UK FOOTWAY DESIGN GUIDANCE

M.H. Burtwell, V. Atkinson
Transport Research Laboratory
Crowthorne, Berkshire, England

L. Hawker
Highways Agency
London, England

Summary

Footway surfacing in the UK consists of either bituminous materials, concrete blocks or Pre-Cast Concrete flags. In 1993 a research project was initiated by the UK Highways Agency and the County Surveyors' Society to improve design methods. Three design categories were established; pedestrian use only, domestic or light vehicle use only and heavy vehicle use based on existing UK recommendations for bituminous, block and flag constructions. Accelerated testing trials were undertaken at TRL's Pavement Testing Facility (PTF) to validate the designs for footways subjected to occasional heavy vehicle overrun.

Construction thicknesses were based on a CBR 2.5 per cent subgrade, in the PTF and on 50,000 standard axles cumulative traffic. Four constructions were built and tested; 90mm bituminous, 105mm bituminous, 80mm blocks and 60mm flags. Measurements of profile and rut development were made at 10,000 standard axles and post-trafficking. A visual assessment of cracking, trips, spalling of blocks or flags, loss of jointing sand, opening of joints and kerb separation were made. Premature failure of the block and flagged footways resulted in a post-traffic investigation and analytical predictions of subgrade strain and deformation to determine the exact failure mechanism.

Introduction

In the UK footway design and construction has been largely based on custom and experience and this has, in most cases, proved to be satisfactory. As roads become more congested vehicle overrun and parking on footways has become more common and such methods of constructing footways are no longer adequate. Currently footway surfacing in the UK consists of either bituminous materials, concrete blocks or Pre-Cast Concrete flags. The choice is influenced by initial cost, ease of reinstatement after statutory undertakers' service repairs and installation, environmental merits and the ability to sustain vehicle overrun.

Vehicle overrun is one of the major causes of footway failure. Overrun causes large flags to break, other surfaces to become rutted and the footway becomes hazardous for pedestrians to walk on. Public dissatisfaction with the condition of footways is increasing. A reduction in the frequency of pedestrian injury accidents [1] and their consequential costs is therefore desirable. The need to reduce accident risk reinforces the requirement for changes in maintenance practice and the adoption of new methods of design and construction to provide

safe and durable footways.

Research Programme

Research in the UK has focused on developing improved methods of footway design and the provision of better design guidance. Views from UK practising highway engineers were sought and existing UK maintenance policy reviewed. It became clear that to be effective the required design methods needed to take account of traffic loading, foundation strengths and construction type. UK design guidance is being categorised based on an assessment of the risk of traffic loading of the footway.

The number of design categories required was determined together with the necessary input parameters for the design procedures defined. Selected designs were compared by means of Falling Weight Deflectometer (FWD) measurements and stress/strain analysis. Accelerated tests on bituminous, block and flag footway constructions were undertaken at TRL's Pavement Testing Facility (PTF) to validate the selected designs for footways subjected to occasional overrun by heavy vehicles. The design methods tested were the UK's Road Note 29 (RN29) [2] for bituminous construction, the current UK Interpave guide [3] for blocks and the National Paving and Kerbing Association's (NPKA) guide [4] for flags. As a result of these investigations recommendations for suitable designs for new footway constructions in various environments have been made.

Failure Mechanisms

Deterioration and failure of footways are rarely due to pedestrian usage. Footways assessed using well established procedures showed that deterioration can be attributed to the causes described in Table 1.

Table 1 Causes of deterioration

Ref No.	Cause of deterioration	Features
1	Poor specification and design	Inadequate thickness, inadequate edge restraint, rutting, depressions, cracking of flags or bituminous surfacing, gaps on modular surfaces, inadequate drainage, insufficient frost protection, ingress of water
2	Faulty construction	Incorrect materials or incorrect methods, inadequate layer thickness, poor surface regularity, inadequate compaction, lack of performance specification for compaction
3	Abuse eg overrun, undertakers' works	HGV overrun, trench settlement, rutting, cracking, loss of interlock on modular surfaces
4	Weathering	Ageing of bitumen, loss of aggregate, fretting, ravelling, potholes, degradation of bituminous materials, clay shrinkage, subsidence, longitudinal cracking
5	Damage by vegetation	Weeds and tree roots, heave, trips
6	Fair wear and tear	Loss of surface texture, fretting
7	User perceived failure	Unacceptable surface appearance eg spalling, cracking, poorly matched materials

New Footway Design Categories

Three design categories have been established; pedestrian use only, domestic or light vehicle use only and heavy vehicle use. The placement of a footway into a design category will depend on the level of pedestrian usage, its physical situation and the risk of vehicle overrun.

Designs for "Pedestrian only" Footways

This design should only be adopted when there is no risk of vehicle overrun, including footways used by vehicles such as mechanised street sweepers, or where the consequences of overrun are deemed unimportant. Highway engineers have been building footways of this type for many years and a sensible design to adopt is that which has been proven in practice. The consensus of opinion in the UK favoured the adoption of 20mm wearing course, 40mm basecourse and 100mm sub-base for this category of footway.

Designs using flag and block footways in the UK generally keep the same 100mm of sub-base, although the minimum thickness recommended by Interpave is only 75mm.

Designs for Domestic Crossings or Light Vehicle Overrun

For this category the consensus is that design should use 20mm wearing course, 50mm base course and 150mm sub-base for a domestic vehicle crossing of bituminous construction.

These designs could also be used for light vehicle overrun situations. Stress analysis of these constructions shows that they have a potential life expectancy of at least 30 years under light vehicle loading but repeated loading by heavy vehicles would greatly reduce the life. On a very weak subgrade very few heavy vehicle loadings would be needed to cause failure.

The bitumen macadam layer could be replaced by concrete blocks and bedding sand or small element flags, 450mm x 450mm or less. Block designs would be 60mm or 65mm blocks, 30mm compacted thickness bedding sand and 150mm Type 1 sub-base. Flag designs would be 60mm or thicker flags, 25mm compacted thickness bedding sand and 150mm Type 1 sub-base.

Designs for Heavy Vehicle Overrun

This category does not include pedestrianised areas, which generally are subjected to a significant number of daily delivery vehicles, public transport and emergency vehicles. For such areas a road design is considered more appropriate.

For bituminous footways the designs in RN29 which are suitable for roads carrying low traffic flows can be applied to the overrun situation. The RN29 design method is based on relating the sub-base thickness to the subgrade CBR and the design traffic. A table is provided for estimating the subgrade CBR according to the soil type and the level of the water table. The thickness of roadbase and surfacing also depends on the traffic loading defined in terms of cumulative standard axles. Design guidance for concrete block paving, in which the designs for "lightly trafficked areas" are based on RN29, has also been published by Interpave.

The NPKA have published detailed flag designs for pedestrian footways, domestic driveways and footways which may be subjected to occasional overrun. The type of flag which can be used depends on the application, as the stress in the flag must be limited. Traffic loading is assigned according to usage - eg residential, local traffic outside shops etc, and subgrade assessment is required. Design thicknesses depend on the type of flag, the CBR of the subgrade and the estimated number of cumulative standard axles. The design guidance for blocks and flags assumes that the combined thickness of the modular paving and sand bedding is equivalent to at least an equal thickness of bituminous material.

For the structural design methods referred to above it is thus necessary to assess both the traffic and the subgrade. However, where overrun would put pedestrians at risk, such as on a narrow footway alongside a busy street, it must be physically prevented to protect pedestrians.

Subgrade Assessment

The assessment of subgrade strength must take account of the variability of strength along the length of the site to avoid risk of failure in weak areas. Sub-base design thickness varies considerably with the CBR of the subgrade.

Discussions with UK highway engineers has led to the conclusion that designs should be based on CBR, which should be measured where possible, otherwise a two per cent default should be assumed. This is in agreement with Lilley [5] who suggests designing block paving footways for only two CBR values, either less than two per cent or at least 20 per cent. He points out that in urban areas the majority of subterranean services are beneath the footways and in consequence subgrades can be very variable. This two per cent default may result in an unnecessarily conservative design.

Traffic and design life

Predicting the number and type of vehicles which are likely to overrun a footway is very difficult, unless they are so numerous that the footway is being used as a road. An added complication arises when vehicles park on footways while delivering, or when very slow moving vehicles overrun the footway. These may be more damaging situations than an axle count would imply. Severe deformation could be caused by long loading times or by canalization of traffic.

The NPKA suggest that each vehicle overrun is equated to one standard axle, and the level of overrun is considered to be one commercial vehicle per day for a residential area and five commercial vehicles per day outside local shops. On housing estates it is likely that 50 years will elapse before footways are replaced.

Pearson [6], states that in Sheffield city, UK, the typical period between footway reconstructions is 50 to 60 years - the footway has to deteriorate over 65 per cent of its area to be a candidate for reconstruction.

For footway design an upper limit of one commercial vehicle per day would seem reasonable. Over 60 years, adopting the NPKA suggestion that one commercial vehicle is

equivalent to one standard axle, gives a design life of 21,900 cumulative standard axles. Assuming that there will be some canalization in a footway situation, which would increase the wear, adopting a design for 50,000 standard axles should be robust.

Accelerated testing

Performance data

Enquiries amongst UK highway engineers has established that performance data on footways is generally anecdotal or incomplete and related to the surfacing rather than to the overall construction. It was therefore decided to construct footways in TRL's Pavement Test Facility (PTF) according to the proposed design methods and to assess their relative performance and modes of deterioration.

The Pavement Testing Facility

The PTF simulates traffic loading on test pavements under closely controlled conditions of loading and pavement temperature. The test machine spans the test pavements, the loaded wheel trafficking the pavement as it travels the length of the machine. A wheel load of up to 10 tonnes, controlled to within $\pm$ 2 per cent of the set load, can be applied by either a single or dual wheel, at speeds of up to 20km/h. Loading and speed are computer controlled and the test wheel, can be programmed to simulate the lateral distribution of wheel loads on a real pavement. Temperature is controlled by infra-red heating to ensure that the effects of other variables are not masked.

Construction details

Four test footways were constructed on a CBR 2.5 per cent subgrade at the PTF. The specified thicknesses are given in Table 2. The bituminous, block and flag constructions were designed to withstand 50,000 standard axles. A fourth bituminous footway, not designed to withstand overrun, was constructed to investigate the failure mechanism. The thicker bituminous pavement was actually constructed slightly thicker than specified increasing the design life to approximately 70,000 standard axles.

Table 2 Construction details

Construction layers	Construction type			
	Flag	Block	Bit 1 (thick)	Bit 2 (thin)
Wearing course	60mm x 300mm x 300mm flags	80mm blocks	25mm DBM	20mm DBM
Bedding	25mm sand	30mm sand	-	-
Basecourse	-	-	90mm DBM	70mm DBM
Sub-base	380mm Type 1	330mm Type 1	310mm Type 1	100mm Type 1

Test conditions

The test conditions were chosen to represent the conditions of footway loading in the heavy vehicle overrun situation. A dual wheel was used with a wheel load of 5.75 tonnes, which will be the maximum EU limit in 1999. With this wheel load, one pass of the loaded wheel is equivalent to approximately four standard axles. The trafficking pattern was such that the wheelpath centre-lines followed a normal distribution with a lateral spread of 0.5m. At one extreme, the outer edge of the wheel was at the edge of the kerb. The footways were tested under equal temperature conditions over the test period. The temperature was between 10°C and 15°C for the first 20,000 standard axles, and between 20°C and 25°C for the remainder of the trafficking. To simulate the slow speed of parking traffic the wheel speed was 10km/h.

Assessment during construction and trafficking

Surface profile, using an optical method, was measured during the construction and throughout trafficking. The FWD was used to assess the structural integrity of the footways immediately after construction. Ruts were measured throughout trafficking using a 2m straightedge and wedge. A visual assessment of the footways was carried out after approximately every 2,500 standard axles. The bituminous footways were examined for cracks. The block and the flag footways were examined for trips, cracked or spalled blocks or flags, loss of jointing sand, opening of joints and separation of the kerb from the pavement.

Results

Visual Assessment

The thin bituminous pavement rippled noticeably under the wheel loading but, initially, recovered without any obvious signs of distress. However, once deterioration started, it progressed very rapidly. The thicker bituminous pavement did not deflect noticeably under the wheel during trafficking and showed no visible signs of deterioration.

The block pavement appeared to be 'solid' under the initial few passes of the loaded wheel but then started to deflect noticeably. The flag pavement deflected very noticeably from the first application of the wheel load. There was no loss of sand through the joints in the kerbs or at the surface and no cracking of the blocks or flags.

Trips and Ruts

After approximately 6,000 standard axles the flag and block footways exhibited trips of about 6mm and 10mm respectively. After 20,000 standard axles the kerbs along these footways had rotated, such that the gap between the kerbs and the adjacent flags or blocks exceeded 10mm. The maximum trip was along the inside edge of the kerb, and was approximately 15mm.

The development of rutting with trafficking is shown in Fig. 1 for each of the four constructions.

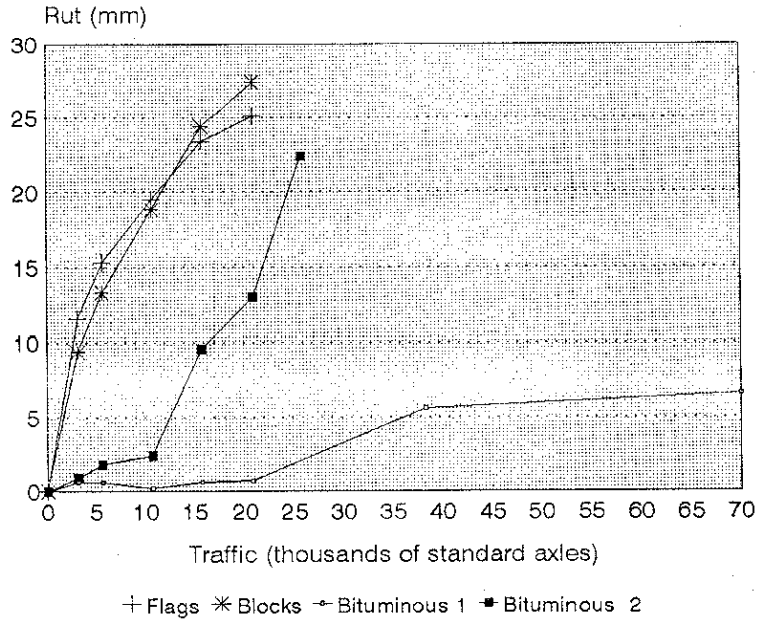

Fig. 1 Rut development with trafficking

For comparison, the average deformation for the blocks and bituminous 1 (thick) constructions are shown in Figure 2. In all the footway constructions, the rutting in the wheelpath was associated with a slight rise in surface level of the adjacent untrafficked area of footway, but this heave was insufficient to explain the majority of the rutting. After 20,000 standard axles, both the block and flag footways showed in excess of 20mm rutting at every measurement position along the footways.

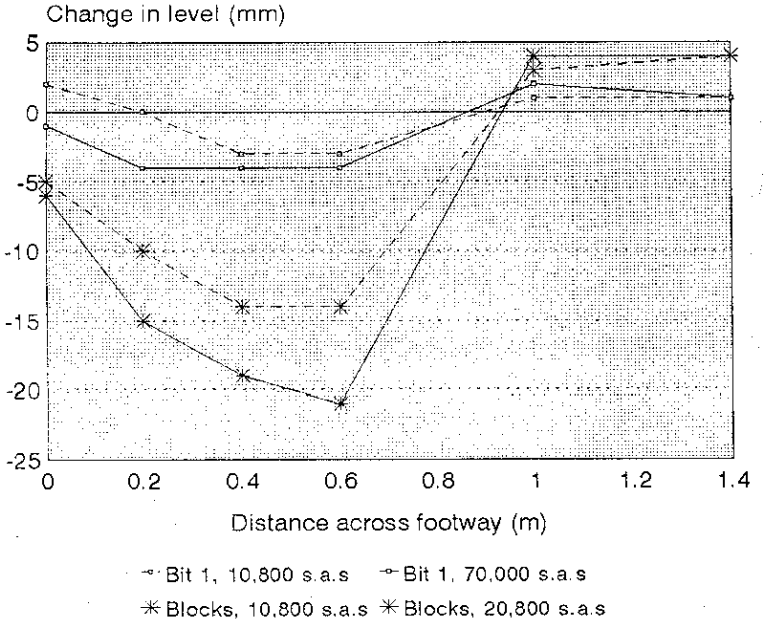

Fig. 2 Average deformation across block and bituminous 1 (thick) footways

Deflections

The FWD deflections measured on the untrafficked footway constructions were back-analysed to give layer stiffness modulii based on the FWD loading, the measured deflections and layer thicknesses. The stiffness modulii obtained for the layers above the sub-base, corrected to a temperature of 20°C on the bituminous footways, were:

Flags + sand (combined)	452 MPa	Bituminous 1	2,500 MPa
Blocks + sand (combined)	781 MPa	Bituminous 2	1,800 MPa

Post-trafficking Investigation

Due to the premature failure of the block and flag footways a post-traffic investigation was carried out on these constructions. The sub-base showed a dense coherent surface with no penetration of sand. Levels taken on the sub-base surface showed that the majority of deformation seen at the footway surface was present at the top of the sub-base. On this basis the deformation was considered to be structural rather than rutting and associated heave of the surfacing. Nuclear density gauge measurements showed no evidence of densification of sub-base material under traffic. Grading analysis of the sub-base material from the trafficked and untrafficked areas indicated that the material under the trafficking line had no more fines than that under the untrafficked area of the footway suggesting no further consolidation had occurred.

Conclusions

1. The PTF tests validated the RN29 design method for bituminous footways subject to heavy vehicle overrun, but the Interpave designs for flag and for block footways did not perform as well as expected.

2. Modular footway designs should be based on an assumed stiffness modulus for the blocks or flags plus sand of 800MPa or less.

3. The assumption of equivalence between blocks and sand, or flags and sand, and dense bitumen macadam appears not to be valid for new constructions. No evidence of 'lock-up' was found in the modular surfacings.

4. The UK Interpave design method,for flag and block footways, was not validated by the PTF experiment. The development of rutting in excess of 25mm caused the footways to fail prematurely, long before their predicted design lives.

Discussion

TRL's General Stress program [7] [8], in which the responses of the pavement layers to loading are calculated according to linear elastic theory, has been used to analyse the footway constructions. The criteria for pavement rutting or permanent deformation is the vertical compressive strain at the top of the subgrade. Based on LR1132 [9] values of 150MPa and 32MPa were derived for the sub-base and subgrade stiffnesses.

Using the measured construction thicknesses and the stiffness moduli obtained from the FWD back analysis corrected to 20°C, the compressive vertical strains at the top of the test subgrades were:

Bituminous 1	8.311×10^{-4}
Bituminous 2	2.257×10^{-3}
Blocks	1.113×10^{-3}

LR1132 gives allowable subgrade strains based on the design life. This results in the following allowable strains, for 85 per cent probability of survival:

N (design life in standard axles)	Strain
20,000	1.22×10^{-3}
50,000	9.66×10^{-4}
70,000	8.87×10^{-4}

The actual behaviour of the footways correlates well to that predicted by the theory. Based on an 85 per cent probability of survival, according to the criteria in LR1132, the Bituminous 1 footway has an expected life of 90,000 standard axles, and the block footway an expected life of 28,000 standard axles. Any decrease in actual life compared to predicted may be due to the narrower spread of traffic across the footway, compared to the spread of wheelpaths on a road.

The Bituminous 2 (thin) construction has an expected life of only 1,750 standard axles at 20°C, increasing to 5,500 standard axles at the increased stiffness at 12°C. In fact this thin construction behaved better than expected.

Because of the robust agreement between the design lives predicted from footway layer stiffnesses compared with the results of the accelerated PTF tests, there is no reason to doubt the stiffness values. There is no evidence for the equivalence between a modular paving and its bedding sand and dense bitumen macadam layer of equal thickness. Nor was there any evidence for lock-up of modular surfacings prior to the surface profile deteriorating. Further research is needed to assess, whether or not, the concept of 'lock-up' applies to a footway situation.

Acknowledgements

Crown Copyright 1996. The contents of this paper are the responsibility of the authors and the Chief Executive of TRL. They do not necessarily represent the views or policies of either the Highways Agency or the County Surveyors' Society .

References

1. Campbell, J. "Step Toe and Sue." in the 'Surveyor,' (Reed Business Publishing, London, 29th April, 1993) pp.16.

2. Road Note 29. "A guide to the structural design of pavements for new roads." 3rd edn. (Her Majesty's Stationery Office, London, 1970).

3. Interpave. "Concrete block paving - structural design of the pavement." (The Concrete Block Paving Association, Leicester, 1991).

4. National Paving and Kerbing Association. "Guide for the design of footways." (NPKA, Leicester, 1991).

5. Lilley, A. "Towards better footways." (British Cement Association, London, 1989).

6. Pearson, D. I. "State of the network." BCA seminar on footways. (British Cement Association, Crowthorne, 1993).

7. Thrower, E. N. "Calculations of stresses and displacements in a layered elastic structure, Part I." RRL Report LR 160 (Road Research Laboratory, Crowthorne, 1968).

8. Thrower, E. N. "Calculations of stresses and displacements in a layered elastic structure, Part II." RRL Report LR 373 (Road Research Laboratory, Crowthorne, 1971).

9. Powell, W.D., Potter, J. F., Mayhew, H. C. and Nunn, M. E., "The structural design of bituminous roads." TRRL Laboratory Report 1132. (Transport and Road Research Laboratory, Crowthorne, 1984).