# CONCRETE BLOCK PAVING FOR PAVEMENT REHABILITATION

J. KNAPTON, B.Sc., Ph.D., MICE, MITE, FFB, C.Eng., Nigel Dixon,Knapton & Partners, England

## ABSTRACT

This paper discusses pavement rehabilitation in terms of assessing the residual strength of a pavement, and the selection of the thicknesses and materials properties of the additional courses. Rehabilitation is discusses for concrete block, rigid and conventional flexible pavements. A method of overlay design termed the modified Component Analysis Method is described in detail. This method has been incorporated in the British Ports Association design manual, and is based on transforming the pavement layers into an equivalent thickness of 12 MPa compressive strength lean concrete, though other materials can also be used. Methods of assessing the existing condition of the pavement are described, and worked examples are included which describe how the design method can be used.

## INTRODUCTION

A well designed and constructed pavement should remain servicable for the period for which the designer intended. During its service life, a pavement is subjected to applied surface stresses from traffic and to internal stresses caused by restraint to thermal and moisture movement. Even a well designed pavement may be damaged by being overloaded or by being subjected to abnormal internal stresses during particularly severe weather. The pavement may remain servicable throughout its design life or for only part of it, but at some stage it will need to be strengthened; otherwise it will have to be taken out of service.

The particular relevance of concrete block paving to overlaying lies in the fact that concrete blocks can be used over an original pavement that is in relatively poor condition, whereas other overlay materials can be used only when the original pavement is in a substantially supportive condition. In practice this means that overlaying pavements with traditional materials is cost effective in a minority of situations. Potentially, concrete block paving could become a means of extending the life of a high proportion of many types of paving.

Once deterioration commences in many types of pavement, total unservicability is imminent and rapid degradation takes place over a short interval, particularly during severe weather. If remedial work is undertaken before deterioration becomes severe, the residual strength of the existing pavement can be taken advantage of so that lower cost strengthening can be undertaken which will extend the pavement's life considerably. It is stressed that the time interval between the onset of degradation and complete failure is rapid and costs of strengthening can rise substantially if it is delayed. The first requirement of a pavement strengthening technique is to assess the residual strength of an existing pavement, taking into account both its original strength and that strength that is no longer available.

Once the residual strength of a pavement has been assessed, the overlay technique must be capable of selecting the thickness and properties of the strengthening materials. Strengthening may extend the life of the pavement or allow an existing pavement to carry heavier traffic.

This paper is concerned with both aspects of pavement rehabilitaion, i.e. the assessment of the residual strength of a pavement, and the selection of the thicknesses and properties of the additional courses, including block paving.

Pavement rehabilitation may take place for reasons other than strength; for example, to restore skidding resistance or to eliminate ponding. Although concrete blocks are suitable for increasing skidding resistance, rehabilitation for structural reasons only will be considered in this paper. The term 'overlay' is used to indicate the provision of extra pavement construction material in order to strengthen the pavement. This term is used henceforth.

## REHABILITATION

### CONCRETE BLOCK PAVEMENTS

A particular rehabilitation problem is one where an existing block pavement is suffering distress. If settlement has taken place and the concrete blocks are substantially damaged, it may be possible to remove them, rescreed the bedding sand and relay the blocks without disturbing the base. If the existing pavement analysis shows this to be inadequate, then an additional thickness of pavement material will be required. The existing blocks may then be relaid over the new base.

If new blocks are required, either shaped or rectangular units may be used. Laying patterns and the method of installation should be in accordance with the recommendations of the manufacturer or the Cement and Concrete Association, U.K. (CACA, U.K.) (1983), or a similar Australian standard. It is recommended that blocks be laid in the herringbone pattern and it is the author's opinion that both shaped ('indented') and rectangular blocks are suitable for highways, but that rectangular blocks only be used for heavier loads.

### RIGID PAVEMENTS

Three types of rehabilitation are possible - (1) thin bonded topping, (2) concrete overslab, and (3) flexible - but only the latter two should be considered for strengthening purposes.

A thin bonded topping should be applied when surfacing defects need to be remedied on a largely uncracked pavement. This is a specialist process which should normally be undertaken by a contractor experienced in this type of work. Surface preparation of the existing slab should be specified carefully. Scabbling of the existing surface is preferred and it should be coated with a bonding agent. The maximum thickness of topping should be 40 mm because of the likelihood of delamination.

When an increase in pavement strength is required, a concrete overslab should be used. This may be plain, reinforced, continuously reinforced or fibre reinforced concrete. It is general practice to position the new pavement joints over the old joints. Reinforcement, tie bars and dowels are used as in single-slab pavements. Before any overslabbing is commenced the existing pavement must be prepared. All defects and causes of failure must be corrected. Extensively damaged areas of existing paving should be replaced. Surface preparation must be the same as for thin bonded toppings.

Alternatively, concrete blocks or asphalt may be used. Care should be taken at joints and cracks to prevent reflective cracking, especially when asphalt is used. With concrete block paving, joints should be covered with a fabric prior to screeding of the bedding sand.

### CONVENTIONAL FLEXIBLE PAVEMENTS

The two alternative overlay materials are additional asphalt or concrete blocks. If concrete block paving is used, care should be taken to aviod using bedding sand to fill depressions. This will lead to depressions forming in the block surface during subsequent plate vibration. Should the existing asphalt be in good condition and an increase in strength required, an unbonded concrete overslab may be laid over the existing surface, or the surface may be cleaned and a course of lean concrete applied before the new surfacing material is laid. Asphalt which has deteriorated should be removed before overlaying. Cold planning is recommended.

## OVERLAY DESIGN TECHNIQUE

Three techniques are generally used to assess the strength of existing highway pavements: (1) Deflection beam method; (2) Falling Weight Pulse Load (Shell) method; and (3) Component Analysis Method (U.S. Asphalt Institute).

The deflection beam (or Benkelman beam) method is widely used in the U.K. and Australia for the design of pavement overlays (e.g. see Kennedy, Fevre and Clarke 1978). The falling weight pulse load method is based on measuring the elastic deflection in a pavement beneath a 150 kg mass which is dropped 400 mm onto the surface of the pavement. An arrangement of springs converts the impact load into an equivalent load of 600 kg acting for a short time on the pavement. The deflection is recorded electronically.

### COMPONENT ANALYSIS METHOD

During the 1960s, the American Association of State Highway Officials (AASHO) emphasised the need for the rehabilitation of thousands of kilometres of sub-standard roads in the U.S. To make this possible, the Asphalt Institute devised a method of evaluating the structural adequacy of pavements and hence a method of designing overlays. As the Asphalt Institute had already developed a design methods for the design of new highways, the overlay design method was developed to work in conjunction with this existing method.

The structural adequacy of a pavement is defined as its ability to carry its predicted traffic without suffering any structural distress. Once the current structural adequacy of a pavement has been determined, the future service life of the pavement may be found. If this is considered to be inadequate, it also forms the basis for designing an overlay. This method is known as the Component Analysis Method.

Firstly, the thickness and condition of each of the courses within a pavement are determined and appropriate conversion factors selected. Secondly, the effective thickness of the existing pavement in terms of full depth asphalt is calculated using the conversion factors (Table 1). These factors are flexible enough to allow a degree of engineering judgement to be used in assessing the condition of the existing materials. The overlay design method is dependent on whether the existing pavement is flexible and rigid, the difference being that, for rigid pavements, the condition after preparation is used to select the conversion factor whereas, for flexible pavements, where preparation work does not affect the strength, its observed condition is used. Thirdly, the total thickness of material required above the prepared subgrade for

the measured subgrade strength and predicted traffic intensity is found from the U.S. Asphalt Institute's pavement design tables. The overlay thickness required is the difference between the total thickness required and the assessed effective existing thickness.

The modified Component Analysis Method is similar except that the pavement is transformed into an equivalent thickness of 12 MPa compressive strength lean concrete. The required 'new' pavement is designed using an existing concrete block pavement design method. The design method used is that incorporated in the British Ports Association (BPA) design manual (Knapton 1982 and 1983), which can be applied to either highway or industrial pavements. However, the component overlay method can be linked to any design method. The reason for transforming all pavement courses to equivalent 12 MPa lean concrete is that the BPA manual includes design charts for that material. The overlay thickness is then determined by subtraction.

The method comprises two stages: the transformation of the existing pavement into an equivalent thickness of lean concrete, and the determination of the thickness and material properties of the overlay.

The transformation to an equivalent thickness of lean concrete is accomplished using the conversion factors shown in Table 1.

TABLE 1

MATERIAL CONVERSION FACTORS FOR COMPONENT ANALYSIS METHOD

| Type of Material | Material Conversion Factors |
|---|---|
| 130 mm concrete block paving including 50 mm sand | 1.1 |
| 12 MPa lean concrete | 1.0 |
| 18 Mpa lean concrete | 1.3 |
| 30 MPa pavement quality concrete | 1.7 |
| Cement-bound granular material | 0.7 |
| Soil-cement | 0.5 |
| Concrete raft units (2 m x 2 m) | 1.5 |
| Open-textured bituminous material stiffened with latex slurry | 1.5 |
| Dense bituminous macadam | 1.0 |
| Rolled asphalt | 0.8 |
| Wetmix macadam | 0.4 |
| Dry-bound macadam | 0.4 |
| Type 1 sub-base material over subgrades with CBR > 5% | 0.3 |
| Type 1 sub-base material over subgrades with CBR ≤ 5% | 0.2 |
| Type 2 sub-base material over subgrade with CBR > 5% | 0.2 |
| Type 2 sub-base material over subgrades with CBR ≤ 5% | 0.1 |
| Subgrade | 0.0 |

## PAVEMENT TRANSFORMATION

When a condition survey or structural analysis of a pavement shows that the pavement is deteriorating, or that it is insufficient to carry new expected loadings, it becomes essential to undertake strengthening measures to extend, or maintain, the servicable life of the pavement. In some situations, deterioration may have become so severe that the most practical solution is to remove the old pavement and design and construct a new one. Frequently it is more economical to overlay the pavement before the deterioration becomes too servere. This is done using the Component Analysis Method already described, assuming that the old and new pavement courses form a composite pavement structure having the strength required to meet the new design criteria, i.e. the overlay forms an integral part of the total pavement so that the strengthened pavement will meet all the requirements of a new pavement in the same location. It is therefore necessary to evaluate the old pavement in terms of the structure and thickness of its components so that advantage may be taken of residual strength in the design process. As the existing pavment constitutes a part of the strengthened pavement, it is essential to determine accurately the thickness of each of the existing courses and the degree of degradation each has undergone.

If records of the original pavement design are unavailable, it will be necessary to either drill cores or dig holes to obtain this information. Testing should be performed even if records do exist to verify the actual situation. Testing should be conducted on the basis of one test every 500 $m^2$ of pavement. There should be a minimum of three tests and a maximum of seven for larger pavements of uniform construction and condition. Where areas are subjected to different types of traffic, each location should be considered separately for analysis purposes. Similarly, if initial testing shows that certain areas of the pavement are stronger than others, it may be preferable to divide the area to be overlaid into zones; at least three tests should be conducted in each zone.

In certain circumstances, the properties of existing materials may have changed since construction, e.g. by cementing action or the intrusion of materials from another pavement course, and it is essential to know if this has occurred. Sampling should also be used to determine the condition of each course so that the appropriate condition factors can be selected. It may be difficult to assess the condition of lower pavement courses, particularly with respect to cracking. In such situations, conservative assumptions should be made.

Once each course has been identified, it is transformed to an equivalent thickness of lean concrete by multiplying its actual thickness by the appropriate conversion factor (Table 1). Most of the materials are defined in U.K. Department of Transport (1976). The relevant clauses for each material in this publication are shown in Table 2.

TABLE 2

SPECIFICATION CLAUSES FOR PAVEMENT CONSTRUCTION MATERIALS

| Material | Clause in Specification* |
|---|---|
| Type 1 sub-base | 803 |
| Type 2 sub-base | 804 |
| Soil-cement | 805 |
| Cement-bound granular material | 806 |
| Lean concrete | 807 |
| Wetmix macadam | 808 |
| Dry-bound macadam | 809 |
| Dense bitumen macadam (base material) | 811 |
| Rolled asphalt (base material) | 812 |
| Dense bitumen macadam (surfacing material) | 903 |
| Rolled asphalt (surfacing material) | 907 |
| Pavement quality concrete | 1001-1004 |

* U.K. Dept. Transport (1976).

The transformed thickness is multiplied by two condition factors (CF): CF1 takes into account the loss of strength of each course owing to cracking and spalling. CF1 values, which can be used for both rigid and flexible pavements, are given in Table 3. CF2 (Table 4) takes into account the reduction in strength of each course as a result of rutting and settlement in the surface of flexible pavements. This is measured as the difference in levels under a 3 m straight edge. If a pavement has deformed, cores should be taken to determine which courses of the pavement are affected. When there is no deformation or cracking the CF values are taken as 1.0, i.e. the material is as new.

The transformation procedure is carried out for each course in the pavement and the sum of the transformed thicknesses is taken as the equivalent thickness of the pavement. The equivalent thickness is used in the design of the overlay.

TABLE 3

CONDITION FACTORS FOR CRACKING AND SPALLING

| Condition of Material | CF1 |
|---|---|
| As new | 1.0 |
| Slight cracking | 0.8 |
| Substantial cracking | 0.5 |
| Fully cracked or crazed and spalled | 0.2 |

TABLE 4

CONDITION FACTORS FOR MAXIMUM DEGREE RUTTING AND SETTLEMENT

| Degree of Localised Rutting or Settlement (mm) | CF2 |
|---|---|
| 0 to 10 | 1.0 |
| 11 to 20 | 0.9 |
| 21 to 40 | 0.6 |
| 40 + | 0.3 |

## PAVEMENT EVALUATION EXAMPLE

A cross-section of an existing 8 m wide, 200 m long road is shown in Fig. 1. Settlement has taken place in the subgrade, resulting in local deformations of 100 mm over much of the pavement. Each course has settled. No cracking or spalling has taken place at the surface, though the soil-cement layer is substantially cracked. Using Tables 1, 3 and 4, each course is transformed into an equivalent thickness of lean concrete as shown in Table 5.

Analysis shows this pavement to be equivalent to 71 mm of lean concrete. Had the settlement not taken place, the pavement would have been equivalent to 235 mm of lean concrete. In this case the pavement was either under-designed, or no account was taken of a compressible subgrade material. It is possible that the settlement was predicted when the pavement was originally designed; hence the use of concrete blocks.

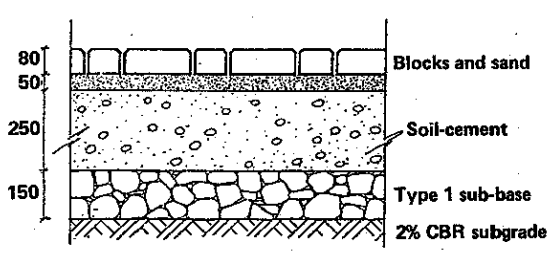



Fig. 1 - Pavement evaluation example

TABLE 5

PAVEMENT EVALUATION EXAMPLE

| Course | Actual Thickness (mm) | Material Conversion Factor | Condition Factor CF1 | Condition Factor CF2 | Equivalent Thickness of Lean Concrete (mm) |
|---|---|---|---|---|---|
| Concrete blocks and sand | 130 | 1.1 | 1.0 | 0.3 | 43 |
| Soil Cement | 250 | 0.5 | 0.5 | 0.3 | 19 |
| Type 1 sub-base | 150 | 0.2 | 1.0 | 0.3 | 9 |
| Subgrade CBR 5% | | | | | |
| | | | | Total | 71 |

DESIGN OF OVERLAY

The design procedure is similar for each material except that where pavement-quality concrete is required as an overslab, the thickness of equivalent 12 MPa lean concrete slab has to be divided by 1.7 before it is subtracted from the thickness of the newly-designed pavement.

DESIGN PROCEDURE

In order to derive the thickness of the overlay it is firstly essential to design a new pavement structure for the required design criteria, using either the BPA or similar design method. The criteria are:

design life
subgrade CBR
LCI of traffic
type of overlay considered

(LCI is a term used in the BPA method to categorise vehicles according to the damage which they inflict on pavements. A highway vehicle with axle loads of 8 t is LCI Category A.)

When the lean concrete overlay option is to be used, the BPA chart for a compressive strength of 12 KPa should be adopted.

The designed 'new' pavement consists of a lean concrete basecourse and concrete block surfacing over a granular sub-base. The equivalent thickness of the transformed pavement is then subtracted from the thickness of the lean concrete base determined from the BPA design charts. This gives the thickness of the overlay.

**OVERLAY DESIGN EXAMPLE**

An existing pavement comprises a substantially cracked concrete slab overlying 150 mm of Type 2 granular sub-base (see Fig. 2). The pavement has been trafficked by a terminal trailer system of LCI Category B. The most severely trafficked part of the pavement is subjected to 700 passes per day of a laden terminal trailer. There is no rutting.

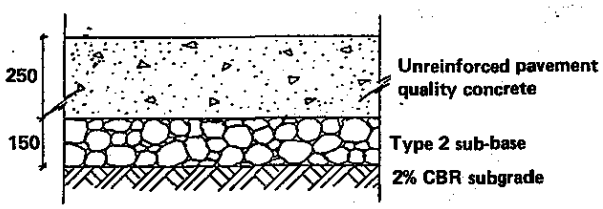


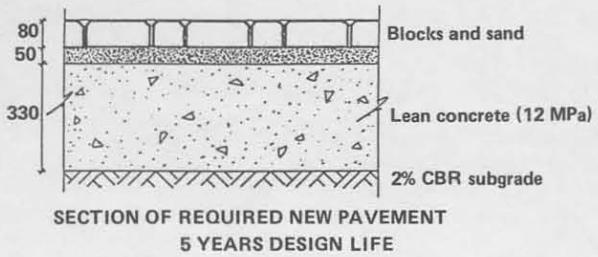

Fig. 2 - Overlay design example: existing pavement

It is proposed to continue with the same operation and two designs are required - one to last five years and one to last 25 years, each of 300 working days - so that an economic appraisal can be undertaken:

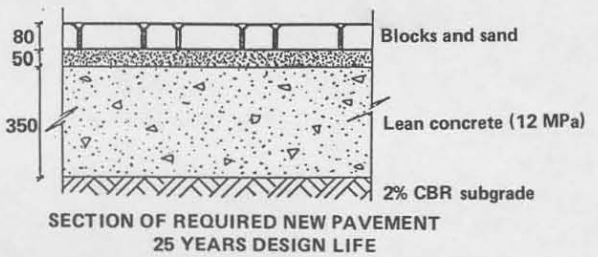
(1) 5 years number of repetitions
= 700 x 300 x 5 = 1,050,000

(2) 25 years number of repetitions
= 700 x 300 x 25 = 5,250,000

Using the BPA design chart for concrete block paving with no sub-base, the pavements shown

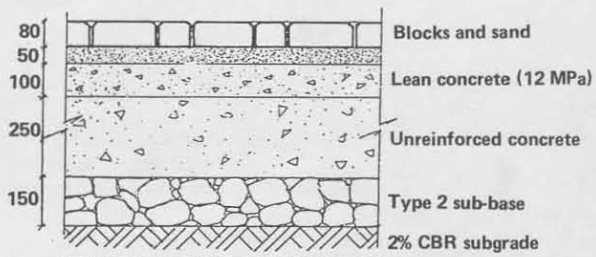



SECTION OF REQUIRED NEW PAVEMENT
5 YEARS DESIGN LIFE

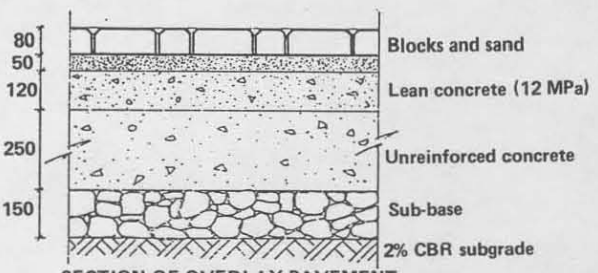



SECTION OF REQUIRED NEW PAVEMENT
25 YEARS DESIGN LIFE

Fig. 3 - Overlay design example: block pavements required




SECTION OF OVERLAY PAVEMENT
5 YEARS DESIGN LIFE




SECTION OF OVERLAY PAVEMENT
25 YEARS DESIGN LIFE

Fig. 4 - Overlay design example: strengthened pavements

TABLE 6

OVERLAY DESIGN EXAMPLE

| Course | Actual Thickness (mm) | Material Conversion Factor | Condition Factor CF1 | Condition Factor CF2 | Equivalent Thickness of Lean Concrete (mm) |
|---|---|---|---|---|---|
| Concrete | 250 | 1.7 | 0.5 | 1.0 | 212 |
| Type 2 sub-base | 150 | 0.1 | 1.0 | 1.0 | 15 |
| Subgrade CBR 5% | | | | | |
| | | | | Total | 227 |

in Fig. 3 are required, with the appropriate calculations as shown in Table 6. Therefore, for each of the two alternative future design lives, the additional thickness of 12 MPa lean concrete required is:

(1) 5 years: 330 mm - 227 mm = 100 mm

(2) 25 years: 345 mm - 227 mm = 120 mm

The two strengthened pavements are as shown in Fig. 4.

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John Knapton's practice, Nigel Nixon, Knapton & Partners of Newcastle upon Tyne and London specialises in heavy duty pavement design and concrete block paving. The practice was founded in 1980 after he left the University of Newcastle upon Tyne where he initiated the First International Conference on Concrete Block Paving in September 1980. He first became interested in concrete block paving in 1973 whilst working as a Research Engineer at the Cement and Concrete Association. He published the worlds first concrete block pavement design guide in 1976 and is the author of the British Ports Association design manual on heavy duty paving. He has published over 40 papers in the related fields of concrete block paving and heavy duty paving. In recent years, he has developed concrete block pavement projects for:

Port of London Authority, U.K.
Port of Sunderland Authority, U.K.
Dover Harbour Board, U.K.
Portsmouth Harbour Commissioners, U.K.
Forth Ports Authority, U.K.
Thai Port Authority, Thailand
Mina Sulman Port Authority, Bahrein
San Fransisco Port Authority, U.S.A.
Port of Portland, U.S.A.
St. Johns Harbour Board, Canada
Cork Harbour Board, Ireland
British Transport Docks Board, Immingham, U.K.

He is a Chartered Civil Engineer and is a member of the Institution of Civil Engineers and the Institution of Highways and Transportation, having graduated from the University of Newcastle upon Tyne with a B.Sc. and a Ph.D. in Civil Engineering.