ECONOMICAL ANALYSIS OF CONCRETE BLOCK PAVEMENTS AT VARIOUS PAVEMENT AND STRUCTURE ALTERNATIVES

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ABSTRACT

This paper presents a comparative engineering-economical analysis of flexible, rigid, and concrete block (CBP) pavements at different structure alternatives. Several key factors were involved in the analysis. They were: three types of traffic categories -- Occasional, Medium, and Very Heavy; one subgrade strength (CBR=4%); local pavement design practice (current design curves for flexible, rigid and CBP pavements; consideration of both initial construction and maintenance costs; total pavement life -- 20 years with major maintenance implementation at 10 and 20 years; local construction and maintenance costs. The results of the analysis showed that: 1) The construction cost of the CBP is higher than that of the flexible pavement at the medium and low traffic categories; however, it is lower for the heavy traffic; 2) The absolute values of construction plus the maintenance cost of CBP are always equal or less than that of flexible pavements; 3) The total CBP cost capitalized to the first day of service is higher than that of the flexible for the low and medium traffic, but became lower for high pavement thickness; and 4) The cost of CBP is substantially lower than the rigid pavement for all traffic categories and all cost conditions.

Introduction

Hundreds of thousands of square meters of concrete block pavements (CBP) are being paved around the world each year, and the amount is rising steadily. Today, after two decades of research, development and practical implementation, concrete block pavements provide an attractive and competitive alternative to the common flexible and rigid pavements. However, apart from the engineering considerations and benefits, any selection and preference decisions should also be based on a sound and realistic economical analysis.

This paper summarizes a comparative economical-engineering analysis of concrete block pavements with respect to the flexible and rigid pavements which are common practice in the local transportation infrastructure. The main objective of the analysis is to determine the

economical benefit of CBP in a variety of uses, from the small residential street up to the heavy industrial facilities.

The economical comparison is made on equivalent pavement structures at three traffic categories under typical subgrade conditions. The economical data refer to the initial construction cost, as well as to the expected maintenance cost, using up-to-date practical unit prices.

Equivalent Pavement Structures

The equivalent pavement structures for the comparison were determined using the local guidelines for the pavement design of urban streets [1]. Pavement design curves in the guidelines are presented for each traffic category. In each category, the pavement structure is determined, based on subgrade strength (CBR for CBP and flexible pavements or modulus of subgrade reaction, K, for rigid pavements). A typical CBP design curve for the medium-light traffic category is presented in Figure 1.

Three traffic categories were chosen for the analysis. They were: "Occasional," "Medium-Light," and "Very-Heavy." These categories are three among the seven presented in the guidelines, as depicted in Table 1.

Table 1: Traffic Categories for Pavement Design [1]

Traffic Category	Category Number	Daily No. of Commercial Vehicles at the 20th Yr. of Service (in two directions)	Cumulative No. of Equivalent 18,000 lb. Standard Axle (in one direction)
Occasional	1	0-15	$0 - 0.7x10^5$
Very Light	2	15-45	$0.7x10^5 - 2.0x10^5$
Light	3	45-150	$2.0x10^5 - 0.7x10^6$
Medium Light	4	150-450	$0.7x10^6 - 2.0x10^6$
Medium Heavy	5	450-1500	$2.0x10^6 - 0.7x10^7$
Heavy	6	1500-45000	$0.7x10^7 - 2.0x10^7$
Very Heavy	7	4500-15000	$2.0x10^7 - 0.7x10^8$

The pavement structures for the three types of pavement and three traffic categories are presented in Figure 2.

A single strength value for the subgrade was chosen for the analysis. This value is CBR = 4% which is the design value of many typical Israeli subgrades.

Initial Construction Costs

The economical comparison between the different pavement structures is based mainly on up-to-date paving costs according to the following sources and conditions:

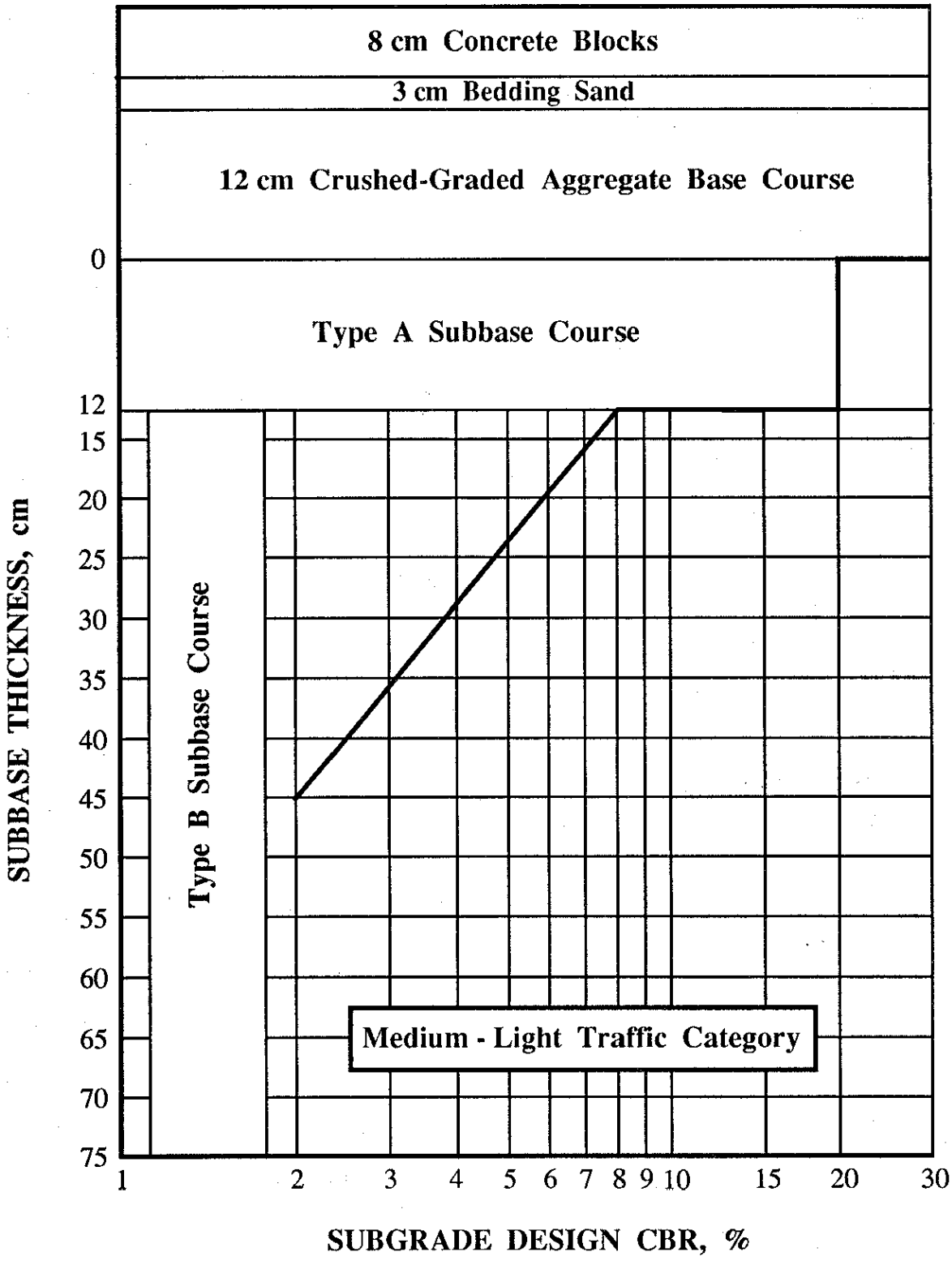


Figure 1: CBP pavement design curve for medium-light traffic category

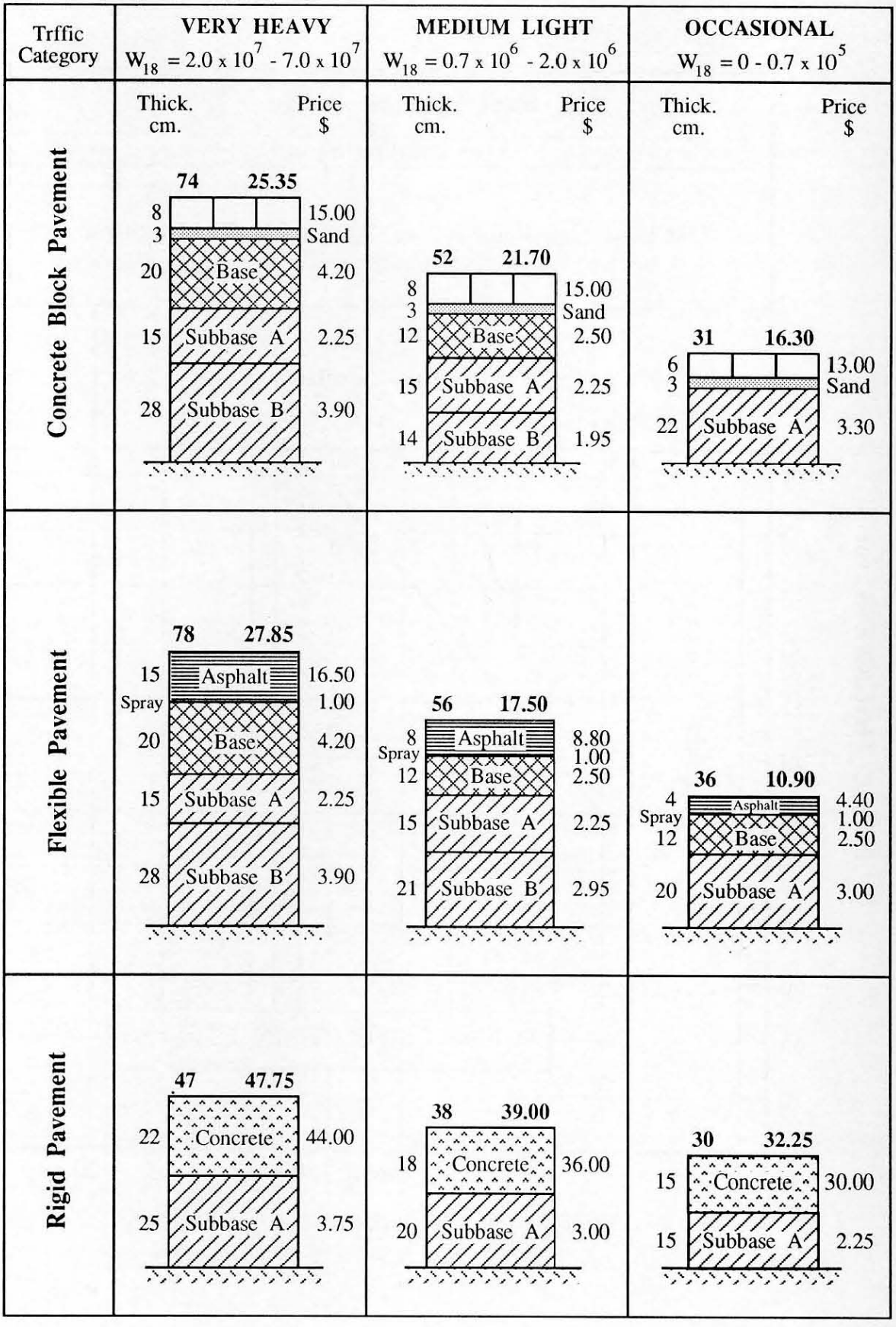


Figure 2: Equivalent pavement structures and initial construction cost (CBR = 4%)

1. The unit costs of the block layers referred to grey pavers of the "UNI," "UNICOLOCK," or 10/20 cm rectangular types. The costs include the supply of the blocks and the complete construction of the bedding and block layers. These unit prices are as follows:

   - 6 cm blocks + bedding sand - $ 13 /m^2
   - 8 cm blocks + bedding sand - $ 15/ m^2

2. The unit costs of the different pavement layers (besides blocks), are based on up-to-date practical paving prices, as published monthly in [2]. These unit prices are as follows:

   - Type B subbase course - $ 14/m^3
   - Type A subbase course - $ 15/m^3
   - Crushed-graded base course - $ 21/m^3
   - Asphaltic prime coat - $ 1/m^2
   - Compacted asphalt concrete - $110/m^3
   - Portland cement concrete (incl.joints) - $200/m^3

3. The economical comparison does not consider some elements which are practically identical in all pavement alternatives, such as:
   - Earth works and grade preparation;
   - Edge elements;
   - Overheads, such as surveying, testing, etc.

4. The local prices were converted to U.S. dollars at the current rate of 3.00 Israeli shekels per 1.00 dollar.

Based on the above prices and conditions, the initial construction costs of the different pavement combinations are also given in Figure 2 (on the left side).

Maintenance Costs

The maintenance costs are based on average periodical maintenance actions and periods for the different pavement types, and under the following conditions:

1. The design period for comparison is 20 years for all pavement types;

2. In the flexible pavement, the predicted maintenance action is cold milling and asphaltic overlay every ten years. This operation includes a 2-3 cm depth milling, a tack-coat, and a 5.0 cm asphaltic overlay. This includes also the preventive maintenance measures taken along the entire service time (crack-filling, pothole filling, etc.);

3. In the rigid pavement, the maintenance action will also take place every ten years, but its cost is estimated to be only one half of that of the equivalent flexible pavement;

4. In the concrete block pavement, the maintenance action will also take place every ten years, and it will include the taking apart and relaying of 40% of the pavement area, including distress correction and replacing of 10% of the paving blocks;

5. The maintenance measures are identical for all traffic categories;

6. The current maintenance unit prices are:

   - Cold milling and 5 cm asphaltic overlay - $ 8/m²
   - Taking apart and relaying of CBP, distress correction, and replacing 10% of the blocks - $ 5/m²

7. The consideration of the maintenance costs will be contrived by two methods:

   a. By adding the absolute maintenance cost to the initial construction cost;

   b. By adding the maintenance cost as capitalized to the construction time, taking into account a 10% annual interest rate and the specified design period and maintenance time. The capitalization factors for these conditions are:

      - For a ten-year period (initial maintenance period) -0.3855
      - For a twenty-year period (secondary maintenance period) -0.1486

8. The above costs, assumptions and conditions are also based on the information given in Refs. [2] through [5]

Comparative Cost Analysis

The complete analysis of calculated prices and initial and maintenance costs of the different pavement structures are summarized in Table 2.

The following are the principal conclusions that can be derived from the comparative economical analysis of the construction and maintenance costs for the different pavement structures under the three traffic categories:

1. For the occasional traffic category, typical to small residential streets, the initial construction cost of the CBP is higher than that of the flexible pavement by about 50%. Considering the maintenance costs capitalized to the day of construction, this difference is decreased to 25%. Conversely, under absolute maintenance costs, the CBP and the flexible pavements are almost identical in cost;

2. For the medium-light traffic category, typical for collector streets, parking facilities, filling stations, small aircraft facilities, etc., the initial construction cost of CBP is still higher than that of the flexible pavement, but only by 24%. Considering the capitalized maintenance, this difference is decreasing to 12%. However, under the absolute maintenance cost, the CBP is now cheaper than the flexible pavement by 5%. As for the comparison with the rigid pavement, which is relevant to this traffic category, the rigid pavement is much more expensive than the CBP at the range of 48 to 80% for the different cost combinations;

3. For the very heavy traffic category, typical to major streets, ports, airports, and industrial pavements, the CBP is always cheaper than all other types of pavements at any price

Table 2: Summary of the Construction & Maintenance Costs (Absolute and Capitalized)

Pavement Type	Type of Cost	Very Heavy Traffic	Medium Light Traffic	Occasional Traffic
CBP	Initial construction costs	25.35	21.70	16.30
	Absolute maintenance costs	10.00	10.00	10.00
	Total:	**35.35**	**31.70**	**26.30**
	Initial construction costs	25.35	21.70	16.30
	Capitalized maintenance costs	2.70	2.70	2.70
	Total:	**28.05**	**24.40**	**19.00**
Flexible	Initial construction costs	27.85	17.50	10.90
	Absolute maintenance costs	16.00	16.00	16.00
	Total:	**43.85**	**33.50**	**26.90**
	Initial construction costs	27.85	17.50	10.90
	Capitalized maintenance costs	4.30	4.30	4.30
	Total:	**32.15**	**21.80**	**15.20**
Rigid	Initial construction costs	47.75	39.00	32.25
	Absolute maintenance costs	8.00	8.00	8.00
	Total:	**55.75**	**47.00**	**40.25**
	Initial construction costs	47.75	39.00	32.25
	Capitalized maintenance costs	2.15	2.15	2.15
	Total:	**49.90**	**41.15**	**34.40**

combination. In this category, the flexible pavement is more expensive than the CBP by 10 to 24%, and the rigid pavement is more expensive than the CBP by 58 to 87%.

Major Conclusions

From an engineering viewpoint, the concrete block pavement provides an attractive alternative to the rigid pavement for the medium-light traffic category and heavier, especially when the pavement is exposed to fuel and oil spillage, abrasive forces, static loads, hot exhaust, etc. The use of CBP in these traffic categories, instead of the rigid, provides also an economical advantage, as expressed by the substantial saving in cost.

Engineering-wise, the CBP also provides an attractive alternative to the flexible pavement at a wide range of traffic and loading conditions. This is accompanied by an economical advantage in the heavy traffic categories and at all cost combinations. The economical advantages are also manifested in the entire range of traffic categories when the absolute maintenance costs are taken into account.

Finally, it is quite clear that any promotion or selection of CBP to replace conventional pavement structures should be backed up and validated by both engineering and economical analysis and interpretation that will be applied to the unique conditions of the specific project.

Acknowledgments

This paper was prepared within the framework of a research on "Design and Performance of Concrete Block Pavements for Heavy Loading," financed by Ackerstein Industries Co. The author wishes to thank this Company for its sponsorship and help. Acknowledgment is also due to Mr. A. Aines and Mrs. F. Hirosh for their technical and administrative assistance.

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