WHOLE-LIFE COST ANALYSIS OF CONCRETE BLOCK PAVING

by

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Summary
One of the major advantages claimed for a well-constructed, interlocking, concrete block pavement is low maintenance cost over a long life. In order to take into account the different maintenance costs associated with alternative pavement surfacings, it is necessary to calculate discounted, whole-life costs in which all costs throughout the analysis period are accounted for. Maintenance costs for concrete block pavements are not readily available and a plea is made for the collection of the required data. The elements of cost to be taken into account are discussed and equations developed to compare block paving with a bituminous surfacing over a forty year period. Values of discounted, whole-life costs are calculated for three discount rates, using typical cost data. The advantages of a low maintenance pavement are shown to be greatest at low values of the discount rate. Comparison of the costs of alternative surfacings, on the basis of initial construction costs alone, does not reflect the economic benefits of low maintenance costs and re-usability of pavers.

INTRODUCTION

Among the advantages attributed to interlocking concrete block pavements, when compared to other forms of surfacing, are low maintenance costs over a long life and the ability to re-use pavers for pavement reinstatement following access to buried services. If alternative surfacings are considered only on the basis of initial construction costs, the long-term economic benefits, accruing from the advantages noted, will not be taken into account. It is argued that alternative surfacings should, more properly, be compared on the basis of discounted whole-life costs, in which the effects of differing maintenance and rehabilitation costs are included. This form of economic analysis is only possible if real cost data are available for all elements of cost including annual maintenance. At the present time, the costs of annual maintenance of different surfacings are not well documented and this paper is, in part, a plea for the collection and dissemination of the necessary cost data.

BLOCK PAVING APPLICATIONS

Applications of concrete block paving may be grouped according to the predominance of either engineering or architectural aspects. Pavers are appreciated by architects and landscape architects for their human scale and for the diversity of shape and colour which they offer. In typical architectural applications, it is aesthetic factors rather than economics which govern the choice of materials. These applications may include road pavements, particularly in areas of urban renewal, however, in most engineering applications,

any aesthetic appeal is usually of secondary importance compared to cost. Concrete pavers are frequently used for pavements supporting traffic and heavy, industrial loads on roads and in ports, container terminals, heavy equipment maintenance yards and airports. In these engineering applications, cost comparison of technical alternatives is usually the deciding factor. Thus, in these applications it is important that the method of ecomomic analysis used, reflect the full spectrum of costs and benefits for each alternative design.

COST EVALUATION

Where concrete pavers are selected primarily for their architectural or aesthetic features, economic criteria are of lesser importance and comparative economic analysis of alternatives may be considered unimportant. However, where material selection depends on the ability of the pavement to meet functional, engineering performance criteria, the comparison of the costs of alternative surfacings is likely to be decisive. In such cases, economic analysis of technically acceptable pavement alternatives should be an essential step in the selection process. This has been recognized, for example, in South Africa[1] where cost analysis is an integral part of the design of structural, concrete block pavements. In order to compare the costs of pavement design alternatives, a common analysis period must be selected and all costs occurring during that period should be taken into account. In practice, this is seldom done, due in part to the difficulties in predicting future costs and in part to political aspects of the financing of public sector road projects, in which there is considerable pressure to select the pavement having the lowest initial construction cost. In the case of block paving the absence of reliable, long-term maintenance cost data is a further obstacle. As different pavement surfacings have different lengths of service life and require different levels of maintenance expenditure, an accurate comparison of the total costs of alternatives can only be made through the use of discounted, whole-life (or life-cycle) cost analysis.

WHOLE-LIFE COSTS

Under the combined effects of climate and traffic, every pavement begins to deteriorate from the moment it is completed. This may be expressed as a progressive decline in the riding quality to some terminal value at the end of the pavement's service life. Moreover, in calculating the design life of a pavement in terms of the traffic it will carry, it is assumed that regular routine maintenance, and in the case of asphalt pavements, occasional surface dressing to maintain skid resistance, will be required. Thus, in addition to the initial construction cost, there will be a series of maintenance costs incurred which must be taken into account. In whole-life cost analysis, all costs are considered over the analysis period. It is assumed that the alternative pavement surfacings being compared will each procure the same benefits and that the different surfaces will not result in significant differences in vehicle operating costs. The purpose of whole-life cost analysis is to show which form of construction

will produce the lowest discounted total cost over the life of the structure. This will not necessarily be the pavement structure paving the lowest initial construction cost. The main economic factors affecting the cost are:- analysis period, pavement service life, discount rate, construction costs, maintenance costs and salvage value.

ANALYSIS PERIOD AND SERVICE LIFE

In whole-life cost analysis it is necessary to establish an analysis period, within which all costs will be taken into account. It is convenient to take the analysis period equal to the service life of the pavement. However, pavements constructed with different surfacing materials are designed for different service lives. For example, in the U.K., design lives of twenty years for bituminous surfacings and forty years for concrete roads are commonly used.[2] Twenty years is also recommended for roads surfaced with concrete pavers.[3] In order to compare the costs of alternative pavement designs, a common analysis period must be selected. There are two main approaches:-

(i) to select an analysis period equal to the longest design life. For example, taking forty years as the design life of a concrete road and twenty years for a bituminous pavement, an analysis period of forty years would conveniently encompass two, twenty year, bituminous design lives.

(ii) to select an analysis period equal to the shortest life and to take into account the residual value, at the end of the analysis period, for pavements having longer lives.

The first approach has been applied to footways in the U.K.[4] using design lives of fifty years for concrete flags and twenty-five years for bituminous construction. This approach is useful for low values of the discount rate.

DISCOUNT RATE

In order to compare costs occurring at different times, it is necessary to select a discount rate to express future costs in terms of their present worth. The discount rate is the minimum attractive rate of return on an investment. The choice of an appropriate discount rate is important and the sensitivity of the cost analysis to changes in the discount rate, should be checked. It higher discount rates, the effect of long-term cost savings is diminished and the contributions beyond approximately thirty years become negligible.

CONSTRUCTION COSTS

It will normally be possible to determine initial construction costs accurately, on the basis of either prices bid for the job or currently published unit costs. As different surfacing materials aften require different thicknesses of roadbase and sub-base layers, each design should be costed per unit of surface area for each layer. It is not necessary to include items which may be identical whichever surfacing is selected, for example, kerbs and gutters, drainage, etc.

MAINTENANCE COSTS

Different pavement surfacings require different routine maintenance. It should be assumed that preventative maintenance will be carried out when required on the basis of engineering judgement. In the case of bituminous surfacings, allowance should be made for filling cracks as soon as the occur, so as to avoid water infiltration and further deterioration. Every five to seven years, surface dressing will be required to restore skidding-resistance. Strengthening overlays should be budgeted for when rutting in the wheel paths reaches 10mm so as to preserve the structural integrity of the existing pavement. The time taken to reach this state of rutting will depend on the traffic using the road. Maintenance costs for well constructed concrete block pavements will generally be low and will often be associated with particular features, for example, it may be necessary to replace small numbers of blocks physically damaged by container handling operations or by slewing of tracked vehicles. Concrete block paving is often selected where severe differential settlement is expected. This will require lifting the pavers, restoring the roadbase and relaying the pavers. It has been suggested[5] that a typical allowance for this at U.K. ports would be of the order of £0.04 per square metre, per annum (1988 prices).

SALVAGE VALUE

The salvage value of a pavement at the end of the analysis period is the value assigned to the pavement materials for re-use, most probably in another pavement structure. In the case of concrete block paving, undamaged pavers which can be lifted, cleaned and relaid will have a salvage value. The salvage value is considered to be a negative cost and will be discounted to year zero.

OTHER COST FACTORS

In some cases differences in the time taken to construct the pavement and open it to traffic will give rise to cost differentials. An example of this occurred in the construction of the concrete block taxiways at the Dallas/Fort Worth airport where the use of pavers reduced, by two hours per night, the period of adjacent runway closure. This was estimated[6] to have saved US$37,130 per day in reduced airline delays, or a total of more than four million US dollars over the full construction period. A second example of this nature occurred during the construction of an ore processing plant in South Africa[7] where concrete blocks were used to pave roads, storage areas, and general open spaces. The fast-track construction programme required use of the pavement by steel fabricators as soon as possible after construction was complete. If in situ concrete slabs had been specified the construction programme would have been delayed due to curing periods and asphalt would have suffered considerable damage by heavy construction equipment. This represents a cost advantage to concrete block paving which should be included in the whole-life cost comparison.

COST DATA

A complete cost comparison for a particular project is seldom made available. However, unit costs for concrete slabs, asphalt and concrete block paving are usually obtainable to permit a comparison of initial construction costs. The big variable between countries appears to be the cost of bituminous paving materials. For example, in the U.K., concrete block paving and hot rolled asphalt surfacings appear to be comparable in initial construction costs, whereas in Canada, the initial construction cost of concrete block paving tends to be approximately twice that of comparable asphalt. Published cost data[6] have shown that installed concrete block paving, in the United States, has historically cost almost three times the comparable cost in Europe, Australia and South Africa. Figures of approximately US$14 per square metre for the latter and US$39 per square metre for the United States are indicative, but must be treated with caution as they are unadjusted for time. Clearly, accurate local project costs are an essential prerequisite to meaningful cost comparisons. Very few data on maintenance costs for concrete block paving appear to be available, but the general consensus of published statements indicates that for a well-constructed pavement these are considered to be negligible. In the Netherlands experience, it has been found[9] that a block pavement has a life of forty years and that one full-scale repair, requiring replacement of five to ten per cent of the blocks, will be required during that life-time. Using these data, Rollings[8] calculated that, for an eight per cent discount rate and a forty year analysis period, a concrete block pavement would have a cost advantage over a comparable bituminous pavement, if the traffic exceeded one million equivalent standard axles. Typical maintenance costs for bituminous and concrete slab surfacings are better known as these have typically been studied by bitumen and cement trade associations. It may be observed that the routine preventative maintenance required by bituminous and concrete slab pavements is frequently not carried out when required but is either omitted or deferred as a cost saving measure. This can be taken into account in the whole-life cost calculations as it leads to reduced structural life and higher rehabilitation costs. Thus the cost advantage of a pavement surfacing which suffers least from neglect of maintenance can be quantified.

SENSITIVITY ANALYSIS

As there will be a degree of uncertainty associated with many of the values used in the cost comparison, it is useful to determine how sensitive the result is to variations in the input values. For example, the discount rate used will be a best estimate, but the outcome will be affected by the value chosen. The calculations should be repeated for higher and lower values in order to determine the sensitivity of the result obtained to variation in the discount rate. All other variables can be treated similarly.

COST COMPARISON

In order to demonstrate the analysis of whole-life costs, consider a road pavement design to support five million standard axles over a subgrade with a California Bearing Ratio of five. This would

result in the typical designs shown in Figure 1. The analysis period is taken to be forty years.

Bituminous surfacing

The costs considered are the initial construction cost, I_A, an annual maintenance cost, M_A and a periodic surface dressing cost, D. It is assumed that maintenance will be required each year and that the funds will be available and considered spent at the beginning of each year. Surface dressing will be carried out during the seventh and fourteenth years. The cost of surface dressing, when carried out, is considered to include that year's maintenance costs. Construction funds are considered spent one year prior to the entry into service of the road. At the end of twenty years service the bituminous pavement will be replaced by a new one and the cycle of costs from year zero to year twenty will be repeated from year twenty-one to year forty. These cash flows are illustrated in Figure 2. The discounted costs will be as follows for a discount rate of 'a' per annum:-

$$WLC_1 = I_A + \sum_{n=1}^{20} \frac{M_A}{(1+a)^n} + (D-M_A)\left[\frac{1}{(1+a)^7} + \frac{1}{(1+a)^{14}}\right] \quad \cdots \quad (1)$$

where WLC_1 is the discounted whole life cost of the first hot rolled asphalt surfacing from construction to the end of its twenty year life. The total whole-life costs for the two asphalt pavements will therefore be:-

$$WLC_A = WLC_1\left[1 + \frac{1}{(1+a)^{21}}\right] \quad \cdots \quad (2)$$

Using discount rates of five, ten and fifteen per cent, the following expressions can be derived:-

a			
0.05	WLC_{A5}	$= 1.359I_A + 15.283M_A + 1.653D$	. . . 3(a)
0.10	WLC_{A10}	$= 1.135I_A + 8.783M_A + 0.776D$	. . . 3(b)
0.15	WLC_{A15}	$= 1.053I_A + 6.046M_A + 0.517D$	. . . 3(c)

Substituting the following values in U.S dollars per square metre, $I_A = 18.4$, $M_A = 0.45$, and $D = 2.05$, one obtains the whole-life costs shown in Table 1.

Concrete block paving

The costs considered are the initial construction cost I_B, and an annual maintenance cost M_B. The pavement, with routine maintenance is considered to last for the full forty years of the analysis period and to have a salvage value, S, at the end of that period. This is treated as a cost reduction at the end of the forty years. The cash flows are also shown in Figure 2. In this case the discounted, whole-life costs will be given by the following expression:-

$$WLC_B = I_B + \sum_{n=1}^{40} \frac{M_B}{(1+a)^n} - \frac{S}{(1+a)^{41}} \quad \ldots\ldots \quad (4)$$

using discount rates of five, ten and fifteen per cent, as previously,
the following expressions can be derived:-

a			
0.05	WLC_{B5}	$= I_B + 17.159M_B - 0.135S$	. . . 5(a)
0.10	WLC_{B10}	$= I_B + 9.779M_B - 0.020S$	. . . 5(b)
0.15	WLC_{B15}	$= I_B + 6.642M_B - 0.003S$	. . . 5(c)

substituting the following values in U.S. dollars per square metre,

$I_B = 23.60$, $M_B = 0.131$ and $S = 5.90$, one obtains the whole-life costs shown in Table 1.

Discount Rate	Asphalt	Pavers
0.05	35.27	25.05
0.10	26.42	24.76
0.15	23.16	24.45
Initial Costs	18.40	23.60

Table 1 Whole-life costs in U.S. dollars per square metre

DISCUSSION

It can be seen that the discounted cost approach results in a greater difference between initial construction cost and whole-life cost for pavements which require more maintenance over their service lives. For the low maintenance costs assumed for the concrete block pavement, whole-life costs were not appreciably greater than initial construction costs and were insensitive to the discount rate in the range five to fifteen per cent. At a discount rate of five percent discounted maintenance and rehabilitation costs for the asphalt surfacing were of the same order of magnitude as initial construction costs, but were significantly reduced as the discount rate increased to fifteen per cent. Clearly, whole-life cost analysis can only be useful if costs can be accurately estimated. Whole-life cost analysis shows that pavements having low maintenance over a long life become increasingly attractive at lower discount rates.

CONCLUSIONS

- Comparison of alternative pavement surfacings on the basis of initial construction costs does not take into account long-term economic benefits of low-maintenance pavements such as those surfaced with interlocking concrete pavers.
- Whole-life cost analysis takes into account all costs over

a given period of time and allows comparison of alternative pavement structures on the basis of discounted total costs.

- Particularly for low values of the discount rate, the ranking of pavement structures on the basis of whole-life costs can differ from that based on initial construction costs.
- Meaningful whole-life cost analyses require accurate estimates of all costs over the full analysis period.
- The benefits accruing from the low maintenance required by a well-constructed interlocking concrete block pavement can be taken into account through the use of whole-life cost comparisons with alternative surfacings.
- There is a need for data concerning the actual maintenance requirements and associated costs of in-service concrete block pavements

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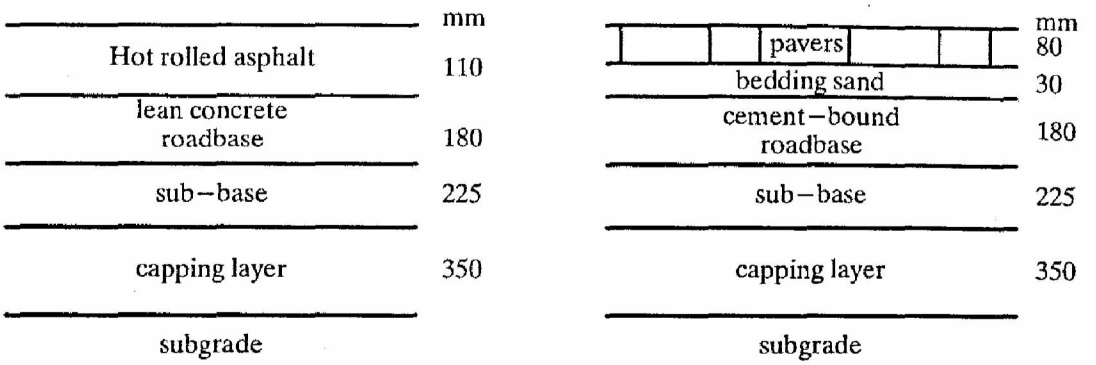
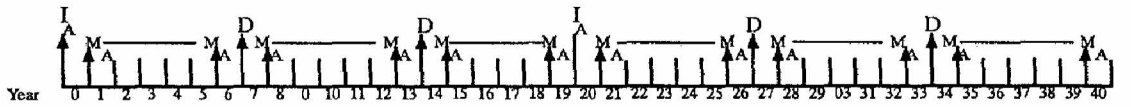
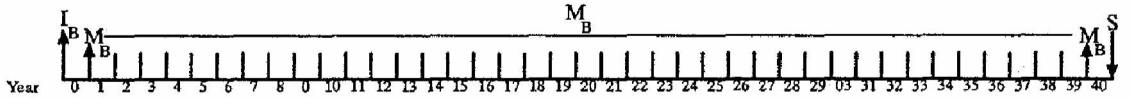


Figure 1 — Pavement designs for cost comparison



(a) Bituminous surfacing



(b) Concrete block Pavement

Figure 2 — Cash flows for cost analysis