DEVELOPMENT OF A PAVEMENT DESIGN METHODOLOGY FOR CONCRETE BLOCK PAVEMENTS IN ISRAEL

Moshe Livneh* Ilan Ishai** Simon Nesichi***

*Professor and **Associate Professor of Civil Engineering, Transportation Research Inst., Technion, Haifa, Israel

***Assistant Chief Maintenance Engineer for Methodology, Public Works Dept., Israel Ministry of Construction & Housing

SUMMARY

The rapid growth of concrete block pavements in Israel in the last decade has raised the need for developing a design method for this type of pavement that is suited to local conditions. This need was shared by both designers who were not acquainted with concrete block pavements and block manufacturers who had been trying to compete with the more "conventional" types of pavements, mainly the flexible asphaltic pavements.

The flexible pavement design method, which was modified for use in CBP design, is the current Israel Public Works Department (IPWD) design method for interurban highways. This method was developed as a synthesis of the Peltier formula for flexible pavement design thickness, based on an earlier version of the British Road Note 29, and of local experience with pavement materials.

Layer equivalency values enabling the replacement of the IPWD flexible-pavement component layers (bituminous concrete, granular base and sub-base) by equivalent layers of CBP (blocks and sand bedding) were derived from a comprehensive analysis of existing data. The layer equivalencies were superimposed on the IPWD flexible-pavement design charts, and thus CBP design charts were developed for five traffic categories. The interim design method was further extended to traffic categories not dealt with in the current IPWD flexible pavement design method: occasional and very-light, on the one hand, and up to heavy and very-heavy loading, on the other hand.

The interim design method has become available to local engineers in the last three years, and been implemented with no problems so far in most projects under construction. The CBP pavement design method is now being validated through two parallel efforts: systematic follow-up on existing CBP pavements in service and continuation of the analytical and practical research (to include also simulative laboratory testing).

The paper describes in detail the development of the CBP pavement design methodology and its validation. It also presents the layer equivalencies and design curves for the entire range of traffic categories.

INTRODUCTION

Concrete block pavers were first manufactured in Israel in 1975. Since then, production has increased rapidly to a total area of more than 12 million square meters, half of it in the last four years. This rapid growth necessitated the development of technological backing and a design method suitable to local conditions.

Consequently, starting in 1984, the largest concrete block manufacturer in Israel -- Ackerstein Zvi Ltd., Concrete Products Co. -- have sponsored a full-scale research program at the Technion's Transportation Research Institute. This research, entitled "Interlocking Concrete Blocks for Heavy Traffic in Highways & Airports," is mainly aimed at updating the current international technology on concrete-block pavements (CBP) and implementing it experimentally toward the development of a design method and technology suited to local paving practice.

During the research (which is now in the middle of its second stage) and the practical utilization of the technology, vast amounts of data, design practice, practical experience and feedback have been accumulated. At the same time, the use of CBP in Israel, as in many other parts of the world, is growing rapidly and has become an attractive engineering and economical alternative to flexible pavement, on the one hand, and slabbed rapid pavement, on the other hand.

A thorough review of existing CBP design methods, presented at the 1st and 2nd International Conferences on CBP, revealed considerable differences in layer thicknesses as well as the material properties of pavement structure yielded by these methods (1). These differences precluded the possibility of a direct adoption of any of these methods for Israeli conditions. As a result of the pressing need for a local design method, however, it was decided that its development would rely on well-established flexible pavement design methods and their modification for CBP's through the use of layer equivalencies.

This paper describes the development of an Israeli concrete block pavement design methodology and its initial validations. The layer equivalencies and typical design curves, representing the entire range of traffic categories, are also discussed and demonstrated.

BASIC CONSIDERATIONS

Because of the pressing need for a local CBP design method, it was decided that its development would follow the same lines that had been previously adopted by other researchers and organizations; e.g., U.S. Army Corps of Engineer (COE) (1); the U.K. Cement & Concrete Association (2); and in Japan (3). These organizations developed design procedures for CBP by relying on well-established flexible pavement design methods and by modifying these methods through the use of some form of layer equivalency. Since no time was available to the present research for laboratory or field studies, however, the need for a very conservative design method was dictated. Thus, a local flexible pavement design method, the current Israel Public Works Department (IPWD) design method for interurban highways (4), was modified for use. The layer-equivalency values for this modification were derived following a comprehensive literature review (5).

DEVELOPMENT OF THE DESIGN METHOD

The Israel PWD flexible pavement design method was developed as a synthesis of the Peltier formula for flexible pavement design thickness, based on an earlier version of British Road Note 29 (6), and of local experience with pavement materials (4).

A pavement structure is readily determined by using design charts similar to the one presented in Figure 1, in which the only input parameters needed are the design subgrade CBR value and the traffic category. Five traffic categories, varying from light (up to 150 commercial values, CV, per day) to very heavy (up to 15,000 CV per day), were recognized for investigation with this method. Recent analyses (5) have shown that the method yields very conservative designs compared with the current COE CBR design method (7). This conservatism was in line with the predetermined aim of achieving conservative designs for CBP, too.

In the literature survey from which were derived the layer-equivalency values enabling the replacement of the IPWD flexible pavement component layers (bituminous concrete, granular base and subbase) with equivalent layers of CBP (blocks and bedding sand), an attempt was made to gather all the information regarding specific layer-equivalency values as given by Shackel (8), Knapton (9), Miura et al. (3), etc. Layer-equivalencies were also calculated by comparing flexible and concrete block pavement structures designed for similar input conditions by various organizations that had developed design methods for both pavement types. For example, comparisons were carried out on flexible versus CBP structures designed both by the COE relevant design methods (1,7) and by the NITRR methods (10,11).

Based on this survey and these comparisons, the following layer-equivalency values were adopted:

A. For occasional to very-heavy traffic categories:

1. concrete blocks/bituminous concrete - 1.5
2. concrete blocks/granular base - 2.3
3. sand bedding/granular base - 0.5

B. For heavy and very-heavy-industrial traffic categories:

1. concrete blocks/bituminous concrete - 1.45
2. concrete blocks/granular base - 2.0
3. sand bedding/granular base - 0.5

These layer equivalencies were superimposed on the IPWD flexible pavement design charts, and design curves for CBPs were thus developed. A set of nine design charts represents the entire range of traffic categories, from "Occasional" to "Very-Heavy-Industrial" (12,13). Table 1 defines the nine traffic categories in terms of the number of repetitions of a standard 18-kips axle.

Table 1: Definition of Israeli Traffic Categories for Pavement Design

Traffic Category	Category Symbol	Equivalent No. of Repetitions of 18-kips Standard Axle
Occasional	1	0.7×10^5
Very-Light	2	2.0×10^5
Light	3	0.7×10^6
Medium-Light	4	2.0×10^6
Medium-Heavy	5	7.0×10^6
Heavy	6	2.0×10^7
Very-Heavy	7	7.0×10^7
Heavy-Industrial	8	4.4×10^8
Very-Heavy-Industrial	9	2.0×10^9

The entire range of traffic categories is represented in this paper by three typical charts, for the Occasional, Medium-Heavy and Very-Heavy-Industrial categories, as shown in Figs. 2 through 4, respectively.

Equivalent components of the CBP and the flexible pavement, as derived through the use of layer-equivalencies, are compared in Table 2 for the Light and the Very-Heavy traffic categories. This comparison leads to the following inferences:

a. Generally, the layer equivalencies adopted yield designs close to the U.S. COE method: the concrete blocks and sand bedding are equal to the upper 140-170 mm. (depending on the traffic category) of the flexible pavement, compared to the 165 mm. used in the development of the U.S. COE method.

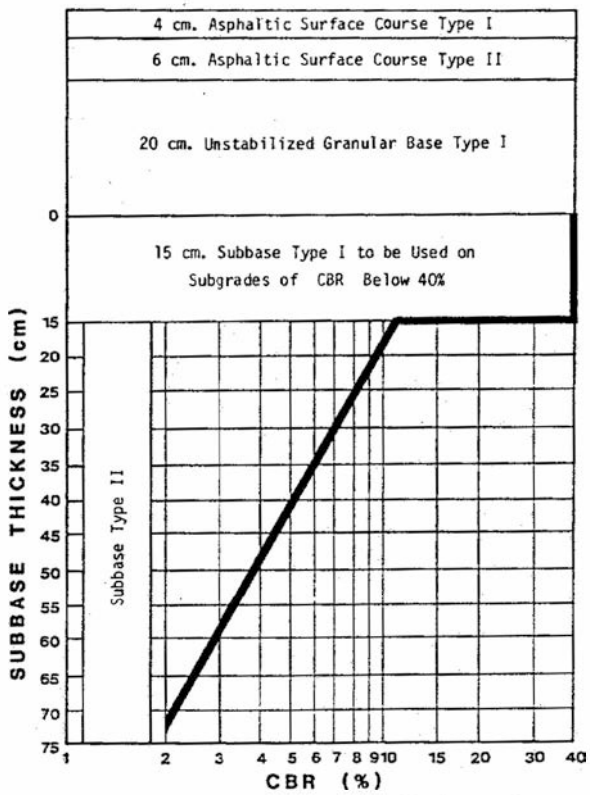


Figure 1: Flexible pavement design chart for very-heavy traffic category according to Israel PWD Design Method [4].

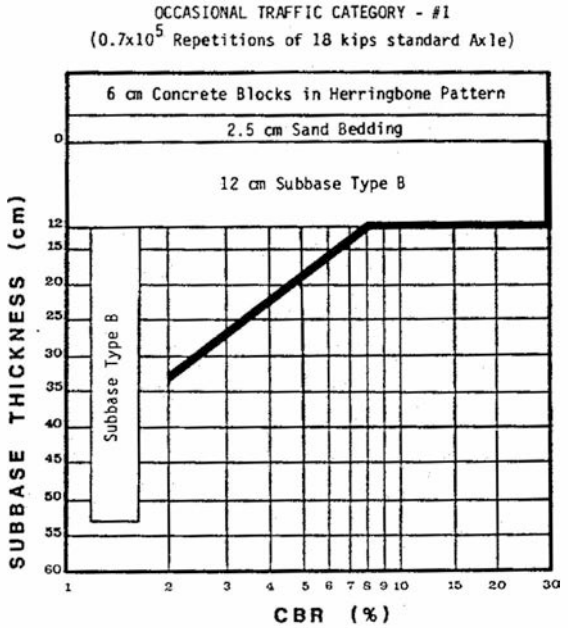


Figure 2: Design chart for concrete block pavements for occasional traffic category (#1)

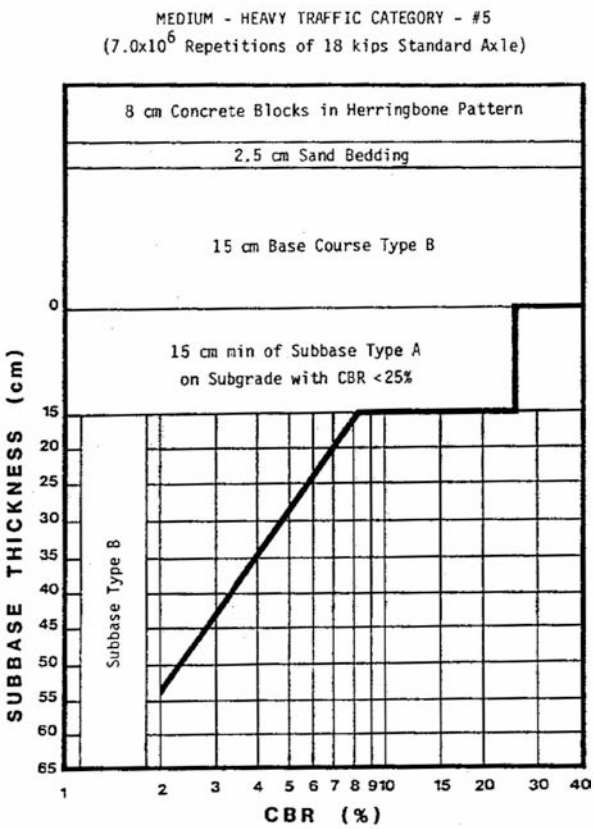


Figure 3: Design chart for concrete block pavements for medium-heavy traffic category (#5)

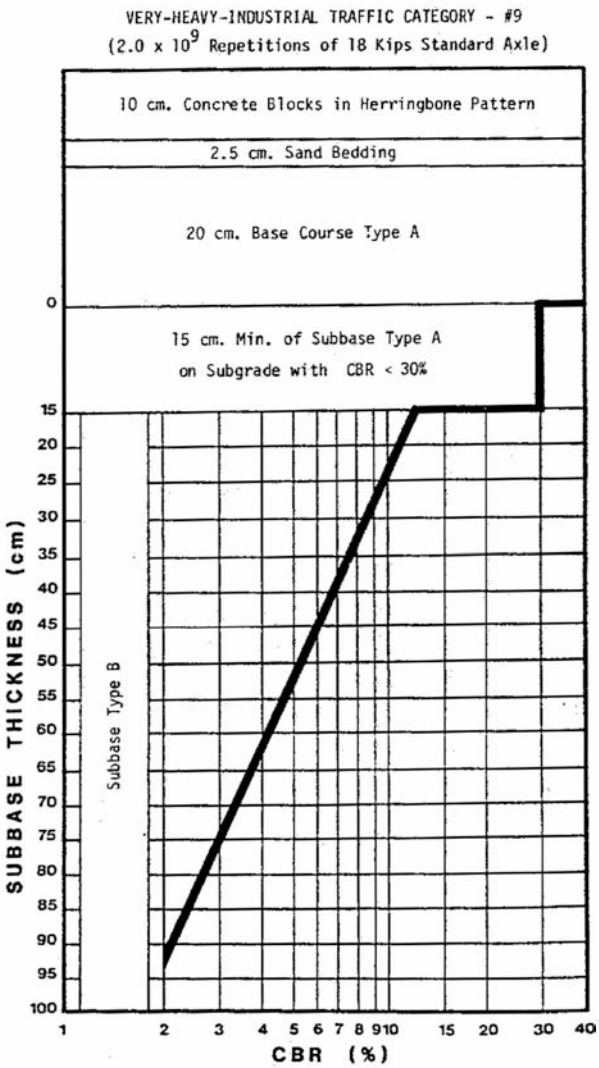


Figure 4: Design chart for Very-Heavy-Industrial traffic category (#9)

b. The Israeli method seems to be better suited to local conditions, since, unlike the COE flexible-pavement design method, the quality requirements of the flexible-pavement layers are reduced for the lower traffic categories (4). It is logical, therefore, that the same CBP components may replace greater thicknesses of poorer materials.

Table 2: Concrete Blocks & Sand Bedding Layer Thicknesses: Equivalency to Flexible Pavement Layers

Traffic Category CV/day)	Concrete Blocks & Sand Bedding Layer Thickness (mm)	Equivalent Flexible Pavement Layer Thickness (mm)
Light		BC: 50 GL: 120 Total: 170
Medium-Light		BC: 50 GL: 120 Total: 170
Medium-Heavy	Conc. Block: 80 Sand Bedding: 25 Total: 105	BC: 80 GL: 70 Total: 150
Heavy		BC: 80 GL: 70 Total: 150
Very-Heavy		BC: 100 GL: 40 Total: 140

VALIDATION AND MODIFICATIONS

Serious time-limit and budgetary problems have so far prevented the undertaking of laboratory and field studies to assure the reliability of the design method. In order, however, to check whether the predetermined aim of achieving a safe and conservative method was achieved, another approach was implemented: designs yielded by the Israeli method were compared with designs derived from existing methods in other countries for identical input conditions. Typical results are shown in Figure 5. It can be seen that the designs using the Israeli method for two CBR values (5 and 20 percent) and various traffic categories are generally the most conservative.

Since the design method became available to local engineers (about three years ago), it has been implemented in most of the projects under construction. No problems have been encountered so far. Since the method is conservative, on the one hand, and the reliance on layer equivalencies for its development is basically scientifically questionable, on the other, further modifications, and later its replacement with a more rational method, are planned. These modifications and the possible replacement will be carried out during the current, second phase of the research in the following stages:

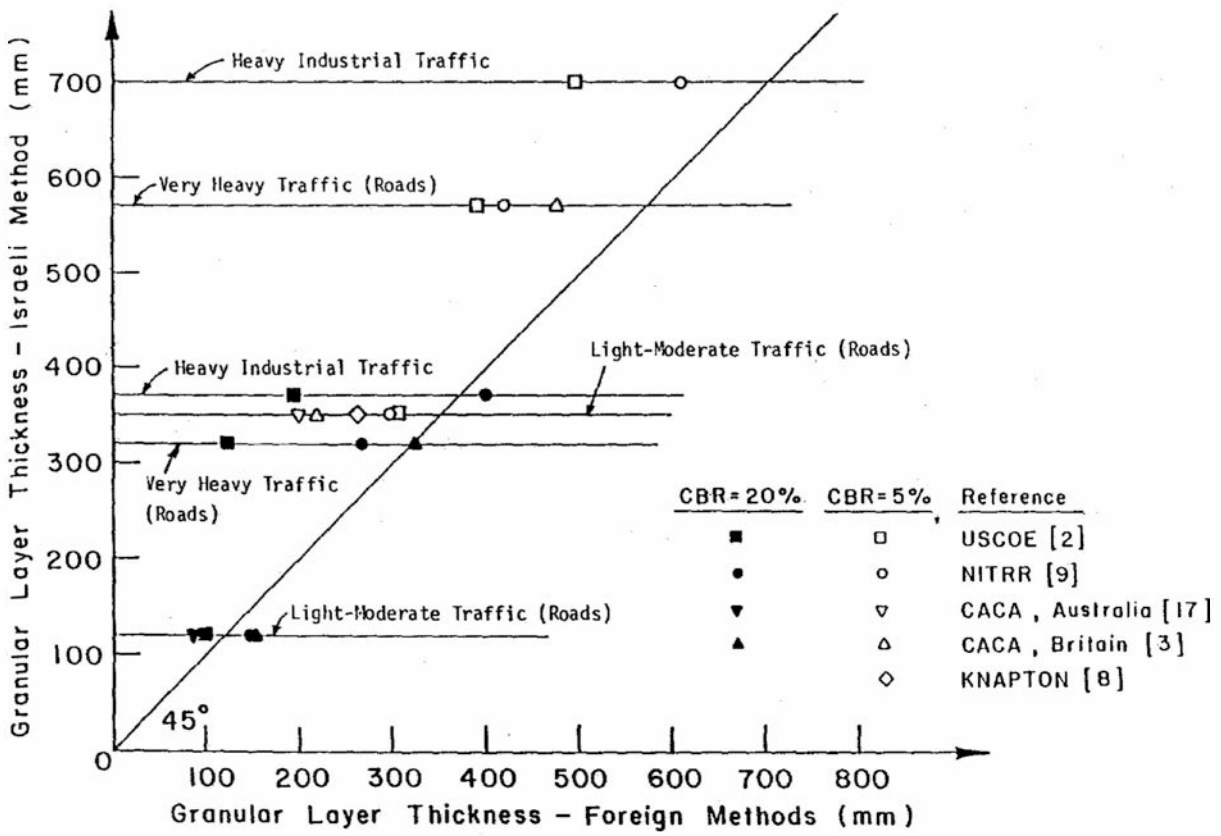


Figure 5: Comparison of granular layers (base and subbase) thickness required by the Israeli Design Method vs. thickness requirements according to foreign methods

a. Designs yielded by the current method will be checked for their factor of safety against subgrade shear and critical rutting through the use of multi-layered programs and comparisons will be made with strain criteria suggested in the literature. A high factor of safety may allow some thickness reductions in the current designs.

b. A comprehensive field study and simulative laboratory testing will be carried out for the purpose of arriving at reliable values for the assumed elastic parameters of the concrete block layer; the strengthening phenomenon ("lock up") reported by various researchers will be evaluated. The data will be used as input to the development of a new design procedure that will rely on multi-layered models.

GENERAL GUIDELINES AND QUALITY REQUIREMENTS

Based on the world-wide literature and on the local paving experience involving flexible, rigid and concrete block pavements, the following guidelines and quality requirements were recommended and adopted for CBP (5,13):

Quality Requirements for the Blocks

The successful performance of blocks produced in Israel according to Israel Standard No. 8 indicates that conformity with this Standard meets all normal requirements. At the same time, in those cases in which the block is expected to be subjected to particularly heavy abrasive stresses (14,15), it is possible to apply stricter requirements for strength and resistance to abrasion than those of the above Standard.

Selection of Optimal Block Shape

The issue of selecting an optimal shape for the blocks is problematic and controversial. Selection of the optimal block type must be guided by the following considerations:

a. the best stress-distribution capacity;

b. ease of laying.

As to stress-distribution capacity, there is a strong controversy between two schools: that which can be termed the "Australian" and "South African" schools, on the one hand, and the "British" and "Dutch" schools, on the other. The first school, relying on various laboratory experiments, claims that interlocking-shaped (jagged) blocks with geometric pegging at all four corners provide a better distribution of stresses; the second school contends that interlocking blocks are no better than others and that successful surfaces constructed from smooth-cornered blocks are proof of this. With the present state of knowledge, it is impossible to recide either way; therefore, the only requirement for block shape recommended at the moment is that the block must be capable of being laid in a bi-directional combination.

As to ease of block laying, the following aspecis should be considered:

a. It is preferable that the shape of the blocks should be such that the block is "self-locating"; i.e., that an unskilled worker will not have to deliberate how to place one block beside another.

b. The shape of the block must be such as to permit good control of the width of the joints (spaces) between blocks. This space greatly influences the mechanical function of the whole pavement, and the optimal recommended width is in the range of 2-5 mm. Smooth-cornered blocks are therefore preferable at this point. So far as jagged blocks are concerned, it is possible that the wearing down of formworks in the factory will make it difficult to manufacture different production series of identically shaped blocks, and larger joints than desired will result as a consequence.

In summary, considerations of ease of execution indicate a certain advantage for smooth blocks, but these considerations cannot in themselves dictate the optimal block shape.

Quality Requirements of the Sand Under the Blocks

The quality of the sand in the joints and in the layers under the blocks has an important influence on the quality and performance of the entire pavement. The reason for this is that the sand constitutes one of the elements that provide the paving with its flexible character. The quality requirements of the sand layer beneath the blocks are as follows:

a. Layer Thickness - The recommended thickness of the sand layer before compaction is 30-35 mm. After compaction beneath the blocks, the compacted thickness will be 25-30 mm, according to the recommendations of the design charts.

b. Grading Range - The recommended grading range of the sand is that presented in Table 3. In general, this sand should not contain any plastic fines.

c. Moisture Content - The recommended range of moisture content is 4%-8%. Conformity with the grading range appearing in Table 3 permits the exceeding of this recommended range. Non-observance of the recommended moisture-content range when the sand contains more than 15% silts and clays (particle size smaller than 75 microns) might cause considerable settling of the sand layer (up to 50% of the layer thickness).

Table 3: Recommended Grading Range for the Sand Layer Beneath the Blocks

Sieve Size	% Passing
9.52 mm.	100
4.75 mm.	95-100
2.36 mm.	80-100
1.18 mm.	50-85
600 µm	25-60
300 µm	10-30
150 µm	5-15
75 µm	0-10

Quality Requirements of the Sand in the Joints

The quality requirements of the sand in the joints are based on experience and are as follows:

a. Maximum Particle Size - 1.2 mm. This particle size permits the construction of joints in the range of the recommended width (2-5 mm.).

b. Recommended Quantity of Clay Fines - The recommended quantity of clay fines (i.e., smaller than 75 microns) is 10%-15%.

Use of Curbstones

A necessary requirement for the proper functioning of the pavement is that the block pavement be confined with curbstones. Non-observance of this rule might eventually result in a slow process of joint movement and unravelling, the penetration of water into the joints and, eventually, destruction of the pavement.

A conventional curbstone conforming to the appropriate Israeli Standard is usually used. In special cases, such as a situation in which the pavement is being filled and is exposed to especially heavy loads, more massive curbing means may be required (14,15).

Construction Procedures

Since the local paving specifications do not yet include details as to the construction procedures for concrete block pavements, the following general guidelines were adopted with reference to the layer of blocks, the sand beneath them, and the sand in the joints. (The construction procedures for the other pavement layers and for the subgrade are no different from those specified for flexible pavements).

a. Laying and leveling of the sand layer beneath the blocks - This layer must be laid at an uncompacted thickness of 25-30 mm. The thickness of the layer will occasionally be greater in places where it is necessary to fill small concavities in the sub-base or base-course. It is not necessary to compact this layer directly, and it is preferable to make do with the compaction obtained through the passage of the roller on the blocks. The sand layer must not be stepped on or damaged before it is covered with blocks. Consequently, the recommendation is not to spread and level a quantity of sand exceeding the work capacity for one day.

b. Laying of Blocks - The blocks can be laid either manually or mechanically. In Israel, only the manual method is used, and therefore the following refers only to this procedure.

The blocks must be laid so that the width of the joints are in the range of 2-5 mm. When the surface is supposed to bear traffic loads, the blocks must be laid in bi-directional combination. Under special circumstances, such as for pedestrian surfaces and paths, architectural designs, etc., and in those cases in which traffic loads will not be a factor, other ways of laying the blocks can be adopted, such as in uni-directional combination. In cases in which a smaller block than usual is required (closing corners, combination with corner stone, etc.), the regular block may be hewed down to size. It is recommended, however that blocks smaller than 1/4 of the original size not be used.

c. Compaction of Sand in Joints - After the blocks are laid, it is necessary to compact and submerge them into the sand layer. It is also necessary to fill the joints with the proper sand, conforming to the quality requirements detailed above. This should be carried out in at least three passes of a vibrating plate roller. The first passage of the roller pushes the blocks into the sand and causes part of the sand layer to rise into the lower part of the joints. Next, the sand that is supposed to fill the joints must be swept into the spaces between the blocks.

After the filling stage, at least two more passes of the roller are required. The recommended roller speed is 3-4 kph, and the vibration period 20 seconds. In case of CBP meant for heavy loading, the recommendation is to "iron" the pavement surface with several passes of a regular paving pneumatic roller as the final stage of construction.

It should be noted that the correlation between the form and quality of compaction and the performance of the pavement has been little researched. The little information existing on the subject indicates that a correct compaction process might speed up the "locking" process of the pavement. Proper compaction also improves the pavement's impermeability to water.

Solution of Special Subsoil Problems

The detailed structural solutions presented in the design charts do not consider a number of difficulties that might develop in problematic subsoils. The difficulties detailed below require special engineering solutions, which are, as stated, beyond the standard ones.

a. Considerable volume changes in subsoil (swelling on the one hand and collapse on the other).

b. Faulty structural support stemming from such problems as gradient stabilization, non-uniform soil types along the route, etc.

c. Subsoils containing soluble salines that might percolate into the sub-base and sub-course layers and cause their deterioration or a decrease in their density.

All these problems require special solutions as recommended in the relevant geotechnical and paving technology literature.

Drainage and Compaction

Practical experience indicates the great importance of drainage in pavements of this type. As in other types of pavements, the issue of drainage can be divided into two: drainage of the upper run-off and subsurface drainage. The importance of draining the upper run-off stems from the fact that the joints between blocks are filled with sand, which, at least at the beginning of the pavement's life, is a substance with high permeation and water-transfer ability. At later stages of the pavement's life, as a result of climatic influences, traffic loads, penetration of dirt, such as tyre residues, etc., into the joints, a kind of "plug" is formed that seals the joints against further penetration of water until the permeability of the pavement is approximately equal to that of flexible asphalt pavement.

In order to ensure proper drainage of the upper run-off, therefore, it is recommended that the minimal transverse gradient for concrete block pavements be 2.5% and the minimal longitudinal gradient be 1%. When the possible longitudinal gradient is less than 1%, it is recommended that the minimum requirement for the transverse gradient be raised to 3%.

As to subsurface drainage under the same ground and environment conditions, the requirements are identical to those of flexible or rigid pavements.

The compaction requirements for the subgrade, sub-base and base course are as specified for conventional flexible pavements with the appropriate traffic category.

Maintenance and Re-Use of Blocks

One of the significant advantages of using blocks is the ease of maintenance and the ability to re-use the blocks. Maintenance work usually includes repair of damaged sub-bases, replacement of damaged blocks and weeding out of vegetation between the blocks by means of pesticides.

It should be noted that the replacement and re-use of blocks are regular occurrences in the maintenance of pavements of this type. In any case, withdrawal of blocks from their place in the pavement for purposes of treating the sub-base might cause some movement of the remaining blocks and difficulty in replacing the blocks that had been removed. This problem can be overcome by taking measures to fix the remaining blocks in place and to prevent their movement.

SUMMARY

This paper described the development of the Israeli concrete block pavement design methodology and its initial validation. The layer equivalencies and typical design curves representing the entire range of traffic categories were also discussed and demonstrated.

Since the design method has become available to local engineers (about three years ago), it has been implemented with no problems so far in most of the projects under construction. Because the method is very conservative, on the one hand, and the reliance on layer equivalencies for its development is basically scientifically questionable, on the other, further modifications, and later the replacement of this method with a more rational method, are planned. These modifications and possible replacement will be carried out during the current second phase of the research.

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