CONCRETE FLAG PAVING IN MUNICIPAL ENGINEERING

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ABSTRACT

Flag paving is widely used in Municipal engineering but sometimes presents significant technical challenges. This paper looks at the issues of choosing suitable paving materials and of designing and constructing flag pavements to ensure good in-service performance. The paper begins by looking at the factors that need to be considered in setting up and running a consistent and cost-effective paving policy for roads, footpaths and pedestrian areas in Municipal work. The use of flag paving under traffic poses particular difficulties to pavement engineers and the paper looks at ways in which potential problems can be avoided by careful design coupled with an understanding of both the advantages and limitations of this form of construction.

1 INTRODUCTION

Flags are defined as pavers having a plan area equal or greater than 0.08 m^2 and are typically 300 mm x 300 mm or larger in plan. Concrete flags first came into common use about 110 years ago in the UK, when they started to replace traditional stone flags, used at that time for surfacing prestigious urban pedestrian areas. They rapidly gained in popularity because they were cheaper than stone flags in both cost and construction with savings resulting mainly from the dimensional accuracy of the concrete flags. Subsequently they have become widely used throughout Europe and the rest of the world.

2 REQUIREMENTS AND POLICIES FOR MUNICIPAL PAVING

Municipal paving should meet the following requirements:

1. It should achieve satisfactory in-service performance under pedestrian and vehicular traffic and yield an adequate service life.
2. It should be cost-effective, economical and not require frequent replacement.
3. It should be durable and resist weathering.
4. It should integrate with services and intrusions.
5. It should be easy to lay, lift, repair and clean whilst meeting O H & S requirements.
6. It should allow the designer to control pedestrian and vehicular movements by visual means e.g. by the choice of colour, surface texture, shape, size and laying pattern.
6. It should allow the designer to divide the project into distinct areas which can be individually replaced so that the visual impact of the replacement paving is minimised.
7. It should mix and harmonise with other common paving materials.

Most municipalities use a range of paving types. For example, granites, slates and other natural stones are often used together with a wide range of square and rectangular concrete flags, plus concrete and brick pavers and asphalt paving. To control paving choices many major municipalities are developing paving policies. Inter-alia such policies need to consider:

2.1 Paver Suitability.

Amongst the various types of paving used by municipalities, flags are accepted, worldwide, as one of the most attractive and durable forms of surfacing and are playing an increasing role in Australian municipal engineering. Municipalities should determine, as policy, what pavers are suitable for footpath and street pavements. This then provides a basis both for council's own operations and for developers. Here the objective should be to achieve a sound basis for long term planning of paving projects without the need to constantly change the sources of supply or paving types. This usually implies that only a limited range of materials, shapes, sizes etc. should be included in the suite of approved paving. The number of colours allowed will usually need to be restricted in order to achieve consistency throughout the municipality. Different pavers may need to be assigned to different functional areas of the municipality and consistency in their use may need to be enforced.

In selecting pavers for inclusion in the suite of approved paving the following factors should be considered.

- The ability of a flag to resist loads and traffic decreases as the plan size of the flag increases.
- Large flags perform worse than small flags. (Large flags also pose more O H & S risks – see below).
- The plan dimensions of flags should not be considered in isolation from their thickness and strength because the ability of a flag to carry load or traffic depends on achieving the correct relationship between all three of these factors.

In these respect, the CMAA Guide (1) specifies flag thicknesses, plan sizes and strengths that have been combined with the objective of achieving satisfactory in-service performance.

2.2 Performance.

The performance in terms of serviceability and safety needs to be predicted at the design stage. Different criteria will rule for pedestrian and trafficked areas. Because concrete flag pavers meet tight dimensional tolerances they are easy to lay so that lipping does present not a trip hazard to pedestrians. They also meet slip resistance requirements and can provide a skid-resistant running surface for traffic that also shows satisfactory riding quality.

2.3 Costs.

The costs not only of constructing but also of cleaning, maintaining and rehabilitating the paving need to be considered. In this respect the honed finishes now becoming widely available for flags make them easier to clean than many other surfacings. For costing purposes realistic analysis period need to be selected. Typically these should be less than 20 years. In this respect, it is instructive to note that municipal engineers in the UK and Europe expect to have to replace at least 5% of their paving each year.

2.4 Operational Health and Safety.

O H & S requirements should form an integral part of any paving policy so that risks to personnel both during construction and subsequent maintenance are minimised. The main issues here are the weight and size of paver that can be handled and lifted without using machines. Although there is no obstacle to using machines to lay flags, lifting them for trenching and other maintenance operations by machine is usually not feasible. Here there may be additional suction forces between the flag and bedding that need to be overcome it addition to the unit's dead weight. For handwork, flags up to about 400 x 400 mm meet most O H & S requirements. By contrast, larger paving units pose O H & S risks unless purpose-made machines are used to lay them.

2.5 Aesthetics.

The choice of paver size, shape, colour and texture together with the laying patterns and detailing jointly control the appearance, sense of scale and place etc. of the paving. Here the paving needs to be selected to give architects and landscapers the scope to provide a quality civic statement. In this respect, concrete flag paving is unique in terms of the wide range of colours, textures and finishes that are available to the designer. Generally, darker colours are to be preferred because they do not show up staining, dirt and chewing gum as readily as light coloured flags and require less cleansing. As noted elsewhere, honed finishes aid cleansing operations.

2.6 Environmental Considerations.

The choice of pavement can have major influences on the environment in terms of albedo and drainage. These environmental aspects of paving are assuming an increasing importance in municipal engineering and new forms of pavement, eg. permeable paving, have been developed to meet this need. These have recently been reviewed elsewhere (2).

In common with other forms of concrete paving, concrete flags of all colours have high albedo and therefore minimise the heat island effects that are common in paved urban areas. During manufacture, concrete also produces less green house gas emission per unit weight than paving materials such as asphalt.

Because flags have a much greater spacing between joints than pavers it would be expected that the road noise generated by traffic would be less than for conventional pavers. However, measurements to confirm this are not yet available.

3 CONCRETE FLAG PAVING IN AUSTRALIA

In contrast to many countries, especially in Europe, where such surfaces are commonplace, in Australia the high costs of manufacturing flag pavers by traditional wet-cast methods meant that the usage of flags was limited. However, during the last decade, the introduction of versatile modern paver manufacturing plant has made flags economically competitive with other forms of paving and flags have been rediscovered by designers and specifiers.

Concrete flags began to be used in major projects including malls and down-town streets around Australia during the 1990's. At that time, there was no industry or national code of practice for the specification, design and detailing of flag pavements. The need for structural design recommendations was soon demonstrated when problems were encountered where the pavements carried vehicular traffic and a number of the pavements failed in service, typically by cracking and disintegration of the flags. Often the problem was due to a failure to properly anticipate the volumes and type of traffic to be carried. It therefore became clear that design and construction recommendations for flags carrying traffic were required. For these reasons, in 1997, the Concrete Masonry Association of Australia began a major study of flag paving beginning which led to the publication of a Design and Construction Guide for Concrete Flag Paving in 2001 (1). The background to this Guide has been described in detail elsewhere (3).

4 TRAFFICKED FLAG PAVING

Most municipal pavements carry at least some occasional traffic. This comprises light service vehicles of less than 3 tonnes gross weight, commercial vehicles exceeding 3 tonnes gross weight, armoured vehicles servicing ATMS, emergency vehicles such as fire engines and escape ladders, cars and pavement cleansing machines. Failure to adequately recognise and quantify the traffic has led to several malls and so-called “pedestrian” precincts being under-designed, leading to pavement failures in service.

4.1 Flag Properties.

The stresses generated by traffic depend on both the plan dimensions and flag thickness and, consequentially, different strengths are required for different flag sizes to avoid cracking in service. Following detailed analysis of the stresses generated in flags by traffic (2), the flag sizes and strengths given in Table 1 are recommended for routine use.

Table 1. Flag Properties Required for Trafficked pavements

Application	Vehicle Traffic	Nominal Size (mm)	Thickness (mm)	Characteristic Breaking Load in kN
Pedestrian and Light Vehicles Only (LV)	LV Only	Any up to 450 x 450	50	8
Pedestrian & Commercial Vehicles (CV), Streets	< 100,000 CV’s	300 x 300 400 x 400 450 x 450	60 65 70	13.8 (4.8)* 15.5 (4.8)* 18.8 (5.1)*

* (Calculated Required Minimum Flexural Strength, MPa)

The theoretical values of flexural strength are shown in parentheses in Table 1 only for information. In practice, concrete flags are required to comply with the minimum breaking load strengths set out in the Table for all categories of use. In the case of dimensions, no restriction is placed on the flag dimensions for pavements subject to purely pedestrian traffic but for pavements carrying light vehicles a minimum thickness of 50 mm is required. For pavements carrying commercial vehicles, restrictions are placed on both the plan dimensions and minimum thicknesses. Deviation from these dimensions is not permitted where commercial vehicles are to be carried. The tolerances on flag dimensions are required to be in accordance with AS/NZ 4456.3.(4)

Opinions concerning the required thickness of flags vary widely. In Europe flag thicknesses up to about 180mm, are routinely specified where commercial traffic is to be carried. Such flags are too heavy to be installed by hand, pose major O H & S risks and require specialised laying equipment. Because this equipment is not available in Australia, it was decided to restrict the flags to be covered by the CMAA design guide (1) to those capable of hand laying. This implied a maximum flag size of 450 x 450 x 70mm. However, as noted above, 400 x 400mm flags are about the largest units that meet O H & S weight requirements.

4.2 Choice of Basecourse Type and Thickness Design

Experience has shown that the behaviour of flags under traffic is different and indeed inferior to that shown by most small element pavers. For this reason, flag pavements should not be designed using the same norms as small-element concrete segmental paving nor should similar levels of performance in service be expected.

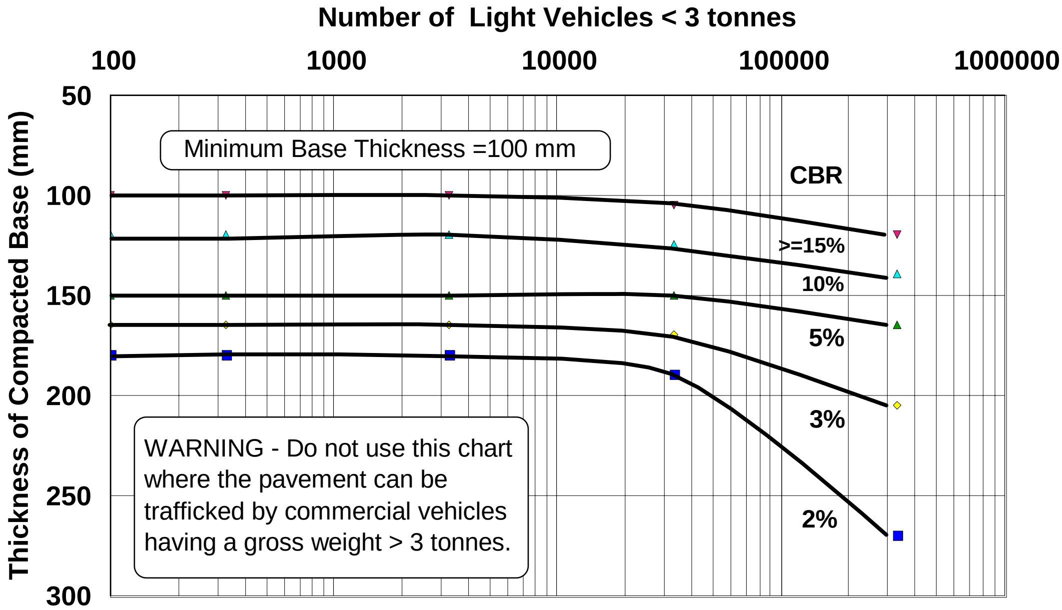

Figure 1. Basecourse Thickness under Concrete Flags subject to Light Vehicles only.

Where the pavement is to carry commercial vehicles the subgrade strength is expressed as a representative soaked CBR value based on laboratory tests. For pedestrian areas and pavements subject only to light traffic the CBR may also be estimated from soil classification data or by selecting presumptive values. Where the subgrade CBR is less than 4% the use of a select subgrade material (capping layer) or subgrade stabilisation with lime and/or cement is normally required (1).

Both unbound granular materials such as crushed rock and cemented materials are commonly used under flags. The design procedure permits the use of both of these materials up to traffic levels of 50000 commercial vehicles (CV's). For higher traffic intensities only cemented base is recommended, otherwise the flags may become overstressed and crack. Analyses similar to those used in the LOCKPAVE design procedure (5, 6) were used to calculate the thickness of basecourse required to support the flags. The thicknesses are presented as functions of the traffic volumes and subgrade strengths in Figures 1, 2 and 3. For light vehicles having a gross weight of less than 3 tonnes the theoretical thicknesses of bound and unbound base were found to be similar and, for simplicity, the thicknesses plotted in Figure 1 are envelopes of those for both bound and unbound base materials.

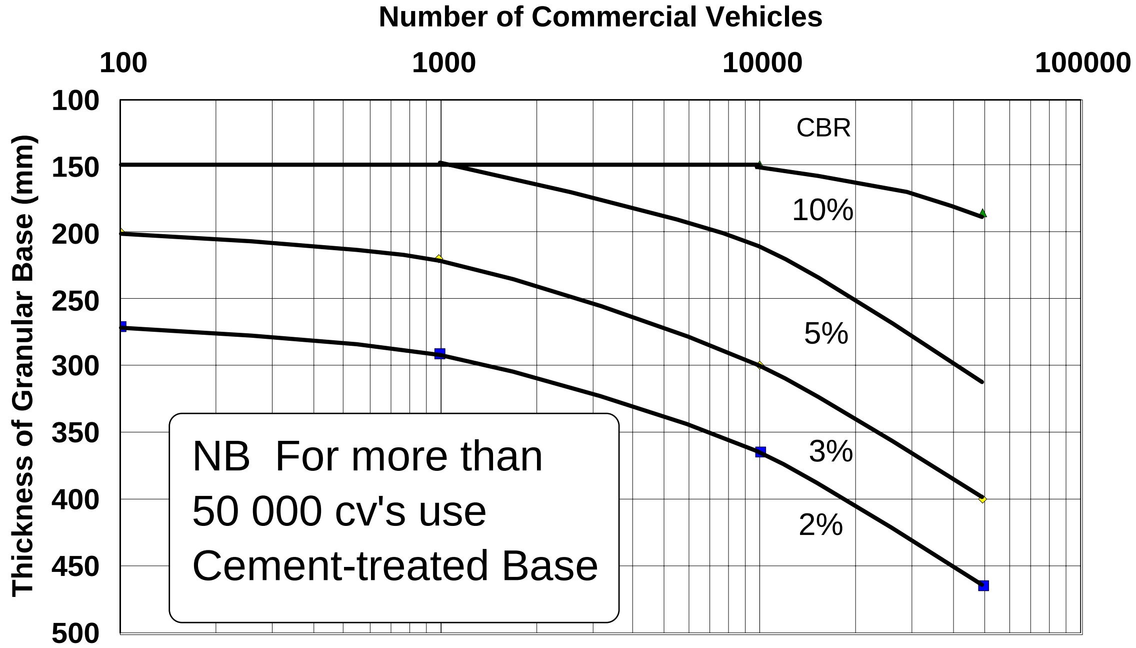

Figure 2. Granular Basecourse Thickness under Concrete Flags Carrying Less than 50000 Commercial Vehicles

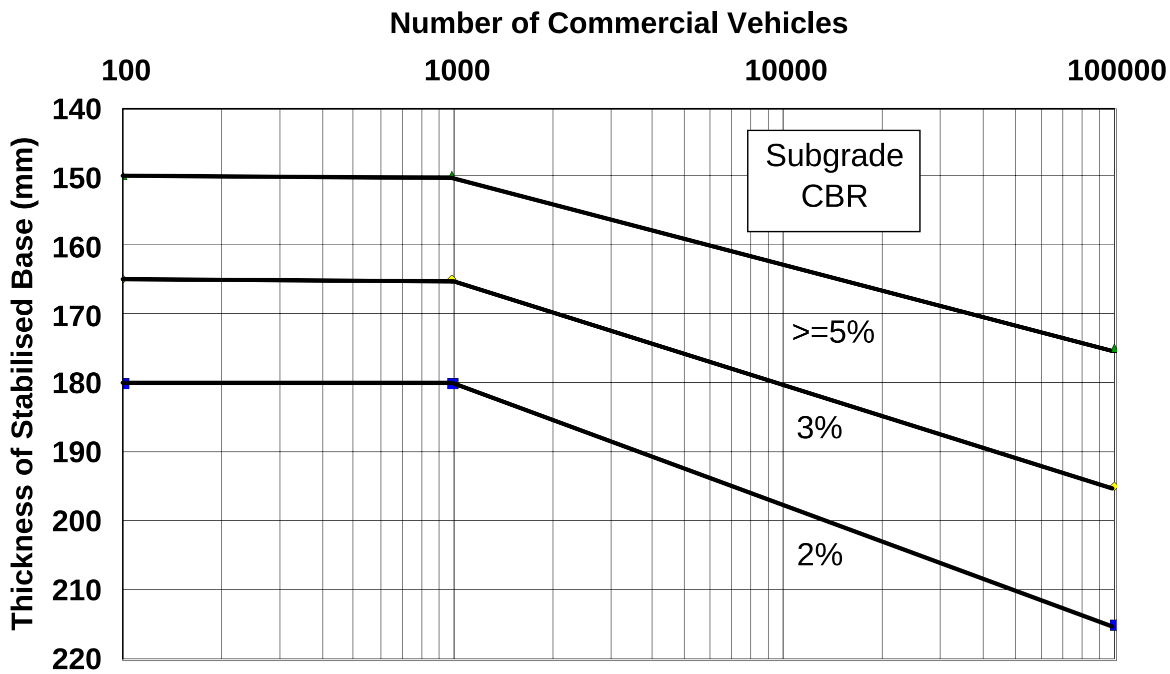

Figure 3. Cement Stabilised Base Thickness under Concrete Flag Pavements Carrying more than 50000 Commercial Vehicles

4.3 Bedding Materials

Some flag pavements built to carry traffic in Australia have been laid in mortar over concrete slab bases. Often the flags have been laid butt-jointed on conventional 1:1:6 mortars. Large numbers of domestic driveways and some residential streets have been installed this way and are claimed to have performed satisfactorily although there is no documentation to support this. However, the performance of mortared pavements under downtown traffic has been much less satisfactory and major failures have occurred in Brisbane and Newcastle, amongst other places. Similarly, failures in mortared flag paving have been commonplace in Europe (3) whenever significant truck traffic is involved. For these reasons, the CMAA Guide (1) specifically eschewed the use of mortar as a bedding for flags carrying vehicular traffic.

As shown in Figures 1 to 3, concrete flag pavements bedded on sand are limited in terms of the numbers of vehicles that they can carry. Moreover, as already noted, the use of mortared flags has often been associated with early failure under traffic. Recently, new ways of overcoming these shortcomings by the use of proprietary mortars and adhesives to fix the flags on to a concrete base have been developed. These materials were evaluated by accelerated trafficking studies in Melbourne of four full-scale prototype flag pavements using the ARRB Accelerated Loading Facility (ALF). Details have been given elsewhere (7).

In the ALF tests, flags, 400 x 400 mm in thicknesses of 40 and 53 mm were fixed in both stack and stretcher bonds on a rigid concrete base. Two types of fixing were examined. These comprised proprietary mortar and adhesives. Tests panels were orientated both normal and at 45° to the direction of trafficking. Trafficking was conducted using a dual wheel driven in one direction over the pavements. Half-axle, dual wheel loads from 40 kN to 80 kN were studied with up to 60 000 wheel passes per test panel. Overall, the tests showed that it was possible to achieve good levels of performance in the proprietary pavements under traffic levels appropriate to Malls and Minor and Local Access Streets according to AUSTROADS traffic classifications (8).

The ALF trials of flag paving were specific to those particular proprietary paving systems and should not be seen as endorsing the general use of flags installed on mortar beds. Until more documented experience with mortared flag paving is available and pending the development of design methods for such forms of construction the CMAA Guide (1) remains the only design guidance for flag paving carrying traffic. This is limited to flags laid on a sand bedding course. In this respect, experience in Europe (3) shows the need to use a more restrictive specification for the bedding sand than is required for normal small element segmental paving (9). Specifications for suitable sand bedding materials have been given elsewhere (1).

5 SPECIFICATION OF CONCRETE FLAGS

To avoid or minimise damage to the flags occurring in service it is important that the flags be chosen to match the intended application. As noted above, it is necessary to ensure that the combined effects of the dimensions and strengths of the flags are adequate for the proposed use. The plan dimensions, minimum thicknesses and minimum strengths that are required are given in Table 2 for common applications (1). Table 2 sets out the quality requirements for segmental pavers and flags but not the design requirements. It includes performance criteria, general requirements and deemed-to-satisfy solutions for both concrete and clay units. These requirements are summarised in Table 2 below.

Concrete flags should comply with the properties set out in Table 2 for all categories of use. In the case of dimensions, no restriction is placed on the flag dimensions for pavements subject to purely pedestrian traffic but for pavements carrying light vehicles (< 3 t) a minimum thickness of 50 mm is required. For pavements carrying commercial vehicles (>=3 t) restrictions are placed on both the plan dimensions and minimum thicknesses. Deviation from these dimensions is not permitted where commercial vehicles are to be carried.

Table 2 Concrete Flag Properties

Pavement application[1]	Vehicle traffic[2]	Nominal size mm	Minimum Thickness mm	Characteristic breaking load[3,4] kN	Dimensional deviations (work size dimensions) mm Plan		Height		Abrasion resistance (mean)[5] for pedestrian volume			Slip resistance classification (Class)
					SD[6]	Mean	SD[6]	Mean	Low	Medium	High	
Pedestrian only	Nil	Any	Any	5.0	1	± 1.5	1	± 2	7	5	3.5	W
Pedestrian and light vehicles (LV) only	LV only	Any up to 450 x 450	50	7.0	1	±1.5	1	± 2	7	5	3.5	W
Pedestrian/ commercial		300 x 300	60	13.8	1	± 1.5	1	± 2	7	5	3.5	W
vehicles (CV)	<100,000	400 x 400	65	15.5	1	± 1.5	1	± 2	7	5	3.5	W
only, streets	CV's	450 x 450	70	18.8	1	± 1.5	1	± 2	7	5	3.5	W
AS/NZS Standard	Not applicable		Not applicable	AS/NZS 4456.5	AS/NZS 4456.3 Method B				AS/NZS 4456.9			AS/NZS 4586

NOTES:

1 Salt resistance for concrete flags is determined by Test Method – AS/NZS 4456.10

2 For CV traffic >100,000 an interlocking concrete segmental pavement should be designed, specified and detailed in accordance with T44, T45 and T46[12,13,14]

3 At 28 days
Characteristic Value – the value that will be exceeded by at least 95% of the units in the lot (see AS/NZS 4455.1.4.5)
Lot – a group of units of a single type with specific characteristics and dimensions presented for sampling at the same time (see AS/NZS 4455.1.4.13)

4 It is common to test at an early age and correlate results

5 At 90 days

6 SD = Standard deviation

6 CONCLUDING COMMENTS

Flags represent an important component of municipal paving. This paper shows that flags can fulfil most requirements for urban paving. Experience has shown that, where problems have arisen, these often stem from a failure of designers to properly consider the effects of traffic. In reality, few municipal pavements are completely free of traffic. For this reason the CMAA design method (1) ensures that the designer is required to confront traffic considerations at an early stage of design and must identify whether the traffic comprises light or commercial vehicles. The LOCKPAVE mechanistic procedure that has been used for nearly 15 years in the design of small element paving has been combined with theoretical studies and trafficking test data from Europe to produce the design curves given above (3). These curves are restricted to flags laid on sand beddings. Nevertheless, there is a growing interest in installing flags on mortar over concrete slab bases. Hitherto such pavements have performed badly under down-town traffic. However, new proprietary methods for fixing flags to a concrete substrate have recently been developed and tested (7). The need for good specifications that are sometimes stricter than those customarily used for small element pavers has been strongly emphasised. Overall, however, if vehicular traffic is to be carried, it should not be forgotten that flags can never provide the levels of performance that are now routinely expected from small element paving (10). Accordingly conventional concrete pavers will continue to play the major role in urban trafficked paving.

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