned West Midlands experiment. Focus is then turned to a 200 metre guideway opened in January 1995 in Kesgrave, a village east of Ipswich. The guideway consists of Essen-style pre-fabricated reinforced concrete panels, with steel channel galvanised traps at each end of the guideway to deter trespassing vehicles. In addition, the guideway is designed for narrow gauge buses, 2.4 metres wide, and cannot accommodate standard buses. The vehicles used are British-built Dennis Darts with Plaxton Pointer bodies.

The Leeds busway is described as a ‘congestion buster’ with short sections of one-way track at approaches to traffic light controlled junctions with transponders to trigger the lights. Unlike that used in Ipswich, the track consists of a reinforced concrete roadway and separate extra deep kerbstones acting as walls for the buses’ guide wheels. Initially services were provided by a dedicated fleet of Scania N113 buses fitted with Alexander bodywork. An articulated Alexander-bodied Mercedes-Benz 0405G was subsequently obtained on loan.

On 31 January 2002, 2.3 km of guided busway was opened in Bradford as part of a Quality Bus Initiative that included new pedestrian crossings, footpaths and seats plus major landscaping.

Guided Busway
DESIGN HANDBOOK

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