Department for Transport

CPNI

Centre for the Protection of National Infrastructure

Traffic Advisory Leaflet 02/13

May 2013 (as amended October 2017)

Bollards and Pedestrian Movement

Bollards are a common design of Vehicle Security Barrier (VSB) that are required in certain locations to mitigate criminal or terrorist vehicle-borne threats. The latter is reduced by VSBs protecting people (from a vehicle as a weapon attack) and buildings (from a vehicle delivering a large explosive device) by enforcing stand-off. Bollard type VSBs provide a solution that resolves many common operational issues faced at busy transport interchanges. Further examples of VSBs can be found in Traffic Advisory Leaflet (TAL) 01/11 *Vehicle Security Barriers within the Streetscape*.

Observational surveys and research studies have been carried out under normal travel conditions to assess whether permanent bollard schemes affect pedestrian movement or give rise to additional health and safety concerns.

This TAL outlines the findings of these studies and provides guidance to inform the planning and design of bollard schemes installed for the purpose of hostile vehicle mitigation.

Information about the *Influence of Bollards on Pedestrian Evacuation Flow* is available in TAL 01/16.

Introduction

When considering the installation of bollards in the public realm, designers should take a holistic approach to ensure an appropriate level of physical protection is provided whilst minimising any negative impact on pedestrian movement.

To meet security requirements, bollards must be positioned to maximise blast stand-off distance, and spaced at a maximum air gap (between bollards) of 1,200mm. Additional considerations include meeting objectives for health and safety, site operation, cost and aesthetics.

Sites that experience high volumes of pedestrian use must accommodate movement safely, and at the required level of comfort and convenience. Many organisations take advantage of a variety of site assessment methods, including the use of pedestrian simulation software tools to integrate pedestrian movement analysis into their design process.

Findings from observation studies and literature reviews show that, under normal conditions, bollards spaced with air gaps of 1,200mm have a minor effect on pedestrian convenience, which includes making changes to body position or reducing speed for a short amount of time (less than a second). Under normal conditions pedestrian health and safety was not seen to be affected.

The study also shows that bollards have less effect on pedestrian movement (including collisions with other pedestrians, reductions in speed or detours from a preferred route) than other commonly recurring urban features such as retail kiosks or mobile newspaper vendors. Where pedestrian movement is affected, the influence of bollards can be seen in the behaviour of pedestrians located in the immediate space surrounding the bollard(s).

In using this guidance it should be noted that the design of a bollard scheme must achieve a balance between multiple operational and security requirements. Whilst it might not be possible to satisfy all considerations to the highest level, this leaflet will help the designer to develop a solution that meets the individual site needs to a manageable level.

Pedestrian movement

Pedestrian movement is affected by the following interrelated issues:

1. **Route Capacity** – the rate at which pedestrians can safely pass through a space during a defined period. The "flow" is a measure of the number of people passing a fixed point in a given time interval, measured in people per minute per metre (p/min/m). For a given width of path the flow is a function of the speed and density of the crowd, and the width of the path. "Unit flow" is a measure of "flow", which is independent of path width and is measured in people per minute per metre (p/min/m). Unit flow is used to assess whether the speed and density of pedestrian movement remains within acceptable levels. For design calculations, an upper limit for pedestrian flow is defined as 82 p/min/m (Department for Culture Media and Sport [DCMS] 2008).
2. **Comfort** – the amount of personal space available to pedestrians and the ability to move freely. Described in terms of pedestrian density which is measured in people per square metre (p/m^2), with the upper limit of pedestrian density defined as 40 people per $10m^2$ (DCMS 2008). The space per pedestrian, measured in square metres per person (m^2/p), is used to assess the "level of service" with multiple comfort scales defined (Transport for London [TfL] 2010, Fruin 1987).
3. **Convenience** – the ability of a person to follow their preferred route between two points at their favoured speed. "Desire lines" describe preferred routes through a space. Actual paths taken can be measured in terms of speed, journey duration and distance.
4. **Conflict** - a discrete event that alters the natural flow of movement. Conflicts can occur between pedestrians and the physical environment, or between two or more pedestrians. Conflicts can include collisions or behaviours necessary to avoid a collision such as stopping or sudden changes of direction.

These issues and their components can be assessed and evaluated to investigate if, and how, pedestrian movement is influenced by the design of a physical environment that includes a bollard scheme.

Observations & findings

Bollards have been observed under normal travel conditions (including peak times) and pedestrian movement measured in relation to Route Capacity, Comfort, Convenience and Conflict.

Observation studies were carried out at nine sites including some of London's busiest railway terminals, interchanges and a sports stadium.

Where possible, studies took place at locations where new bollard schemes were proposed to allow a before and after comparison to be made.

A range of bollard types were studied ranging from 900–1,100mm in height, and 100–300mm in width. Bollards observed in these studies were smooth edged, stainless or painted steel.

Various bollard configurations were observed including linear and semi-circular arrangements. At all transport sites bollards were spaced at 1,200mm air gaps.

Studies also considered other everyday public realm features such as newspaper vendors, retail kiosks and building entrances.

The following pages describe the findings.

Route Capacity

Flow

Under normal travel conditions, pedestrian flows were seen to be concentrated at specific parts of an entrance/exit space. In all observations it could be seen that areas in alignment with wider pedestrian flows recorded higher levels of use. It was found that despite the uneven distribution of movement and the presence of bollards, flows across an exit were not adversely affected even during peak times.

Flow behaviour

Where bollards were arranged in straight lines perpendicular to the direction of movement, there was very little divergence from desire lines. Pedestrians were able to deal with bollards by raising their hand to avoid making contact, or if necessary by twisting to fit through the air gap between bollards at the same time as another pedestrian.

When bollards were arranged in straight lines parallel to movement (such as along a kerb edge), pedestrians were seen to react more significantly. Instead of repeatedly raising their hand to avoid multiple bollards, pedestrians changed path to give a wider margin of avoidance.

Comfort

Density

Under normal travel conditions, the highest pedestrian densities were recorded in locations that formed part of wider pedestrian desire lines. This indicates that the configuration of the surrounding urban environment has a greater influence on typical pedestrian densities than the presence of bollards.

Across all study locations the highest observed pedestrian densities remained within recommended maximum limits.

Route choice

Features such as building entrances, pedestrian crossings and underground stations (in one case 400m away) were seen to have a greater effect on pedestrian speed and level of comfort than the presence of bollards.

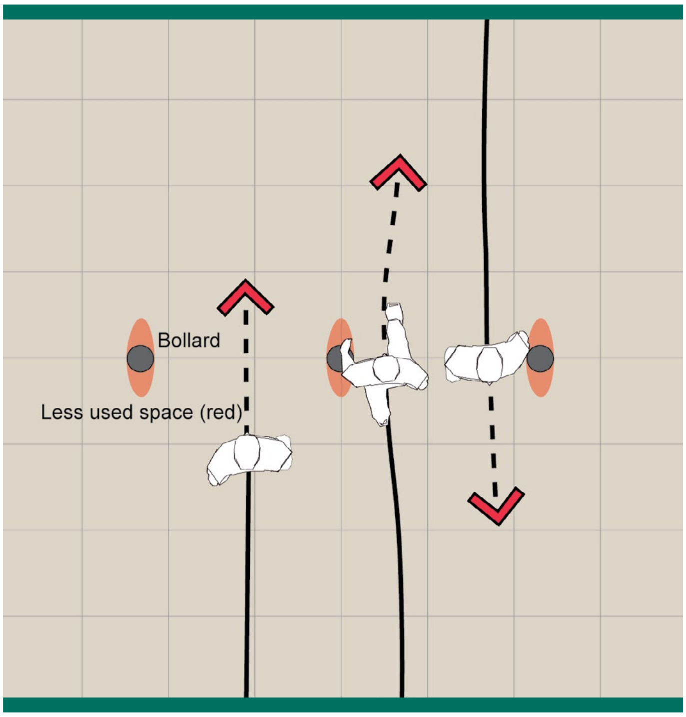

Figure 1: Pedestrians were observed to make tiny adjustments (such as reaching over a bollard) when moving through bollard lines positioned perpendicular to movement.

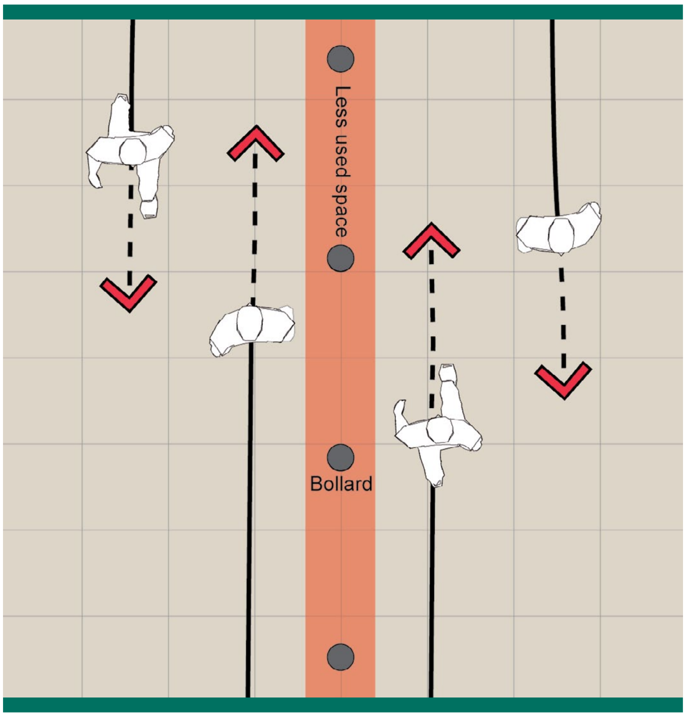

Figure 2: When bollards were placed parallel to movement, pedestrians were observed to avoid walking in the spaces between bollards and leave a more noticeable stand-off distance.

Convenience

Speed

Existing literature shows that the speed of pedestrians in unidirectional flows reduces as crowd density increases above 1 p/m^2 (Fruin 1987). In the case of a crowd exiting a sports stadium where bollards were installed, the relationships between speed and density were observed to be consistent with this research.

In spaces where multi-directional flows meet, the relationship between speed and density was more complex. In some cases, the interactions between flows resulted in larger reductions in average speed than could be accounted for by density. It was observed that the average walking speed of pedestrians who passed through bollards was sometimes higher than those that did not, even at comparable densities in the same location.

Way-finding

The presence of permanent bollards was not observed to change wider scale pedestrian desire lines.

Conflict

Pedestrian conflicts

More conflicts were observed to take place where a combination of certain flow conditions and poor design of the physical environment were present:

- Multiple strong flows meet or cross (see Figure 3);
- Restricted visibility between flows reduces time for negotiation between pedestrians and adjustment of speed and direction (see Figure 4);
- Limited space increases density, particularly where multiple flows interact;
- Stationary pedestrian activity such as localised queuing or waiting occurs.

Introducing bollards into environments where a combination of these conditions occurs could increase the likelihood of conflict.

Pedestrian crossings

Bollard arrangements that passed through pedestrian crossings were not observed to affect crossing behaviour. Formal and informal crossings continued to take place, and no incidents were observed where pedestrians were delayed by the presence of a bollard.

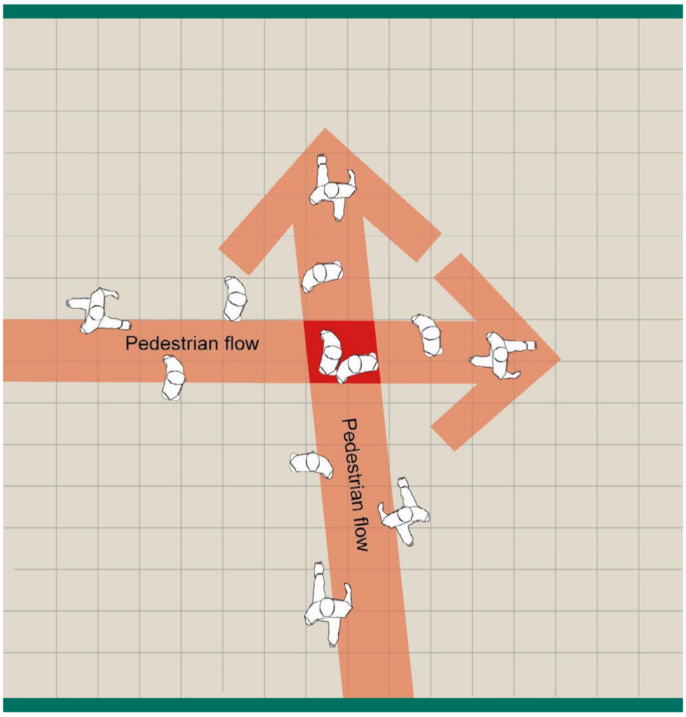

Figure 3: Conflicts were observed to occur in locations where strong flows cross.

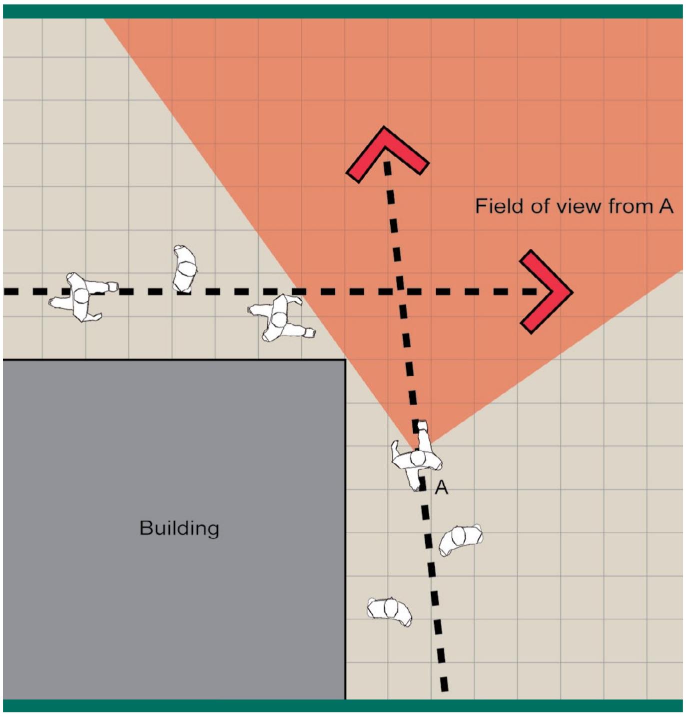

Figure 4: Conflicts were observed to occur in locations where visibility between flows is restricted.

Summary of findings

At all observed locations and under normal travel conditions, the presence of bollards did not reduce the route capacity or comfort to a level where pedestrians avoided using a particular route.

The design of entrance/exit environments, distribution of destinations in the surrounding urban environment, and the resulting pedestrian desire lines means that even in peak periods, observed locations remained within recommended upper limits for pedestrian density and flows were not significantly affected.

Bollards influence individual pedestrian behaviour, however the effects are subtle and can be difficult to identify or measure. Pedestrians were observed to avoid conflicts by pausing for a fraction of a second or twisting at the hips or shoulders to pass between bollards at the same time as other pedestrians. Whilst these adjustments maintained pedestrian speed and minimised any reduction in convenience for the individual, such adjustments can have a cumulative effect on the following crowd.

As security requirements mean that bollards should be located externally in arrangements that maximise blast stand-off distance, positioning of bollards in areas operating close to acceptable limits of pedestrian movement should therefore be avoided. However, detailed study of pedestrian movements is likely to be required in complex situations.

Bollards and the design process

Designing bollard arrangements with regard to pedestrian movement is critical for the successful operation of a site.

To make objective decisions on the design of the public realm, a number of tools and techniques can be used to develop an understanding of pedestrian flow conditions, such as:

- Conducting a desktop review of the site and context to identify pedestrian desire lines;
- Walking similar sites, before and after project completion to get a first-hand experience;
- Observing existing pedestrian flow characteristics where installations are proposed;
- Simulating pedestrian reaction to site modifications using appropriately validated computer software;
- Temporarily trialling proposed modifications at the actual site.

It is important that these methods are selected and applied in a manner appropriate to the project needs, and undertaken by a competent individual following recognised best practice. Particular attention should be given to the accurate simulation of pedestrian movement, where the simulation output can be sensitive to a number of set up parameters as well as the user objectives and their simulation expertise.

Guidance

The following recommendations aim to help designers plan the location and arrangement of bollards to meet security and operational objectives, while minimising any negative impact on Route Capacity, Comfort, Convenience or Conflict.

Where appropriate the following guidance should be considered:

- The total width of a bollard array (measured from the outermost bollard structures) should be greater than the exit width being protected.
- Locate bollards away from a site's natural pinch points (point A in Figure 5), such as narrow passageways, to maintain existing levels of service.
- Place bollards where they will maximise hostile vehicle stand-off but without forcing pedestrians to walk close to road edges.
- Identify pedestrian desire lines by considering influential factors beyond the boundary of the site, such as public transport stations, large office buildings or tourist destinations.
- Position bollards in lines that run perpendicular to pedestrian desire lines.
- Avoid placing bollards in areas where pedestrian conflicts are likely to occur, such as spaces where pedestrian desire lines overlap or areas of limited visibility (point B in Figure 5), especially along narrow passageways, or where stationary activity such as queuing occurs (point C in Figure 5).
- Consider height and visibility of bollards, particularly in low light conditions or during rush hour peaks where they can be obscured by a crowd.
- Specialist site assessment may be needed in high or complex flow conditions.

References

- Guide to safety at Sports Grounds: Fifth edition. DCMS (2008) http://www.tsoshop.co.uk/bookstore.asp?Action=Book&ProductId=0117020745
- Pedestrian Comfort Guidance for London, First edition. TfL (2010) http://www.tfl.gov.uk/assets/downloads/pedestrian-comfort-guidance-technical-guide.pdf
- Pedestrian Planning and Design, Revised edition. JJ Fruin (1987).

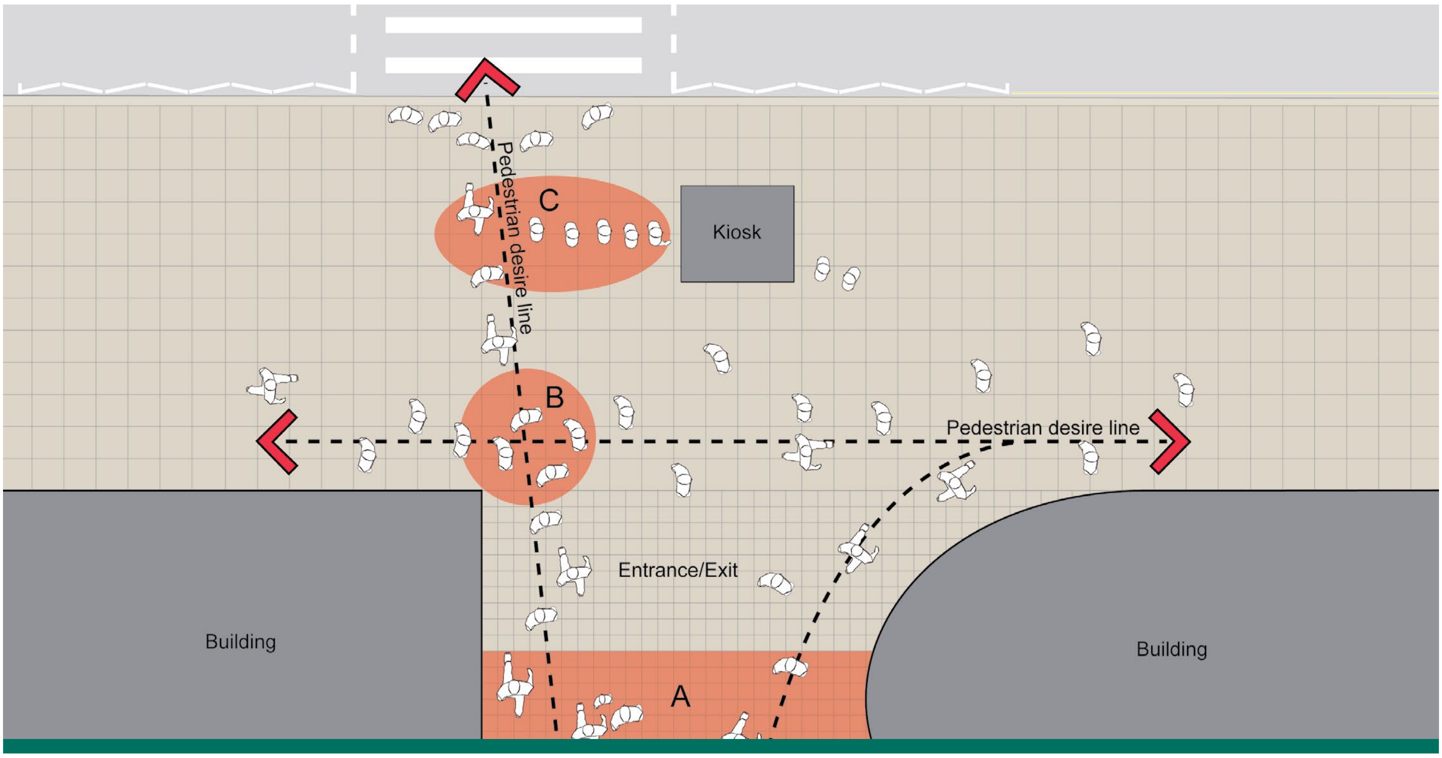

Figure 5: Issues for consideration when designing a bollard scheme.

Recommended further reading

- TAL 01/16, Influence of bollards on pedestrian evacuation flow. DfT/CPNI. https://www.gov.uk/government/publications/influence-of-bollards-on-pedestrian-evacuation-flow-tal-0116
- TAL 01/11, Vehicle Security Barriers within the Streetscape. DfT/CPNI. https://www.gov.uk/government/publications/vehicle-security-barriers-within-the-streetscape
- IWA 14-2: Vehicle security barriers. Application. ISO. https://shop.bsigroup.com/ProductDetail/?pid=000000000030289980
- PAS 69: Guidance for the selection, installation and use of vehicle security barriers. BSI. https://shop.bsigroup.com/ProductDetail/?pid=000000000030274479
- PAS 170-1: Vehicle security barriers. Low speed impact testing. Trolley impact test method for bollards. BSI. https://shop.bsigroup.com/ProductDetail/?pid=000000000030290261
- Integrated Security: A Public Realm Design Guide for Hostile Vehicle Mitigation – 2nd Edition. CPNI. https://www.cpni.gov.uk/hostile-vehicle-mitigation
- Security in Design of Stations (SIDOS) Guide. DfT/CPNI/British Transport Police. http://www.gov.uk/government/publications/security-in-design-of-stations-sidos-guide
- Inclusive Mobility – a guide to best practice on access to pedestrian and transport infrastructure. DfT. https://www.gov.uk/government/publications/inclusive-mobility

Contact details

Protective security advice and a range of appropriately resilient vehicle security barriers or structural elements for embedding in the public realm are available from specialists at the UK Government's Centre for the Protection of National Infrastructure (CPNI) or via the local police Counter Terrorism Security Adviser (CTSA).

Centre for the Protection of National Infrastructure (CPNI)
http://www.cpni.gov.uk

Department for Transport
https://www.gov.uk/government/groups/land-transport-security-division
Email: landsecurity@dft.gsi.gov.uk

Home Office
http://www.gov.uk/government/organisations/home-office

National Counter Terrorism Security Office (NaCTSO)
http://www.gov.uk/government/organisations/national-counter-terrorism-security-office

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The DfT sponsors a wide range of research into traffic management issues. The results published in Traffic Advisory Leaflets are applicable to England, Wales and Scotland. Attention is drawn to variations in statutory provisions or administrative practices between the countries. Within England, enquiries should be made to: Traffic Division, Department for Transport, 3/27 Great Minster House, 33 Horseferry Road, London, SW1P 4DR. Telephone 020 7944 2974. E-mail: Traffic.Signs@dft.gsi.gov.uk

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