London Bus Lane and Bus Stop Construction Guidance
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London Technical Advisors Group

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1. Introduction

Both single and double deck buses introduce heavy loads into the pavement as they travel in a channelized bus lane at a slow speed and even greater point loading as they stop at a bus stop always at exactly the same location.

Asphalt surfacing is particularly prone to deformation in these circumstances. Flexibly laid concrete blocks can be pushed laterally and the sand beneath them displaced by the channelled traffic and by the vibrations when the vehicle is stopped.

The life of the pavement is very dependent on the number of buses and the pavement design.

Many bus lanes and bus stops are introduced into an existing pavement. Depending upon the surface type and finished levels, the new surface can strengthen the road so that structural improvement is unnecessary however each installation should consider this aspect.

Frequently the selection of the surface is made on aesthetic grounds and this guidance is intended to assist with the selection process giving some estimate of the life of the pavement options under the load of the numerous buses typical of a town centre. If the number is significantly less, the life will be increased. This presumes that the structural strength of the pavement beneath the surfacing layer is adequate.

2. Traffic and buses

2.1 Traffic Volume

It is necessary to make an estimate of how many buses will use a particular bus stop and/or bus lane per typical day. This can be obtained from bus timetables. Great precision is not necessary.

The average daily traffic volume can then be multiplied by 365 to get an annual figure, which can then be multiplied by the anticipated life in years before replacement.

The life to replacement for structural purposes is normally taken as 20 years or 40 years.

Replacement of an asphalt surface is normally taken to be when the surface has rutted (deformed) by 20mm. However this is may be unacceptable in an urban situation for a bus stop or bus lane. This degree of rutting is particularly problematic for concrete block paving if such a rut could lead to water ponding, it being forced into pavement by tyres and thus cause rapid failure. The acceptable level of rutting is dependent on the longitudinal gradient of the site to allow water to drain.

For rigid sett paving, the mode of failure is typically from cracking of the jointing mortar caused by the vertical deflection of the pavement under traffic loads. This can be caused by an adequate design but the value below is an estimate based upon fatigue failure of the fine concrete bedding.

The life to replacement for surfacing depends upon the type of surfacing as given below.

Further information on these Surface Types is given in Section 3.

Surface Type	Estimate of life to replacement or extensive maintenance (yrs.)
Asphalt i.e. Thin Surfacing, Macadam, SMA, HRA.	15
Concrete Blocks and clay pavers on sand (flexible lay) Herringbone pattern	25
Stone setts on fine concrete (rigid lay)	30
Concrete pavement (lightly reinforced) (rigid)	40

NOTE: It is presumed that the surface types are correctly installed in accordance with British Standards and/or the Specification for Highway Works on a sound foundation.

Under normal highway design it is assumed that the volume of traffic will increase over the years and a growth factor is used to take account of this. For a 20yr design the factor is 1.09, for a 30yr. design the factor is 1.14 and 40yr design the factor is 1.19

2.2 Traffic Load

Current national traffic guidance states that a bus has 2.6 standard axles. A standard axle exerts a force of approximately 8 tonnes on the road on a tyre patch approximately 200mm in diameter.

Where traffic is slow moving and/or channelled this traffic load has to be increased by a factor of 3.

Flexible designs for asphalt, concrete and clay pavers and in-situ concrete pavement use the total traffic load over the selected design period in millions of standard axles (msa)

This is obtained by multiplying the annual traffic volume by 2.6 to get msa, by the growth factor for the design life, and by 3 for channelization or slow traffic. For flexible pavement, if the failure criterion is less than 20mm, the msa should be increased by 20 divided by the selected rut depth e.g. by 4 for a 5 mm rut depth failure criterion

Example. For flexible laid concrete block and clay paving and asphalt

DATA: 200 buses a day for a 20yr design life. The site is very flat so a 5mm max rut depth has been selected. The calculation is as follows

$(200 \times 2.6 \times 365 \times 20 \times 1.09 \times 3 \times 20/5) /10^6 = 49.6$msa.

NB BS 7533-1 gives the maximum traffic level as 12msa. This is undoubted conservative, but this calculation shows that for these criteria concrete blocks may not be suitable. With a suitable site so that 20mm rut depth can be adopted the traffic load = 12 msa which is just within the BS 7633-1 criteria.

Rigid designs for setts on fine concrete are carried out in accordance with BS 7533-10. This is based upon the number of standard axles per day not the millions of standard axles over a design life. No factor required rutting as rutting is not a failure mode.

DATA: 200 buses a day is 200 x 2.6 = 520 commercial vehicles per day. This is a Site Category I in accordance with BS 7533-10:2010 Table 1.

Rigid designs for lightly reinforced concrete paving are carried out in accordance with Highways Agency HD 26/01 Pavement Design Figure 2.4 for a 40yr design life

Example: For rigid design

DATA: 200 buses a day for a 40yr design life the calculation is as follows. No factor required rutting as rutting is not a failure mode

Calculation: $200 \times 2.6 \times 365 \times 40 \times 1.19 \times 3) /10^6 = 27$ msa.

3. Structural Design Paving support

Structural Design for the foundation and surface layers for new works is carried in accordance with the references in the table below

Surface Type	Structural Design Reference
Asphalt i.e. Thin Surfacing, Macadam, SMA. HRA	HD 25/94 Fig 3.1and HD 26/01 Fig 2.2
Concrete Blocks and clay pavers on sand (flexible lay)	BS 7533-1
Stone setts on fine concrete (rigid lay)	BS 7533-10
Concrete pavement (lightly reinforced) (rigid)	HD 25/94 Fig 3.1and HD 26/01 Fig 2.4

For overlay or inlay to an existing carriageway, structural design for the foundation/support layers requires an evaluation of the strength of the existing road.

The component overlay method described in BS 7533-1, based upon equivalence factors, is relatively simple to use and has proved to be successful since its introduction in 1999. In principle all the materials included in the existing road are related back to macadam with a value of unity. A similar exercise can be done on the foundation layers specified in the relevant Standards and any shortfall made up in pavement quality concrete (min 100mm) or stiff asphalt.

Given the existing standard kerb heights, the addition of the paving to an existing road and reduction in kerb heights, will nearly always provide enough additional strengthening. NB 25mm kerb heights have proved problematic to visually impaired pedestrians unless there is a clear surface type/colour difference on either side

4. Materials' selection

4.1 Asphalt

Asphalt is a mixture of aggregate and bitumen. Bitumen is a viscous liquid that can become very runny in summer so that the material deforms under load. Surfacing can also scuff out under power steering. Asphalt with very little bitumen, such as some macadam mixtures, are not very durable. To design an asphalt surface course and the underlying binder course requires skilled mix design and binder grade selection. All asphalt must also be specified in accordance with the properties and test methods listed in the relevant EN 13108 series of European Standards.

Generally a 10mm Stone Mastic Asphalt to EN 13108-5 (SMA 10 surf) using a polymer modified binder to give a wheel tracking rate, a measure of rut resistance, of Class 2 in PD 6689 Table D.2, is suitable for up to about 100 buses per day and with half the values for Class 2, for greater than this number. A thickness of 35mm has been found most suitable.

A number of proprietary surface courses e.g. 'Supreme' from Aggregate Industries are also available.

With a 10mm red aggregate and appropriate red pigment SMA can have a bright red colour, as used for example at Buckingham Palace. It is also available in black.

An Asphalt Concrete (macadam) binder course to EN 13108-1 (AC20 HDM bin) has been found suitable with 40/60 grade binder for up to about 100 buses per day. For greater than this number the specification should be adopted of polymer modified binder or 30/45 grade bitumen binder to give a wheel tracking rate of Class 2 in PD 6689 Table B.4 Class 2

Bus lanes and bus stops must be machine laid in accordance with BS 594987.

Some deformation of the SMA surfacing will still occur and the UK highways' failure criterion is a 20mm rut. On very flat sites and in areas with high pedestrian use this may be deemed unacceptable in wet weather and an alternative surface may be necessary

4.2 Grouted macadam

Grouted macadam is too slippery for use on normal highways, but especially if the top surface of the grout is removed, a very abrasion resistant, impermeable, fuel resistant and deformation resistant safe surface can be produced that is ideal in this application. The aggregate can be red or pale grey as can the grout. BBA HAPAS Approved products are available that have been in service for over 25 years.

It is normally laid 40mm thick and therefore will require an asphalt base of suitable thickness usually 60mm, but up to 100mm is possible. An AC 20 HMB 30/45 or polymer modified binder course is recommended as above, to ensure adequate deformation resistance.

4.3 Surface treatments

If a more decorative finish than red asphalt is required, the black SMA can have a surface treatment applied.

Suitable surface treatments include cold lay MMA High Friction Surfacing, which is available in buff or pigmented, or a similar product where the aggregate is incorporated within the binder. Both of these systems have been used by TfL for the blue cycleways. The latter is smoother than the HFS. MMA is less prone to damaging the underlying asphalt than epoxy binder, and is much more durable than hot mix products. At least a 10 year life is possible.

4.4 Clear Binder Asphalt

These products are not recommended for such a heavily trafficked area.

4.5 Concrete and Clay pavers

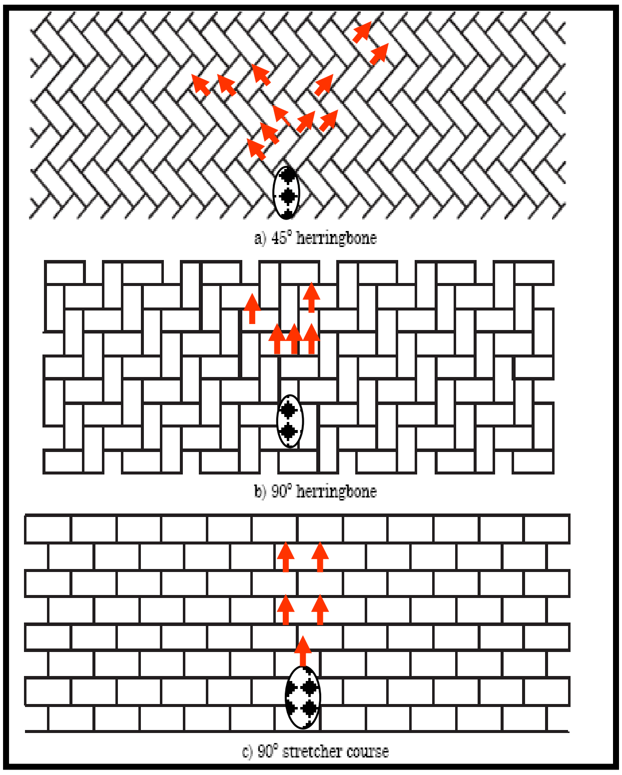
Clay pavers are generally inadequately skid resistant for bus lanes and bus stops though they may be suitable of normal carriageways e.g. speed tables, if the polished skid resistance value [c.f. BS 7932] exceeds 45.

4.6 Concrete block paving (flexible laid)

In order to achieve the life in the table above, the blocks must be laid on the minimum thickness of Cat 1A sand in herringbone pattern and the sand must be drained.

The sand layer is the weakest link in the structure. It is important therefore that is of a consistent and minimum thickness. The value of 30mm is selected to ensure that, with the correct tolerances, the minimum thickness will pertain everywhere. Excessive sand thickness greatly weakens the pavement, leading to rutting and pushing

Cat 1A sand, as required by BS 7533-3:2009 Annex D, is special hard sand that is free draining; a test certificate of compliance should be sought.



Stretcher bond is less effective than herringbone pattern for spreading horizontal stresses, as illustrated in the diagram. As a result they are much more prone to pushing under uni-directional traffic, and particularly at bus stops. This action can, to an extent, be reduced by laying the blocks at 45° to the loading.

Picture 1 Tegula blocks in-service

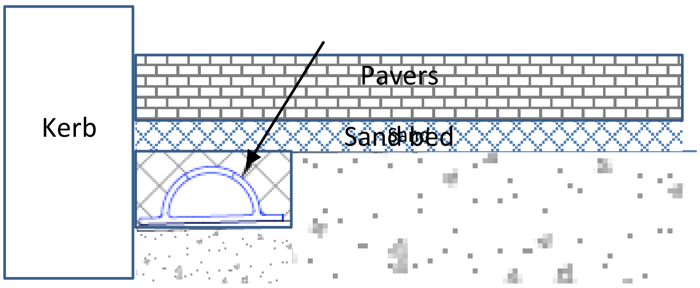
Tegula blocks from Marshalls as shown in Picture 1 are frequently specified for bus stops. They can only be laid in stretcher bond. This seriously limits the number of buses that can be accommodated without pushing or rutting, to possibly less than 50 per day.

Once rutting or shoving occurs and the blocks move, the joints open, water can more readily enter the pavement structure and the sand bed support is weakened. Such movements should not normally lead to a need to relay the blocks for a period of 8+ years, if the sand bed is the correct quality of sand for the traffic intensity and the sand bed is prevented from becoming waterlogged, as recommended in BS 7533-3:2009 Annex D.

Even when properly installed, a small percentage of the surface water penetrates the joints, especially in the early months, until they clog with detritus. This may well be such a low volume of water that the asphalt base beneath can provide an outfall. However if the joints open in service, large quantities of water will enter the sand layer and unless a positive drainage path is provided, the layer will become waterlogged. Thus instead of aggregate interlock spreading the load, the pressure is transmitted to the water. This water carries the sand away from the wheel paths, exude it onto the pavement surface frpm whence it is swept up; rapid failure is then inevitable

The mechanism of failure is commonplace where blocks are inserted into an existing asphalt surface as the milled out area forms a sump.

The solution is straight forward - provide a clear drainage path to an outfall. This is normally done by creating or using a weephole in the gully grating frame or creating one in the frame bedding. The hole is normally covered with a geotextile or similar to prevent sand loss. If there is no gully at hand or the gully spacing exceeds 20m and the pavement is flat, a longitudinal drain inserted adjacent to the kerb on the low side(s) ensures any water can get away. Typical detail using 'Dri-deck' is shown below.



Dri-deck steel drain in slot in the surface along edge preferably filled with coarse sand or lightly compacted open textured macadam to prevent sand migration. Outfall to nearest gully by cutting a hole in the frame

In addition, especially on a flat site, it is possible that the permitted tolerances will create hollows in the concrete base that fill with water, which then lubricates and weakens the sand bed. It is for that reason that minimum falls are recommended in BS 7533-3 which states in Paragraph 5.1.1 'A minimum longitudinal fall of 1.25 % and a minimum cross fall of 2.5 % are recommended for carriageways using paving units as a channel'. If for example the Dri-deck system is incorporated the standard says 'For carriageways using proprietary drainage systems, a 2.5 % cross fall is recommended with a longitudinal fall as recommended by the supplier'.

Where a kerb edge restraint is trafficked it is important that the kerb bedding is at least as strong as any carriageway concrete. This means that the bedding mortar in-situ, must have strength of at least 25 MPa. It must also have some elasticity to cope with the inevitable deflections and **i**mpact loadings. This will not be achieved with standard 1:3 cement: sand mortar. Proprietary mortar complying with BS 7533-7 Annex C, as used for rigid paving, is suitable. Standard details are provided in BS 7533 Part 3 and Part 7

4.7 Concrete block paving [rigid lay]

Tegula and other concrete blocks and stone setts, laid on a fine concrete bed and jointed with mortar as described in BS 7533-7, have performed well on a number of heavily trafficked situations. The finished appearance is somewhat rustic and similar to old sett paving as shown in Picture 2

Picture 2 Tegula blocks laid as rigid paving damaged kerb edge restraint

This method of laying is out with the British Standard, as the blocks are too thin for the structural paving design methodology. It is akin to the tiled floors in internal paved areas.

A successful installation depends on the strong adhesive bond between the pavers and the structural layer below, be it concrete or asphalt, and good adhesion in the completely filled joints between the strong mortar and the pavers. This is possible with the plastic mix fine concrete bed and jointing mortar as specified in BS 7533-7, but it does require experienced competent installers and good workmanship in accordance with NHSS 30.

4.8 Stone sett paving [rigid lay]

There have been many successful installations of stone sett paving as part of environmental improvement hard landscaping with the sett dimensions and design carried out in accordance with BS 7533-10

Pale coloured stone however rapidly becomes unsightly as a result of tyre rubber deposits and lubricant droppings. The skid resistance should be >45 measured by BS 7932, this can affect the surface finish. There should be a difference in colour between the pedestrian areas and bus lane for the visually impaired or tactile paving used

Picture 3 Stone Setts laid as rigid paving damaged kerb edge restraint

However a successful installation depends on the strong adhesive bond between the pavers and the structural layer below, be it concrete or asphalt, and good adhesion in the completely filled joints between the strong mortar and the pavers.

This is possible with the plastic mix fine concrete bed and jointing mortar specified in BS 7533-7, but it does require experienced competent installers and good workmanship in accordance with NHSS 30. The edge restraint must be adequately strong as detailed in BS 7533 -7 Annex D.

The failure in the photograph above was as a result of inadequacies for both these requirements.

4.9 Concrete

An in-situ pavement quality concrete slab with brushed texture finish is widely used in this application. The surface is durable and safe. The surface finish is not appealing aesthetically.

The widespread use of fibres as anti-crack reinforcement makes installation speedier but at least 7days is required before heavy traffic can use the surface.

If constructed properly with due attention to detailing at ironwork and corners of slabs, a 40 year life is forecast.

5. Conclusions

The installation of bus stops and bus lanes into an existing network requires consideration of the underlying structure and the appropriate material for the surfacing

If bus usage is low, this is not a problem for conventional highway surfacing materials.   However as bus usage rises towards 100 buses per day and above, increasing consideration must be given to the materials selected and specified and above all to the detailing and quality of installation.

In order to improve the latter a new National Highway Sector Scheme 30 has been created for concrete, clay and stone paving to ensure that installers and their operatives are trained and competent. An existing NHSS 16 is already in place for asphalt.