THE CHALLENGES OF CONCRETE BLOCK PAVING AS A MATURE TECHNOLOGY

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SYNOPSIS

This paper describes Concrete Block Paving technology as it has evolved over the last 25 years. It is concluded that the technology is already sufficiently mature to support the use of pavers in engineered pavements. However, much more work need to be done to disseminate the technology and make it accessible to engineers and other end-users if the engineering markets for pavers are to be fully developed.

1. INTRODUCTION

The author has had the opportunity to participate in the development of Concrete Block Paving (CBP) technology over the last 25 years. This paper describes how this technology has developed and matured in that time. Although concrete block paving has a long history in Europe it was not until the mid-1960s that concrete block paving became established in Central and South America and in South Africa. During the 1970s CBP was introduced to Britain, Canada, the USA, Australia, New Zealand and Japan. Subsequently the use of block paving spread to the Middle-East and Asia. Most of these regions, especially North America, have experienced a sustained growth in the paving market.

A beneficial result of the spread of concrete block paving beyond Europe was that it removed the material from the conservative, traditional, craft-orientated influence of the Master Paviours and experience-based design and specification. In most of the countries which adopted concrete block paving, skilled labour was at a premium and there was little or no experience in the use of small-element paving. Consequently there was a widely perceived need to establish a sound technological basis for the design and construction of concrete block pavements. This led to a sustained worldwide research effort much of which was conducted outside Europe. This paper examines the development of this new technology.

Figure 1 shows the breakdown of annual paver production worldwide. Less than a quarter of all pavers are currently produced in the English-speaking world. It might therefore be expected that there would be more technical papers on pavers in German and other languages than in English. Surprisingly, this does not seem to be the case. One indication of the growth in interest, worldwide, in CBP is provided by the increasing numbers of technical papers submitted to conferences devoted solely to CBP. The first workshop on CBP appears to be that organised under the auspices of the Australian Road Research Board in Melbourne in 1978 (Sharp and Metcalf, 1979). Soon after, in 1979, the first symposium on CBP attended by international authors followed in Johannesburg, South Africa (Concrete Society, 1979). However, by far the best attended International Conferences and Workshops have been those organised by Small Element Paving Technologists (SEPT). The growth in papers submitted to the SEPT conferences is shown in Figure 2. These now total about 500. However, it is important to recognise that this represents only a fraction of the technical literature on CBP because many papers are not in English or have been presented in technical journals or at BIBM, road engineering or other technical conferences.

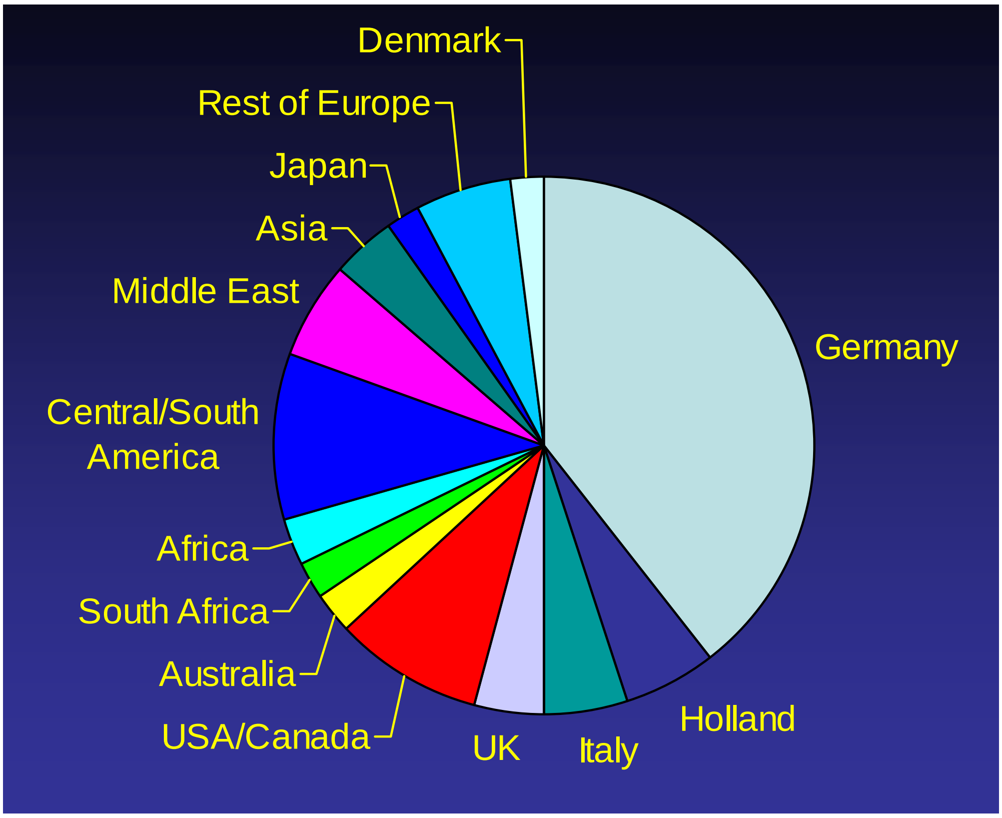

Figure 1. Breakdown of Annual World Production of Pavers.

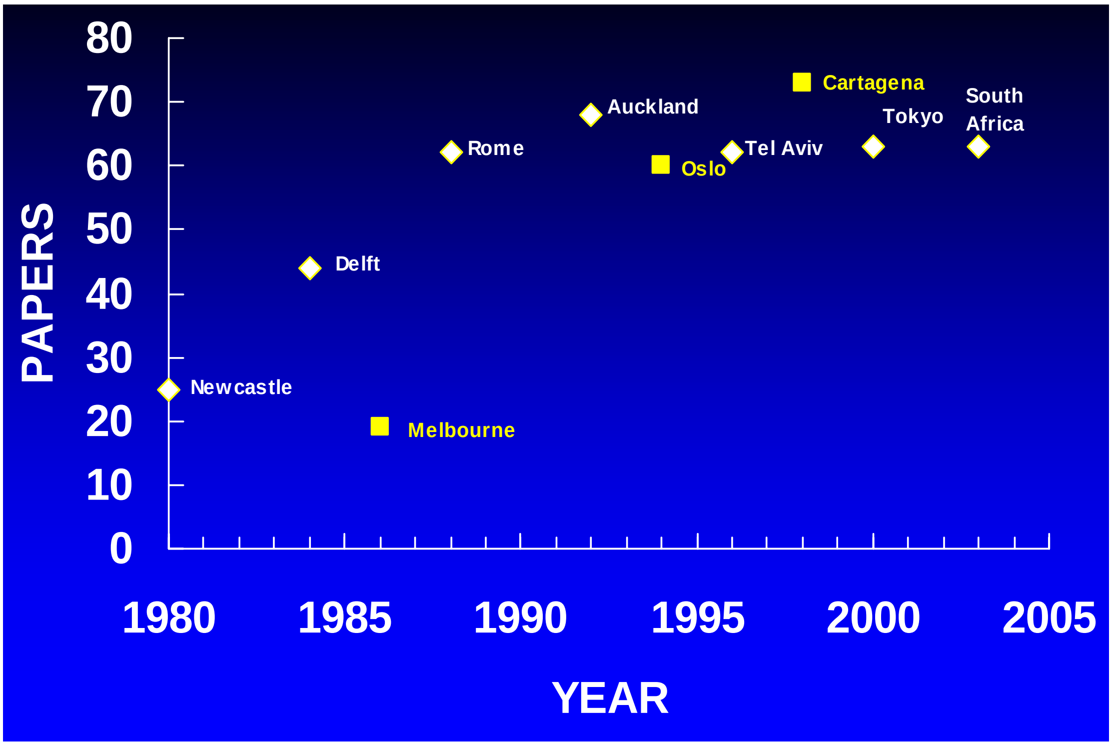

Figure 2. Papers at SEPT Conferences and Workshops, 1980 to 2003.

Figure 3 provides a breakdown of the principal matters discussed at the various SEPT conferences. Although this classification is arbitrary because many papers have touched on more than a single research topic, it nevertheless provides an insight into those areas of technology that have most motivated research.

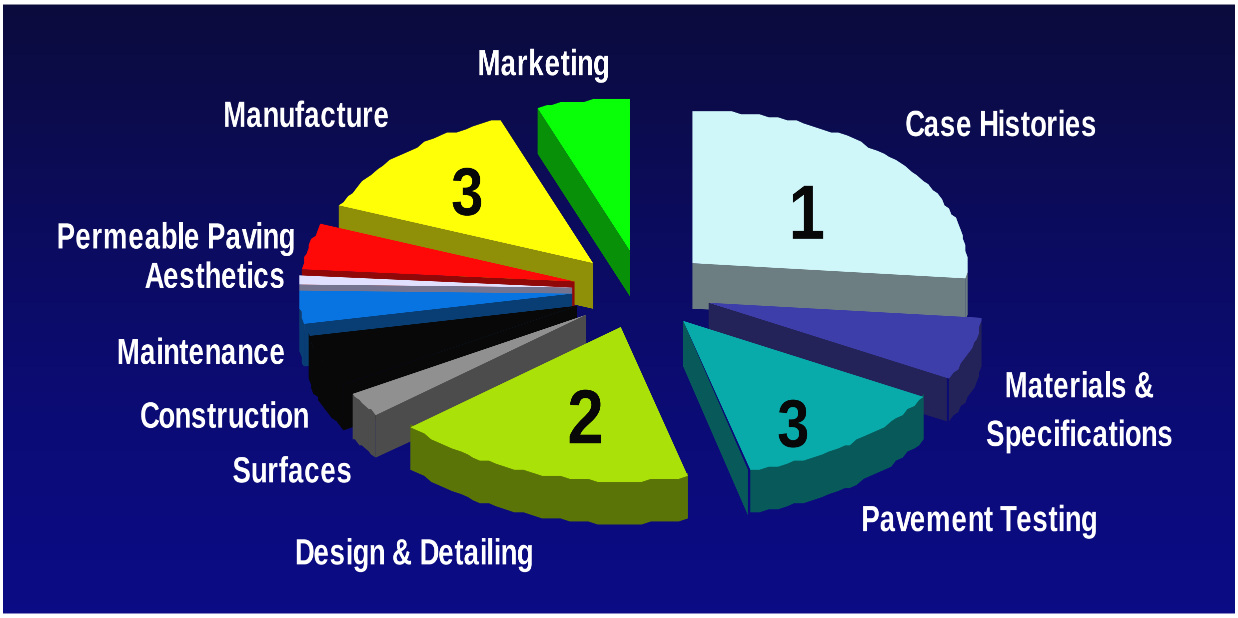

Figure 3. Topics presented at SEPT conferences from 1980 to 2003

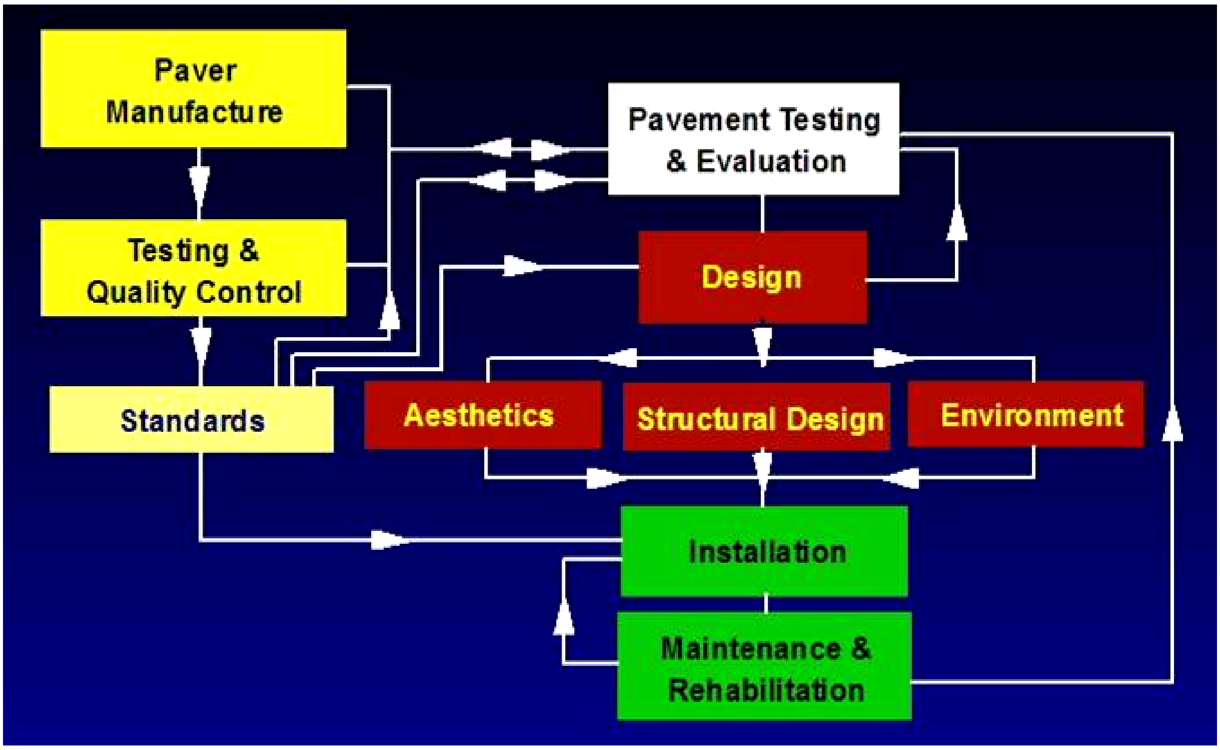

Figure 4. The Technology of Concrete Block Paving

An overview of the technology of CBP is given in Figure 4. Broadly, the technology can be grouped into four areas. These comprise:

1. Paver manufacture, quality control and standards
2. Evaluation of paving through direct testing and case histories
3. Design of Pavements
4. Installation and maintenance of pavements

Each of these areas is now discussed.

2. PAVER MANUFACTURE

Amongst the various streams in the technology of CBP shown in Figure 4, paver manufacture, testing and quality control are the most mature. Indeed, it is axiomatic that the successful marketing of CBP requires the production of good quality pavers using purpose designed paving plant. In this respect, European and American equipment and manufacturing experience lead the world. Here considerable technical expertise continues to be directed towards the development and refinement of plant for manufacturing pavers and for adding value through a wide range of surface finishes.

Paver manufacturing technology impacts directly on both the aesthetics and environmental amenity of pavers. In the case of aesthetics, manufacturing plant and techniques play a critical role in providing the colours, textures and surface finishes required by end-users of pavers. Until recently, only about 20 percent of pavers were marketed with any form of value-added surface treatment. However, this percentage is rapidly growing as CBP comes under increasing competition from clay brick paving, stamped concrete and other decorative surfacings. Here the challenge to the industry is to produce surface finishes that are unique to CBP. Techniques described in the SEPT conferences include honing, bush hammering, shot blasting, rumbling, washing and polymer flame coating.

In the case of environmental amenity, manufacturing technology can contribute to the control of traffic noise by controlling such factors as the size, surface textures and chamfers of the pavers. Other environmental considerations that can be addressed include the provision of high albedo surface finishes. However, the most important contribution that pavers can make to the environment comes from the manufacture of porous pavers or permeable paving. This is discussed further below.

Paradoxically, manufacturing technology is of little concern to end-users provided the pavers satisfactorily meet appropriate product specifications. However, the early development of new markets for CBP has often been impeded by the absence of suitable local standards, specifications or regulations. Consequently, over the 25 years, this problem has been addressed worldwide (eg. Van der Vring, 1994). Model specifications or National Standards for paver manufacture and paver quality now exist in most developed countries although, as SEPT conferences show, these continue to be refined. However, more work still needs to be done on the development of standards and codes of practice for the different applications of pavers i.e. for the specification and construction of the pavements rather than for the pavers themselves; a matter addressed elsewhere at this conference.

3. DESIGN TECHNOLOGY

In Europe, widespread familiarity and experience with CBP backed by design codes and regulations made CBP accessible to engineers although much design was based on experience. However, once pavers were introduced to new markets outside Europe two problems arose. These were:

1) The need to develop new design procedures to address the different traffic loads, materials and climates relevant to the new markets.

2) The need to persuade engineers that were unfamiliar with CBP that it represented a viable alternative to more familiar forms of paving such as asphalt or rigid concrete.

3.1 Evaluations Of Paving

Before engineering design methods could be developed or assessed it was necessary to understand and quantify the behaviour of CBP under road, industrial and airport traffic. This required case histories to be assembled and assessed as well as pavement testing. As shown in Figure 3, these have been major topics at SEPT conferences. Research into these areas was begun in the 1970s and continues up to the present time. Despite the many case histories that have been published for CBP, most quantitative evaluations of CBP have been based on accelerated trafficking studies of actual or prototype road and industrial pavements. More than 200 full-scale pavements have been tested in just South Africa and Australia alone. Such studies have enabled the systematic identification, study and ranking of the performance factors listed in Table 1 and have provided the necessary inputs for developing comprehensive structural design methods. A overview of this technology has been given elsewhere (Shackel, 1990).

Table 1. Factors Affecting the Performance of CBP

Pavement Component	Factors Affecting Performance under Traffic
Pavers	▪ Paver Shape ▪ Paver Thickness ▪ Paver Size ▪ Laying Pattern ▪ Joint Width
Bedding and Jointing Sands	▪ Sand Thickness ▪ Grading ▪ Angularity ▪ Moisture ▪ Mineralogy
Basecourse and Sub-base	▪ Material Type ▪ Grading ▪ Plasticity ▪ Strength and Durability
Subgrade	▪ Soil Type ▪ Stiffness and Strength ▪ Moisture Regime

The testing conducted around the world demonstrates that CBP is unique in many ways. Not only does it respond to traffic in a manner that is quite unlike asphalt or rigid concrete but it behaves differently from other forms of segmental paving such as brick and stone. In particular, it tends to become progressively stiffer and stronger under traffic load repetition and can perform satisfactorily in respect of rutting whilst simultaneously exhibiting levels of resilient deflection that are very much higher than those that would be tolerated in an asphalt pavement. The evidence for these statements has been set out elsewhere (eg. Shackel, 1990). Overall, CBP behaves like an articulated slab and for many purposes may be characterised as such (eg. Shackel et al, 1993, 2000). In this respect it differs from clay brick pavers of similar dimensions and shape. This is due to the high precision and consistency in dimensions amongst concrete pavers – attributes that are not shared by other forms of segmental paving. However, these important attributes are not as widely recognised or accepted as they deserve to be. Consequently, CBP is often insufficiently differentiated by producers and designers alike from competing forms of segmental paving or from asphalt.

3.2 Design Of Concrete Block Paving

Good design should embrace aesthetics, structural capacity and environmental amenity. Each of these areas is now considered separately.

3.2.1 Paver Aesthetics

The aesthetics of paving are covered by routine architectural or landscaping expertise and, as shown in Figure 3, have received relatively little attention at SEPT conferences although a useful introduction to paver aesthetics has recently been published (Smith, 2002). However, the tasks of the designer can be eased by the provision of programs designed to interface with CAD software and, thereby, to assist in the production of drawings and specifications for projects using pavers. Such tools have already proved useful in new CBP markets such as the USA.

3.2.2 Structural Design

An early obstacle to the widespread use of pavers by engineers in new markets has often been the lack of reliable design methods for engineered pavements that are relevant to local conditions. As shown in Figure 3, this has been a perennial topic at SEPT conferences. This has led to a proliferation of design methods for CBP around the world. These have been reviewed elsewhere (Shackel, 1990; 2000). Often such methods comprise simple *ad-hoc* modifications of conventional asphalt pavement design procedures which fail to recognise the unique behaviour features that distinguish CBP from asphalt paving. For this reason, in many areas of the world, as designers and end-users of pavers become more knowledgeable about paver performance, simple modified asphalt pavement design procedures are being replaced by computer-based mechanistic design programs specific to pavers (eg. Shackel, 2000). These model the behaviour of CBP to accord with data from tests of pavers (see above). Such programs make CBP technology accessible even to tyro designers and can readily cope with the wide range of materials, climates and traffic conditions characteristic of different paving markets.

One recent challenge to CBP design technology has been the increasingly widespread use of flag pavers under traffic. Historically, such pavements have not performed well especially when installed on mortar. Flag pavements cannot be designed in the same way as small element segmental paving. Nevertheless new design procedures are emerging (e.g. Shackel and Pearson, 2001) and original techniques for using adhesives in place of mortar have recently been tested (Shackel and Yeo, 2003). The techniques of installing flags on adhesive or mortar represent areas where market potential will undoubtedly promote further developments in CBP technology.

3.2.3 Environmental Amenity

Environmental paving is the area of paver technology that is growing most rapidly. Although pavers offer benefits in terms of their albedo etc., their main contribution to the environment comes from the concept of permeable eco-pavers which originated in Germany some 15 to 20 years ago. Recently, the introduction in the USA of regulations requiring the control of runoff for all projects greater than 0.4 ha has led a rapidly increasing awareness and acceptance of permeable eco-paving by engineers and landscapers. Similar trends are slowly becoming evident elsewhere around the world.

Permeable paving provides the following environmental benefits

a) It reduces or eliminates surface runoff
b) The pavement substructure serves as a drainage and/or water retention system, and

c) The pavement acts as a filter capable of trapping pollutants from rainfall and surface runoff.

The benefits of using permeable eco-pavers are that the storm load on the sewer or drainage system is reduced with consequent reduction in cost, flooding overflow and erosion problems are eliminated or reduced and water is returned to replenish and maintain the water table. At the same time, pollution of streams and water supplies is substantially reduced. At the economic level, benefits accrue because it becomes possible to pave larger proportions of the site than are permitted where traditional impermeable paving is used, i.e. permeable eco-pavers promote more efficient land-use.

Tests in Germany, Austria, Australia, USA and Canada have provided substantial information on the ability of eco-pavers to accept rainfall, to filter out pollutants and to bio-remediate oil pollutants (eg. Pregl and Litzka, 1989; Muth, 1994; Anon, 2002; James, 2002; Shackel 1987, 1990, 1996, 1999; Shackel et al, 2000, 2001). Of equal importance, tests in both Austria and Australia have shown that it is possible to achieve structural performance for eco-pavers that is broadly similar to that measured for conventional pavers (eg. Shackel, 1999; Shackel et al, 2000).

The ability of eco-pavers both to accept high rainfall intensities and to provide good levels of structural support opens up new possibilities for market development in CBP. These new markets embrace both roads and industrial pavements and, because of the special benefits of permeable eco-pavers, extend rather than replace the markets now served by conventional pavers. For these reasons, permeable eco-paving represents one of the most significant developments to have occurred in the evolution of CBP technology for engineered pavements. However, more development and characterisation of basecourse materials for use in permeable pavements needs to be done before the full potential of permeable eco-paving will be realised.

3.3 Paver Installation

In Europe there has long been a tradition of installing pavers by specialist craftsman. Such an approach continues to work well where the pavement primarily serves aesthetic functions eg. in pedestrian areas. However, experience shows that such an approach is often inappropriate when engineered pavement carrying traffic are to be constructed. Here, pavers may be installed either by hand or machine. In countries such as the Netherlands, South Africa and Australia both methods have been studied scientifically (eg Shackel, 1986; Macleod, 1994). In new markets or in the Third World, CBP offers the advantage that it does not require a large investment in installation equipment. Moreover, experience shows that it is feasible to achieve good standards of laying inexperienced and unskilled labour albeit with skilled supervision. In this respect, South Africa has led the way with the Reconstruction and Development Programme (RDP) which promotes the use of local labour to construct township and rural roads and, thereby, benefit local communities (Macleod, 1994).

Although many Europeans believe that long-established traditional; methods of laying pavers are universally applicable this is not always the case. Indeed the substantial research effort into gaining an understanding of the performance of CBP under traffic has led to several subtle but important modifications to traditional installation practice in countries such as Australia (Hodgkinson, 1986). These include the need to limit the bedding sand thickness, to control joint widths, to carefully control the grading and angularity of the sand (Shackel, 1980), to place close tolerances on the finish of the basecourse and, sometimes, to supplement plate compaction with normal road rollers (Shackel, 1990). This means that, in some relatively new CBP markets such as Australia, the construction specifications now routinely enforced are often more stringent than those common in Europe. However, these new procedures have been shown to improve the in-service behaviour of CBP and help achieve an optimal level of performance under traffic. However, particularly in

Europe, many inefficient or poor work practices remain entrenched among paviours merely because they are long established or traditional. Such an attitude can have serious consequences in engineered pavements. Therefore, the industry needs to re-educate some of its more recalcitrant installers. Significantly this problem is being addressed by installer training and qualification programs in much of the New World including the USA and Australia.

4. ASSESSMENT OF THE TECHNOLOGY

Compared to materials such as asphalt and cast-in-place concrete the volume of literature available for engineered CBP is negligible and it may seem rash or premature to claim that the technology of CBP is already viable. However, it should be recognised that, except for flags, pavers are small and ,consequently, the stresses generated within them are of little more than academic interest. Accordingly, material properties *per se* do not dominate an understanding of pavement performance as, for example, in asphalt where factors such as chemical composition, temperature and rheology are complex and can vary widely over time or between projects.. Rather, to understand CBP basically requires an assessment of the interaction between the pavers and the bedding and jointing materials. In this respect, sufficient progress has already been made to provide viable models of CBP behaviour that can be used in design (see above).

In the author’s experience, the main causes of CBP failures are the result of the use of unsuitable materials and/or incorrect construction procedures and standards rather than incorrect thickness design. This is often due to a lack of training by engineers and architects in the techniques of using CBP. In turn, this frequently reflects poor dissemination of the technology.

5. DISSEMINATION OF CBP TECHNOLOGY

The main sources for disseminating information on CBP have been regional concrete paving associations. Here, draw particular attention must be drawn to the CMAA in Australia, CMA in South Africa; Interpave in the UK, ICPI in North America and JIPEA in Japan. Each of these associations has prepared a range of technical documents covering everything from testing pavers to the construction of a wide range of different paving applications. These are often the primary sources of information for practitioners for designing and specifying paving projects. Notwithstanding this, many engineers and architects remain ignorant of the capabilities and technology of CBP and tend to rely on paver manufacturer’s sales publications. Unfortunately, too many manufacturers remain oblivious of CBP technology or of the needs of customers where engineered pavements are involved.

By comparison with asphalt and rigid pavements, the dissemination of CBP technology has been very limited. Outside Europe, few universities teach anything concerning CBP although most students receive limited training in asphalt and concrete paving. Whilst many European text books on pavements include some mention of segmental paving this is often restricted to minor municipal works and little, if any, distinction is made between concrete, stone and brick segmental paving. Just two text books have been published on the technology and application of CBP but one of these is available only in English (Shackel, 1990; Lilley, 1991).

One of the challenges of advancing any technology is that people make efficient use of existing resources. A disappointing feature of many publications on CBP is the unnecessary duplication of research effort that arises when authors have not adequately acquainted themselves with what has already been done or published. In part, this reflects the hitherto limited distribution of conference proceedings etc to university and research libraries. Hopefully, the fact that this conference is published on CD-ROM will make it easier for libraries and, indeed, industry members to acquire and share this information.

Overall, much more work needs to be done to propagate the technology of CBP. The challenge is a daunting one for an industry that is such a small player in the field of engineered pavement construction. However, the increasing penetration of pavers into the residential street, municipal, industrial and airport paving markets shows the rewards that can be won by publicizing the technology. Fortunately electronic information technology promises to make the costs of achieving this more manageable than hitherto.

6. CONCLUSIONS

For much of its history CBP has been a specialised, experience-based craft largely centred on Europe. However, within the space of just some 30 years, concrete block paving has been transformed into a worldwide phenomenon which is increasingly supported by well researched engineering technology. Much of the research has been conducted outside Europe because of the need to demonstrate the technical advantages and viability of pavers to clients and engineers for whom CBP was an unfamiliar and unproven concept.

Some manufacturers still view CBP as an aesthetic product which can be promoted with little knowledge of technology beyond that needed to manufacture the pavers. However, if the industry wishes to win and retain a significant proportion of the market in civil engineering works it will have to better understand and address the attitudes and expectations of engineers than it has done hitherto. This means that paver manufacturers and suppliers will need increasingly to foster and promote the technology of applying CBP in civil engineering works.

7. ACKNOWLEDGEMENTS

Research into CBP technology is now a worldwide phenomenon. However, this was not always so and little of the testing that now provides the foundation the technology would have been initiated or funded but for the crucial roles played by industry associations such as the Cement and Concrete Associations of Britain and Australia, the Concrete Masonry Association in Australia, the Portland Cement Institute and Concrete Manufacturers Association in South Africa, and the Vereniging Nederlandse Cementindustrie in Holland. Research organisations such the CSIR in South Africa were also crucial to developing the technology of CBP. That these organisations became involved in CBP owes much to the pioneering work and vision of men like Paul Morrish of Australia, John Lane of South Africa, Arnold Van Der Vlist of Holland and Alan Lilley of the UK.

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