THE OBJECTIVE SELECTION OF CONCRETE BLOCK PAVING FOR ENGINEERING PROJECTS

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SUMMARY

There is rarely any unique solution to most pavement design problems. Rather, there will normally be a wide range of pavement alternatives representing different combinations of materials and construction techniques that will give satisfactory service. The choice of pavement is often made subjectively i.e. selection is usually a matter of the skill, judgement and experience of each designer. Accordingly, there is little guarantee that the solution will be optimal particularly because relatively few engineers are yet familiar with CBP compared to asphalt or cast-in-place concrete. It is desirable, therefore, to identify objective selection criteria for choosing pavement types. This paper shows that it is possible to minimise the subjective inputs in pavement selection so that engineers can objectively choose the most appropriate pavement for a particular application. This should help CBP win more engineered paving projects.

1. INTRODUCTION

Most pavement design problems have more than one solution. Typically, several pavement alternatives drawn from various combinations of materials and construction techniques can be devised that will meet service requirements. Concrete Block Paving (CBP) is usually only one possible solution and must be evaluated against more established alternatives such as asphalt and/or rigid concrete pavements. Selecting a solution amongst the various alternatives is usually a matter of the pavement designer's skill, judgement and experience with little guarantee that the choice will be optimal. Moreover, because the technology of CBP is unfamiliar to many engineers CBP is likely often to be overlooked or ignored in the pavement selection process. For these reasons it is desirable to promote objective criteria characterising CBP that can be used in pavement selection. It is possible to draw up lists of selection criteria to aid in choosing a pavement type. For example, Table 1 lists subjective selection criteria for CBP compared to asphalt and concrete pavements (after Shackel, 1990, 1996a). This table provides reasons for considering CBP as a possible design solution. However, the criteria in the table are subjective and are difficult or impossible to quantify. They are, therefore, are open to dispute. For this reason they seldom, by themselves, form the basis for choosing a particular type of pavement for a specific design project. Rather, designers usually show a preference towards using objective selection criteria that can be quantified so that comparison between alternatives can be made numerically.

In practice, the initial or whole-of-life cost of a project has usually been the main or even sole arbiter of pavement selection by engineers. However, in recent times, other factors including environmental impact and sustainability have begun to assume equal or greater importance amongst decision makers. This paper looks at ways in which selection criteria can be handled in an objective quantifiable way for CBP.

Table 1. Subjective Pavement Selection Criteria

SELECTION CRITERIA	PAVEMENT TYPE		
	CBP	**Asphalt**	**Rigid Concrete**
Aesthetics	Very good. A wide range of colours, textures & patterns can be readily specified	Very Poor. Difficult to colour. Patterns tend to distort under traffic	Poor. Limited choice of colour. Difficult to pattern.
Construction equipment	Machines for laying pavers are smaller, simpler and less expensive to own, transport and operate than asphalt paving machines or concrete slip formers	Asphalt paving machines are large and expensive to own, transport and operate	Concrete slip form paving machines are large, complex and expensive to own, transport and operate
Overall speed of construction	Relatively slow but can be opened to traffic immediately after compaction	Fast	Slow – often requires lengthy curing before opening to traffic
Trenching and reinstatement	Pavers can be easily and quietly removed and replaced without the need for jackhammers or saws. Original appearance of pavement can be maintained.	Requires jackhammers or saws and is noisy. Original surface cannot be re-laid without expensive reprocessing.	Requires jackhammers or saws and is noisy. Original surface cannot be re-laid without expensive reprocessing
Recycling	Pavers can be recycled and reused without reprocessing	Material needs to be reprocessed before reuse	Material needs to be reprocessed before reuse
Resistance to heavy and/or concentrated loads	Good	Poor	Very good
Resistance to heavy turning or slewing loads	Good	Poor	Very good
Resistance to fuel and oil spillages	Good	Poor	Good

2. QUANTIFIABLE PAVEMENT SELECTION CRITERIA

Pavement selection criteria that can be quantified include:

1. Initial (construction) costs
2. Discounted whole of life costs.
3. Life cycle analyses and other measures of sustainability.
4. Environmental impact ratings
5. Skid resistance of the pavement surface

6. Durability both of the pavement and of the pavers.
7. Components related to aesthetics such as colour and luminance.

3. COST CRITERIA FOR CONCRETE BLOCK PAVEMENTS

The costs of constructing a pavement depend largely on the relationship between pavement type, design loads and subgrade strength. For example, CBP becomes increasingly cost-effective as both the loads increase and the subgrade strength decreases. For CBP, cost information is available for roads and industrial pavements (e.g. Shackel, 1990, 1996a). To date, the most comprehensive cost comparison data originates from ports and container yards in Europe, the USA, Australia and South Africa (e.g. John Emery Geotechnical Engineering, 2000). These data show that the construction costs of asphalt and block pavements are often similar but tend to be less than the costs of cast-in-place concrete pavements. Data on maintenance costs are sparser but indicate that asphalt and concrete pavements tend to have similar costs which are up to three times higher than those associated with concrete block paving (e.g. Shackel, 1990, 1996a).

The utility of a proposed pavement and the associated projected maintenance and rehabilitation strategy is commonly evaluated using economic concepts such as the present worth of costs (PWOC) although for organisations for which interest payments on pavement costs are of little concern, alternative forms of analysis such as cash flow evaluations may be more appropriate. Different types of pavement and/or different maintenance strategies can be readily compared using PWOC analyses. Such comparisons have been reported for both roads and industrial CBP (e.g. John Emery Geotechnical Engineering, 2000). Depending on the discount rate, these analyses are often favourable to CBP.

4. CONCRETE BLOCK PAVING, SUSTAINABILITY AND THE ENVIRONMENT

Measurements of environmental ratings and sustainability often demonstrate advantages for CBP over asphalt or cast-in-place concrete. In general, concrete pavers offer several intrinsic environmental benefits over alternative forms of construction including

1. *Reuse and Recycling*. Unlike alternative pavement surfaces, CBP is relatively easy to lift and reuse whether as part of an in-situ maintenance or repair procedure or in a new location.
2. *Albedo.* Concrete pavers generally exhibit much higher albedo (i.e. the ability to reflect heat and light) than alternatives such as asphalt. The benefits of this are a reduction in heat island effects in urban areas and a more efficient use of electricity in air conditioning and street lighting. This helps reduce the production of greenhouse gases from electricity generation
3. *Durability.* Concrete pavers are made under factory conditions and, subject to careful and controlled manufacture, offer much longer service lives than asphalt surfaces. Effective lives of around 40+ years have been reported (Shackel, 1990, 1996a). The longevity of CBP means that fewer reconstruction cycles are needed and this reduce service delays and demands on construction resources.
4. *Construction Materials.* During manufacture pavers can aid the environment by utilising industrial by-products such as slag aggregates, fly ash and silica fume.

It may be seen that some of these factors were already listed amongst the subjective selection criteria given in Table 1. It will now be shown that several of the factors, in combination with one another, can be quantified in terms of environmental ratings.

Amongst the various form of concrete segmental paving, permeable interlocking concrete paving (PICP) makes the greatest beneficial contribution to the environment. In addition to the inherent environmental benefits of the pavers themselves, permeable concrete block paving offers several major environmental advantages by contributing to the concept of Low Impact Design (LID). Here the objectives are to replicate the pre-development hydrology of a site so that the impact of development is minimized, runoff is reduced by infiltration and impervious cover is minimized; thereby facilitating infiltration. In meeting sustainability and LID requirements, permeable CBP provides (Shackel, 1996a, 1996b):

a) A reduction in the amount of rainfall runoff from pavement surfaces and, thereby, a decrease in the extent of the stormwater drainage system necessary. This is subject to the pavement sub-structure being designed to provide adequate water storage, to achieve suitable emptying times etc.
b) A decrease in the size or need for rainwater retention facilities in projects by using the pavement itself for retention.
c) A reduction in downstream flooding.
d) Assistance in recharging and maintaining aquifers and the natural groundwater and stored water re-use.
e) Help in trapping pollutants that would otherwise contaminate groundwater or drainage systems.
f) Assistance in the biological decomposition of hydrocarbon contaminants.

4.1 Environmental Rating Systems

Sustainable development implies equilibrium between environmental, social and economic objectives protecting the world for future generations. There is a need for green rating systems to measure progress towards these goals. Ratings provide green benchmarks and accountability, promote green strategies and act as market transformation tools. Examples of such systems include:

1. LCA (Life Cycle Analysis). LCA accounts for the environmental loads created by a product or service from "the cradle to the grave" including the recycling and reuse of materials. Potentially the method provides planners with a tool to compare different pavement types and maintenance and rehabilitation strategies in terms of their environmental impacts.
2. LEED (Leadership in Energy and Environmental Design). LEED uses a points rating system for measuring sustainability. Points or credits are earned by showing evidence of compliance with the rating system.

Each of these systems is now discussed further.

4.1.1 Life Cycle Analysis

The interaction between a product and the environment can be modelled using Life Cycle Analysis (LCA). LCA accounts for the environmental loads created by a product or service through its whole life. It seeks to assess environmental impacts in terms of the energy embedded during manufacture etc and the effects of carbon dioxide emissions on Global Warming. LCA therefore examines the amounts of energy imbedded in the materials and required during manufacture, the fossils fuels consumed in manufacture, installation, maintenance, demolition, salvage and recycling, the landfill space for dumping waste (and toxicity) and greenhouse gas emissions. The objectives of LCA include:

1. To help consumers select products that have the smallest adverse impact on the environment.
2. To help producers minimise the impact of their products.

3. To help governments determine which products are result of processes that have unacceptable impacts e.g. in the depletion of the ozone layer.
4. To determine the requirements for a sustainable environment.

Efforts to develop LCA methodology first began in the US in the 1970s but most practical applications have only begun to emerge in the last 10 years. LCA has been promoted by the United States Environmental Protection Agency (USEPA, 1993), the Society for Environmental Toxicology and Chemistry (SETAC) in North America and Europe and the International Standards Organization (ISO). Standard frameworks exist to implement LCA (e.g. ISO 14040-43, 1997-200) and a variety of software tools have been developed such as the EcoConcrete LCA-tool used by CEMBUREAU in Life Cycle Inventories. LCA has also been combined with economic analyses by Carnegie Mellon University's Green Design Initiative group to form Economic Impact-Output LCA, EIOLCA (Conway-Schempf, 1999.) Software has also been developed to implement EIOLCA. (Carnegie Mellon, 1999).

Life-Cycle Analysis (LCA) provides a means for identifying and evaluating environmental impacts associated with the life cycles of materials and services in a "cradle-to-grave" approach. This requires that the method captures impacts from every material and energy input during construction and maintenance and throughout the service life of the pavement, including raw materials, manufacturing, on-site and off-site construction, maintenance, reconstruction, recycling and waste handling.

There is currently considerable argument about applying LCA to pavements and LCA methodologies vary widely between the reported studies. LCA has been used as a decision support tool (e.g. Conway-Schempf, 1999; Horvarth, 2001, 2003). In France, LCA methodology has been extended at Laboratoire Central des Ponts et Chaussees (Hoang et al, 2005) to integrate environmental assessment and road planning. LCA has also been used to assess the environmental impacts of particular surfacing materials. To date, only one of these studies appears to be directly relevant to concrete block paving. This is the Green Guide to Specification published by the Building Research Establishment (BRE) in the United Kingdom (Anderson et al, 2002). This covers such issues as toxicity, primary energy, emissions, resources, reserves, wastes generated, recycling, and replacement interval.

BRE uses a common set of criteria to rank the environmental impacts of materials. The criteria include climate change, ozone depletion, consumption of materials, water and fossil fuels, emission of pollutants and waste. For each criterion an environmental impact rating of A to C is assigned using measured data with A representing the least impact and C the worst. Using consensus weightings for the criteria, an overall A, B or C rating can then be assigned to each material studied. This provides a simple way for designers to select materials in terms of their environmental impact. The BRE report covers a wide range of pavement surfaces including concrete block paving, grass stones, bricks, granite setts, asphalt and cast in place concrete. Concrete pavers achieve an A rating overall showing that they have a low impact on the environment. By contrast, asphalt and in-situ concrete both have worse environmental ratings than CBP.

4.1.2 Leadership in Energy and Environmental Design (LEED)

Originally developed by U S Dept of Energy but now administered by the US, Canadian and other Green Building Councils, LEED is a self-assessing, voluntary system for rating new and existing construction and sites. LEED evaluates environmental performance from a "whole building" perspective over a project's life cycle, providing a standard for a "green project" or a "green site". Significantly, while private sector participation is voluntary, many municipalities in North America are

beginning to require that city-owned or funded projects, including pavements, achieve LEED objectives.

By contrast to Life Cycle Analysis which serves to assess the sustainability of the materials used to construct a pavement, LEED enables the environmental impacts of the pavement to be rated. However, LEED is not specific to a pavement as a stand-alone project but, in its current implementations, treats it merely as one component of some bigger construction project. This makes it difficult to use LEED where the pavement exists in isolation from other building works and, together with the arbitrary nature of LEED ratings, must be considered a major drawback to using LEED for pavements in the long term. However, its increasingly widespread adoption by state and municipal authorities in North America make LEED an attractive tool for comparing pavements, at least in the short term.

Details of the LEED system are given elsewhere (e.g. LEED-Canada, 2004) and useful guidelines for applying LEED to CBP have been published by ICPI (2005). LEED is a points rating system for measuring environmental impacts. Points or credits are earned by showing evidence of compliance with the system. Considering only those aspects of the LEED system relevant to pavements, concrete block pavements can earn LEED credit points for:

1. Water efficiency – up to 2 points
2. Reductions in stormwater runoff – 1 point
3. Reductions of TSS and phosphorous – 1 point
4. The use of high albedo surfaces – 1 point
5. The use of salvaged or recycled materials– up to 4 points
6. The use of materials extracted, processed and manufactured regionally – up to 2 points

A project requires at least 26 credit points to achieve LEED Certification but it is not possible to earn these points solely from the paving. Conventional (impermeable) paving can earn up to 7 LEED credits and permeable paving can earn up to 11 points. Up to 2 additional points may be awarded if the paving embodies innovations such as substantially exceeding LEED performance targets (e.g. in terms of water efficiency) or by applying techniques such as life cycle analysis (LCA) of the materials. As noted above, LCA analyses have been performed for pavers and CBP would qualify under this provision.

Despite the arbitrary nature of the weightings used, LEED nevertheless provides a numerical basis for comparing pavements forming part of some larger construction project and therefore can assist engineers to select a pavement objectively. This can work to the advantage of CBP in pavement selection because CBP generally can attract more LEED credits than asphalt or in-situ concrete.

4.2 Surface Characteristics

The surface characteristics of CBP have been reviewed elsewhere (Shackel and Candy, 1988; Shackel, 1990, 1996a). These include attributes such as colour and luminance which relate to the aesthetics and appearance of the paving and performance factors such as roughness or riding quality, skid resistance and noise generation.

4.2.1 Aesthetics and Appearance

Whilst in many countries such as Australia the market penetration of CBP has been linked successfully to providing economic pavements meeting customary engineering serviceability criteria, other markets, such as that in the USA, have hitherto been largely led by aesthetics (Shackel, 2003). This has alienated some engineers from CBP as an engineering alternative because aesthetic considerations appear to be incapable of being quantified and, therefore, of being ranked objectively or consistently. Although the assessment of aesthetics is qualitative and is associated with non-monetary costs and benefits, these can be assessed by using multi-attribute decision analysis tools such as the ASTM analytical hierarchy process (AHP) to supplement economic and other assessment measures (ASTM, 2002). Such tools do not yet appear to have been applied to CBP. Nevertheless, it should be recognized that several important factors whereby paving achieves its aesthetic impact can be quantified. These factors include measurements of both colour and luminosity. Such data are already available for CBP and demonstrate practical advantage over competing products such as asphalt.

Concrete blocks are unique amongst pavement surfacings in respect of the ease with which colour may be controlled. This allows engineers to specify colour as a design element. Direct measurements of colour in CBP and asphalt have been made at the Australian Road Research Board (Jenkins and Sharp, 1985). A simpler alternative to direct colour measurements is to characterise CBP in terms of the luminance factor. This is a measure of the amount of light reflected by the material. The luminance factor of pavers typically ranges between about 0.15 and 0.30 (Shackel and Candy, 1988) although higher values can be achieved by appropriate, albeit often expensive, adjustment of the concrete mix. Irrespective of the paver colours, these values are much higher than the luminance factors normally measured for asphalt (*circa* 0.07). This shows that, pavers, irrespective of their colour, reflect between 2 and 3 times more light than asphalt. This has beneficial impacts on safety, the visibility of the road surface by day and by night and street lighting costs. Luminance therefore provides a more practical measure of the appearance of paving than colour *per se.*

4.2.2 Roughness and Riding Quality

Relatively few measurements or assessments of the surface roughness of CBP are available (e.g. Lekso, 1980; Miura et al, 1984). In general, these tend to indicate that CBP yield measures of roughness that are inferior to asphalt surface although this is not necessarily perceived to be the case by drivers. This is one area where reported measurements may not be favourable to CBP selection.

4.2.3 Skid Resistance

Numerous surface friction and skid resistance measurements for CBP have been reported (e.g. Smith, 2000). These generally show that skid resistance values for CBP compare favourably with those measured for asphalt. For example, the British Pendulum Numbers, BPN, Skid Numbers, SN, and SCRIM values of CBP are generally well above those typically specified for safe highway operation (e.g. Smith, 2000).

4.2.4 Noise Generation

Increasingly, the traffic noise generated on urban road surfaces is being considered by municipal authorities as a criterion for selecting pavements. There are several noise measurements available for CBP (e.g. Samuels and Sharp, 1984; Shackel and Candy, 1988; Shackel, 1996a) and numerous techniques for modifying pavers to minimize road noise have be reported. In general the measurements tend to show that traffic noise on CBP measured at the kerb or building line is no worse than for asphalt surfaces for dry surfaces and may be less for wet roads (e.g. Miura et al, 1984) provided vehicle operating speeds do not exceed about 50 kph (Shackel, 1996a).

5. RANKING SELECTION CRITERIA

The various selection criteria discussed above are ranked in Table 2. Numerical values can be assigned to each of the criteria listed in the table. The criteria are ranked as A, B or C with A being the best. This has been done because, for all the criteria, the numerical values are either project or paver specific. Suitable values can be obtained either by tests or from the literature.

Table 2. Rankings Of Quantifiable Selection Criteria

SELECTION CRITERIA	PAVEMENT TYPE		
	CBP or PICP	Asphalt	Rigid Concrete
Construction Costs	A	A	B
Whole of Life Costs	A	B	C
LEED Credits	B – CBP A - PICP	C	B
Sustainability – LCA e.g. BRE Ratings	A	C	C
Surface Roughness	C	A	B
Skid Resistance	A	B/C	A/B
Traffic Noise	A/B	A	B/C
Service Life	A	B	A
Surface Durability	A	C	A
Luminance factor	A	C	A

6. CONCLUSIONS

This paper shows that CBP can be ranked numerically against alternative forms of construction such as rigid concrete and asphalt. These rankings cover most of the factors that engineers, state or municipal authorities consider in the project-specific selection of pavement type. This means that objective, numerically based comparisons between CBP and other types of pavement can be made. As shown above, the literature shows that many of these comparisons can be to the advantage of CBP, particularly in the economic and environmental areas.

Hitherto engineers and state and local authorities have used cost as the main criterion for choosing amongst pavement alternatives. Increasingly, however, issues of sustainability, environmental impact and safety have been treated as selection criteria of equal or even greater importance. Both LCA and LEED provide ratings that can be used objectively to rank pavements in terms of sustainability and environmental impact. As shown above, the ratings implicitly include several of the factors that need to be considered when selecting a pavement but which, hitherto, have often been ignored because they

have been difficult to quantify. Interlocking concrete block paving in general and permeable block paving in particular show benefits under these rating systems because they make beneficial contributions to sustainability and the environment. Indeed, both CBP and PICP exhibit significantly better environmental credentials than asphalt or cast-in-place concrete pavements.

Until engineers gain more experience in designing and constructing CBP they will remain reluctant to use it in preference to more familiar materials such as asphalt. Accordingly it is important to draw the attention of administrators, planners, designers and specifiers to the existence of selection criteria that can be quantified and which enable CBP to be objectively compared with established pavement types. This will aid them to justify choosing CBP. Such selection criteria therefore deserve to be integrated into the decision making processes involved in pavement planning, design and implementation. This will ensure that the benefits of concrete block paving are considered more comprehensively that has often been the case in the past.

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