THREE-YEAR PERFORMANCE OF CONCRETE BLOCK PAVEMENTS UNDER HEAVY ABRASIVE CATERPILLAR LOADING

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UMMARY

This paper describes the performance of interlocking concrete block pavements (CBP) exposed to heav and abrasive caterpillar loading during their first three years of service. It is a continuation of paper presented by the authors at the Second International Conference on CBP, held in Delft in 198 which described the design and construction phases of this project.

Based on the behaviour of CBP and their performance function with time, the condition of the pavem was analyzed with respect to three types of traffic categories: (a) roads and aprons for pneumatic vehicles and for vehicles with rubber-padded caterpillar chains; (b) aprons for parking and mainte ance of heavy vehicles with exposed metallic chains; and (c) access roads for fast heavy vehicles with exposed metallic chains.

The paper describes the development of failure modes in these three categories and analyzes the caus and the deterioration mechanism. Conclusions and recommendations are given with respect to the stru tural and functional suitability range of CBP for caterpillar loadings. Verification and modifica ion of the pavement design method are also discussed.

1. INTRODUCTION

During the Second International Conference on Concrete Block Paving held in Delft, the paper entitled "Interlocking Concrete Block Pavement for Heavy Abrasive Caterpillar Loading" (1), was presented by the authors. It described a case study in which interlocking concrete block pavements (CBP) were designed and constructed for operational and maintenance use by heavy caterpillar vehicles. The paper presented in detail the following aspects of that specific case and technology: (a) preliminary consideration and feasibility test section; (b) cost-benefit considerations; (c) pavement design and cross-section details; (d) quality requirements for blocks and sand bedding; (e) block production; (f) quality control of blocks -- procedure, problems and solutions; (g) construction procedure; (h) actual caterpillar loading test.

The specific project described was then in its last stages of construction, several months before its opening to service. Successful performance during production, construction and actual loading tests permitted the introduction of the proposed quality control criteria, testing procedures and construction specifications.

This CBP complex is now at the beginning of its fourth service year in accommodating the extensive operations of caterpillar vehicles. During this period, annual monitoring of pavement condition and performance has been performed.

The present paper describes the behaviour of the CBP and their performance function with time with different types of caterpillar loadings and operations. The development of failure modes in the various traffic categories and an analysis of the causes and deterioration mechanism are also discussed.

2. PROJECT DESCRIPTION

In Ref. (1), the authors described this specific project as a case study in which interlocking CBP were designed and constructed for the operation and maintenance of heavy caterpilla loadings. The following is a summary of some of the aspects characterizing this specific case and technology:

2.1 Pavement Design & Cross Section

The design of the CBP was based on a prelim ary method using a conventional flexible pave ment design with the application of equivalen factors for the blocks and sand bedding. The design parameters and values for the specific location were as follows:

Design subgrade CBR - 5%

Traffic category - Very Heavy (VH)

Climatic condition - Arid Zone

Based on the Israel Pavement Design standards and curves for the Arid Zone location, this i the appropriate flexible pavement structure:

Bituminous concrete courses (binder and wearing)	- 10 cm.
Crushed, graded base course	- 18 cm.
Subbase course	- 18 cm.

The following layer equivalencies were used substituting a flexible pavement for the con crete block pavement (2,3,4):

Concrete block layer	- 1.0
Bituminous concrete layer	- 1.5
Base course layer	- 2.5
Sand bedding layer	- 2.5

Subbase course layer - 3.0

By applying the above layer equivalencies, the following concrete block pavement structure was proposed for the design:

Interlocking concrete block layer ("UNI" type)	- 10 cm.
Sand bedding layer	- 4 cm.
Subbase course (type A)	- 26 cm.
Total thickness of pavement structure	40 cm.

The pavement was to be based on a compacted subgrade. Requirements for the subgrades as well as for the subbase course are identical to those specified for a flexible pavement.

It should be noted that this CBP design procedure was a preliminary one, undertaken prior to the systematic and analytical development of a local Israel CBP design method. The current Israel CBP design method and technology will be presented by the authors at the Third International Conference on CBP (5).

Figure 1 demonstrates a typical cross-section of the concrete block pavement used in aprons and connecting roads. A concrete edge element, designed to support the block pavement and to withstand excessive horizontal forces, was introduced between the pavement and the shoulders. The edge beam was to be case in place prior to the construction of the pavement layers.

2.2 Quality Requirements for Blocks and Sand

The quality requirements for the interlocking blocks were related to type, materials, production, dimensions, curing and physical properties after curing. All these requirements were based on the Israel Standards for superior-quality, industrialized, prefabricated concrete products.

The physical criteria for the blocks were essentially based on Israel Standards Nos. IS-26, IS-106 and IS-108 for a B-600-type concrete (the highest quality specified, and with a nominal compressive strength of f_n = 600 kg/cm^2). The physical requirements for the cured blocks (after 28 days) are presented quantitatively in Table 1.

Table 1: Physical Requirements for the Concrete Blocks

Property	Average Value (n > 6)	None of the Samples will possess a value of:
Compressive strength (kg/cm^2)	$f_c > 1.15\ f_n$ > 690	< 0.75 f_c < 520
Bending strength (kg/cm^2)	> 70	< 52
Resistance to abrasion (mm.)	< 2.0	> 2.3

The compressive strength was to be tested on 10 x 10 cm. sawed cubical samples coated with a sulfur leveling capping.

The bending strength was to be tested on the complete block resting on two supports near edges of its longitudinal dimension. A point load was applied in the middle.

The abrasion resistance was to be tested on sawed sample according to the "wear test with the grinding wheel according to Bohme" (German Standard No. DIN 52108), with the application of 440 revolutions.

The sand bedding underneath the block was to consist of pourable, non-plastic, dust-and organic-substances-free dune sand. The moisture content of the sand during laying should be less than 4%.

The joints filling sand was to consist of fine clean, angular, graded quarry sand (all passing through the #10 sieve).

2.3 Block Production

The "UNI"-type HD10 blocks were produced in a newly erected plant with a line specially designed and constructed for concrete block production. The production procedure was fully automated and controlled.

In general, high quality aggregates were used for the blocks (hard gravel, flint, dolomite basalt), together with type-300 Portland cement. In the production process, a thin layer of quartz penetrated to the upper surface of the block. After forming and compaction, the blocks were cured in trays in a controlled moisture chamber for several days, and then piled and stored in the factory yard for a minimum of 30 days before testing, approval and shipment to the site.

Table 2: Details of the First Year Production of "UNI" blocks for the Project

Period	Production Quantity (m^2)	Type of Aggregate
May 1982	10,100	crushed gravel + fl
June 1982	9,900	crushed gravel + fl
September 1982	7,400	crushed gravel + fl
1-16 Oct. 1982	6,900	crushed gravel + fl
17-31 Oct. 1982	6,200	Dolomite with basal
January 1983	5,200	Dolomite with basal
February 1983	6,900	Dolomite with basal
1-17 March 1983	3,800	Dolomite with basal
17-31 March 1983	6,500	Dolomite, basalt, gravel and flint
April 1983	2,500	Dolomite, basalt, gravel and flint

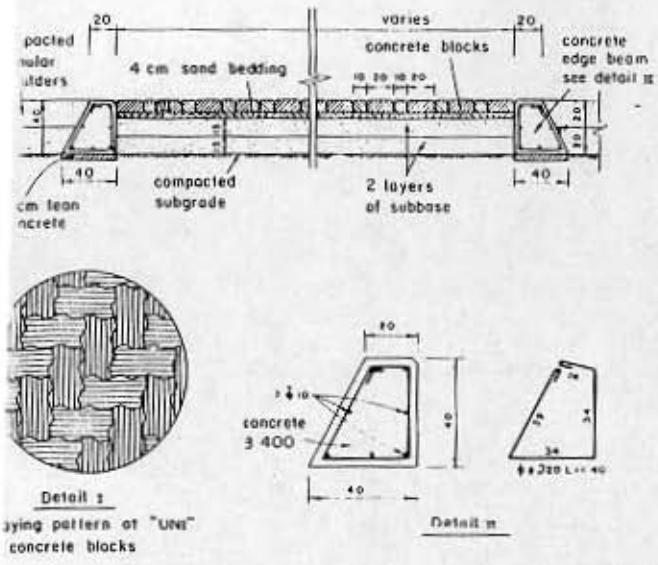


Figure 1: A typical cross-section of the concrete block pavement

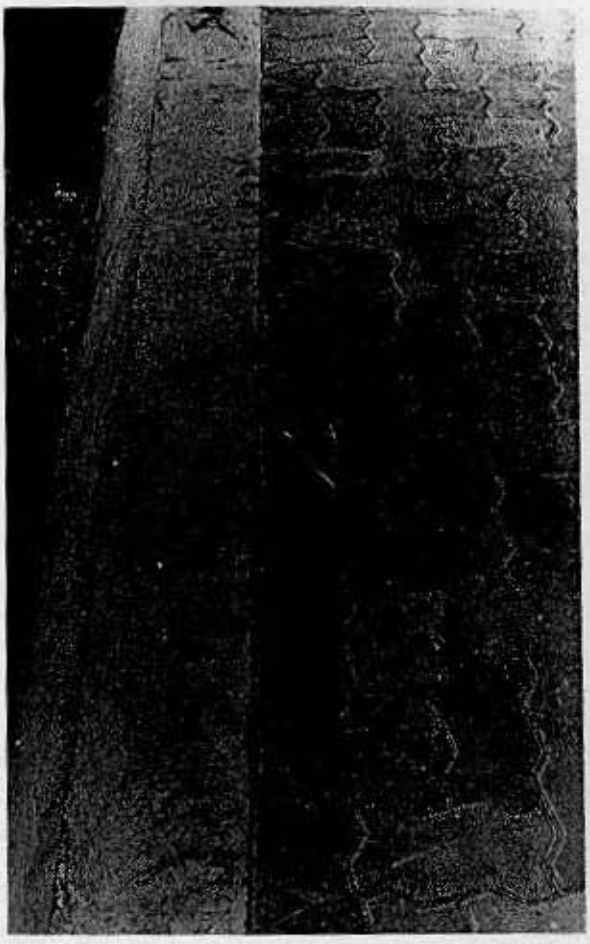


Figure 3: Pavement surface and edge beam after completion of the entire construction procedure



Figure 2: Completion of blocks laying near edge beam



Figure 4: Chain pattern of the test caterpillar vehicle

2.4 Quality Control

The quality control (Q.C.) of the block production for the project was performed by an independent authorized laboratory (the construction laboratory of the Israel Standards Institute -- southern office). The following actions were involved in the Q.C. procedure:

a. Visual inspection of trays for immediate elimination of faulted blocks right after forming and compaction;

b. Random selection of a daily sample (minimum of 6 blocks for each test);

c. Testing of samples 28 days after production (for compressive strength, bending strength and abrasion);

d. Analysis of results by the project designer (who provided overall supervision of the project);

e. Approval or rejection of the daily lot for shipment to the site;

f. In case of rejection, selection of a second sample for a second (and final retesting).

During the production and quality control procedures, several problems developed with relation to testing, sampling and quality of the blocks. Many of these problems were due to the fact that a new product, a new plant, and unfamiliar sources of aggregates were involved. The problems were treated both analytically and experimentally, and proper solutions were tried and successfully adapted (1).

2.5 Construction Procedure

The following stages summarize the construction procedure for the concrete block pavement used in the project:

a. Construction of embankment and subgrade layers according to conventional flexible pavement specifications;

b. Casting of concrete edge beams on top of a layer of lean concrete, as shown in Figure 1 (minimum curing time for subsequent construction was 7 days);

c. Construction of subbase layers according to conventional flexible pavement specifications;

d. Spreading and leveling of the sand bedding layer;

e. Laying of the blocks in a "herringbone" pattern, as described in Figure 1, from the edge beam on one side to the edge beam on the other side (see Figure 2); when necessary, blocks were cut by a special device; they were laid by hand with a maximum joint width of 3 mm;

f. Performing initial compaction on the same day by at least 3 passes of a vibrating plate with a dynamic force of 2,000 kg;

g. Filling of joints with quarry sand b: sive brooming, and performing 4 addi passes of vibrating-plate compaction completion of the initial compaction;

h. Performing heavy proof-rolling by 8 p of a 12-ton pneumatic roller. Figure shows the pavement surface and the ed after completion of the entire constr process.

2.6 Preliminary Loading Test

During the completion stages of one secti the project, a loading test was performec an actual heavy caterpillar vehicle. Thi was designed mainly to check and verify s the assumptions and quality requirements concrete block pavements. The test was p ed on a pavement section consisting of a road and an apron area. The block paveme completed with respect to joint filling a initial compaction, but without the final rolling.

The test caterpillar vehicle weighed about tons. Its chain pattern is described in F 4. The operations performed by the vehicl as follows: fast and accelerated travelin straight line; abrupt stopping after fast eling in a straight line, including skiddi with lock chains; turning 90° curves while traveling and after stopping; and spot turr and manoeuvring while locking on side chain

All the operations listed above were extens performed. The following observations were with relation to pavement performance and c dition after the test:

a. Throughout the entire test, the pavement formed excellently as a stable monolithi surface. Not a single case of block def tion, block extrusion, horizontal block ment or breakage of an entire block cros section was observed;

b. There was only minor breakage of the edg corners of bolted blocks; this was a res of straight traveling, turning and abrup stopping and skidding;

c. Almost no abrasion from straight traveli turning and abrupt stopping was observed the contrary, metal traces were noted on pavement surface as a result of the skid after abrupt stopping;

d. There was a moderate amount of breakage edges and corners of blocks; several cas surface abrasion, mainly in bolted block occurred after extensive in-spot manoeuv

It should be stressed that the loading test performed before the final proof-rolling of pavement, which would have "ironed" the pav surface and thus eliminated some of the rel vertical unevenness of blocks. It was conc that, in general, the entire pavement perfc

quite satisfactorily as a stable monolithic surface, despite heavy loading, large horizontal forces and extensive detrimental manoeuvring.

Based on the outcome of the loading test, it was decided to maintain all quality requirements and construction specifications as originally determined for this project and to re-examine them during the first years of actual service operation of future projects.

3. TRAFFIC & SERVICE CHARACTERISTICS

The construction of the roads and aprons with concrete block pavements was completed toward the end of 1983. The entire project was finished in the spring of 1984, and opened to caterpillar traffic in the summer of 1984.

Based on the operational characteristics of the entire complex, the following specific traffic zones were formed in the CBP areas:

a. Roads and aprons for pneumatic vehicles and light and heavy vehicles with rubber-padded caterpillar chains;

b. Service aprons for parking and maintenance of heavy vehicles (up to 50 tons) with exposed metallic chains;

c. Access roads (up to 4 km. length) for fast heavy vehicles (up to 50 tons) with exposed metallic chains.

These zones were operated daily with extensive traffic movements of all vehicle types.

4. PAVEMENT PERFORMANCE

4.1 Pavement Monitoring

The concrete block pavements in the different traffic zones were monitored continuously after they were opened to service. The monitoring was mainly visual and qualitative, and it was undertaken by the civil engineering staff in coordination with the departments responsible for operating these pavements.

Monitoring was also carried out by the authors on the following dates:

- July 1985 (after one year of service);
- January 1986 (after one and one-half years of service);
- July 1986 (after two years of service);
- October 1987 (after more than three years of service).

These periodical monitorings involved visual inspection, staff questioning, photographic recording and distress-mode analysis.

4.2 Roads and Aprons for Caterpillar Vehicles with Rubber-Padded Chains

Inside the complex, several CBP roads and aprons were used exclusively for servicing pneumatic vehicles and caterpillar vehicles with rubber-padded chains. Despite the intensive traffic activity of those vehicles, both in slow and fast movements, the CBP performance was excellent during the entire three years of service. Apart from minor damage in a few blocks, the CBP is found to be very stabl without block breakage, abrasion or rutting; this can be seen in Figure 5, which demonstrates pavement condition after one year of service (July 1985) and after more than three years (November 1987).

4.3 Service Aprons for Heavy Caterpillar Vehicles with Exposed Metallic Chains

In these service aprons, the caterpillar vehicles move slowly in straight lines or perform steering and turning manoeuvres. Often, vehicles enter the apron directly from the adjacent field, bringing dirt and flintstone particles on the top of the CBP surface.

At present, after more than three years of intensive service, the CBP is quite stable and intact, showing no signs of settlement, deformation, rutting or horizontal movement of blocks. Only a limited amount of breakage of blocks in their entire cross-section could be found.

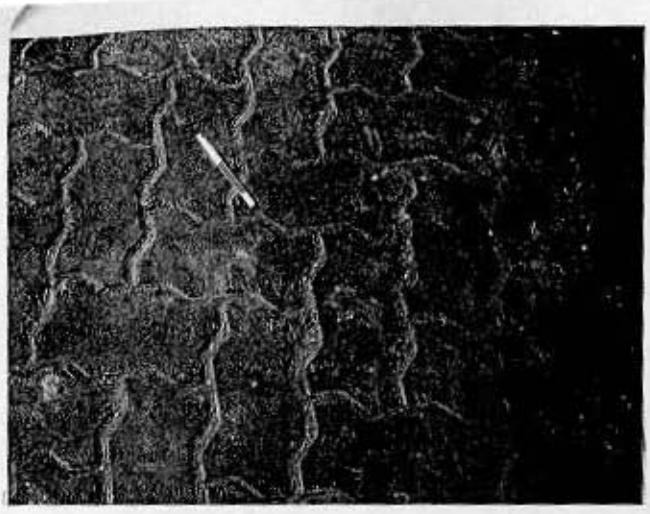
On the other hand, a gradual development of block surface abrasion and of upper corners breakage was detected, starting from the end of the first year of service (see Figure 6). The severity of the abrasion and corners breakage depends on the traffic intensity at each location. Some of the corners and of the entire block breakage can be attributed to the pressing of the vehicles' chains on flintstone particles, thus transferring very heavy "point loading" to the blocks.

As a result of block abrasion and corners breakage, the upper joints between blocks have widened, but only down to about 10-15 mm. (of the 100-mm. block thickness). As can be seen in Figure 6, the pavement condition has remained stable during the last year and a half; this is mainly due to the improvement of the cleaning routine of the aprons.

Generally, because of the stable and monolithi CBP surface, the aprons as a whole still func tion satisfactorily despite the surface distress.

4.4 Access Roads for Fast and Heavy Caterpill ar Vehicles with Exposed Metallic Chains

Despite the fast and heavy movement of caterpillar vehicles with exposed chains, the CBP access roads performed quite satisfactorily during the first year of service. Starting with the second year, however, a gradual and



a. July 1985



b. July 1986



c. November 1987

Figure 5: Typical pavement condition during service on roads and aprons for pneumatic vehicles and caterpillar vehicles with rubber-padded chains



a. July 1985



b. July 1986



c. November 1987

Figure 6: Typical pavement condition d service in service aprons fo heavy caterpillar vehicles w exposed metallic chains

peedier deterioration began to be observed. urface abrasion, block corners breakage and ntire-block breakage all developed rapidly at he chain paths (see Figure 7).

he extensive abrasion, especially the large mount of entire-block breakage, is quite clear- y due to the fast movement of the exposed hains. This causes the segments of a chain to it the pavement surface with a heavy, sharp knife-impact" blow, resulting in severe damage o the blocks.

espite the abrasion and breakage, the CBP evertheless remained stable and monolithic at he end of the second year of service, and howed no signs of settlement, deformation, utting or horizontal movement of blocks. This an be seen on the left side of Figure 7.

After three years of service, the pavement con- dition of about 80% of the access road length as remained almost unchanged, even though most of the blocks in the chain path were broken to half their length. Here, also, the CBP rem- ained stable and monolithic (see Figure 7).

At the end section of the access road, however, a new phenomenon developed. Here, at local spots, the CBP lost its interlocking potential as a result of excessive abrasion and breakage. This led to the local loss of bearing capacity, and a local settlement and rutting developed. With further traffic, a total pavement failure at this location became imminent, as was obser- ved in one spot during the pavement monitored in November 1987. The above steps in CBP failure are demonstrated in Figure 8.

The local excessive abrasion and breakage are assumed to be mainly due to a uniform abrasion resistance of block lots. This is clearly reflected in Figure 7 (July 1985), where a zone of blocks with lower abrasion resistance is clearly visible after one year of service.

The sensitivity to abrasion and breakage of the end section of the access road compared to the better resistance of the entire length of the road can be explained by the non-uniformity of aggregates in block production during the con- struction period. This is clearly reflected in Table 2.

The local total failure of the pavement could have been prevented by the replacement in time of the small abrasive spot with new blocks. This act of maintenance is quite easy and cheap when performed in time, and represents one of the major advantages of concrete block paving.

5. SUMMARY AND CONCLUSIONS

This paper has described the performance of interlocking concrete block pavements (CBP) exposed to heavy and abrasive caterpillar load- ing during their first three years of service. It is a continuation of a paper presented by the authors at the Second International Confer- ence on CBP, held in Delft, which described the design and construction phases of this project.

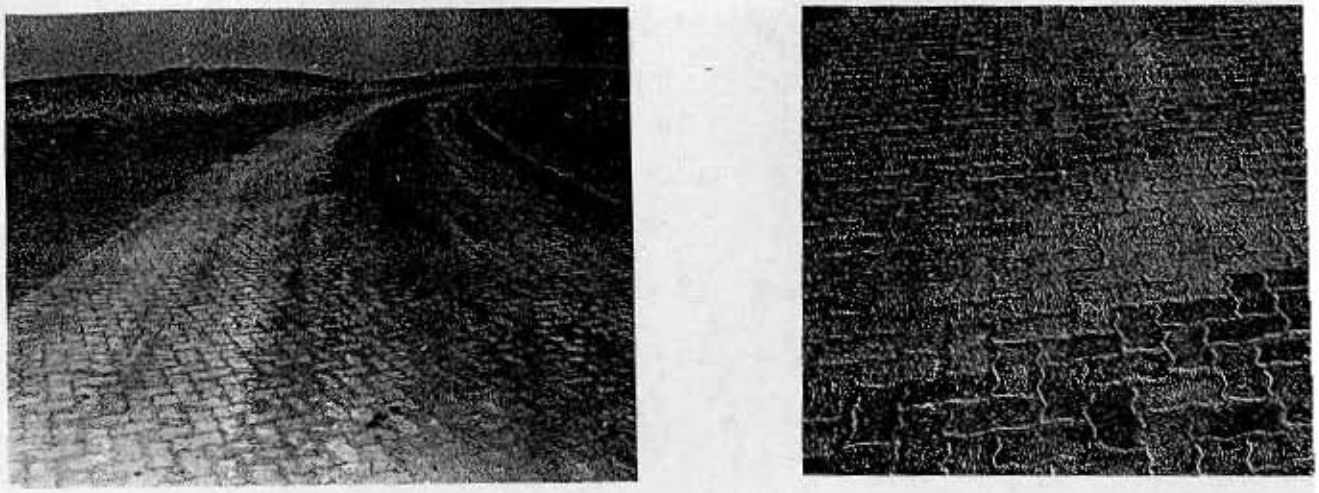
The specific project described in the earlier paper was then in its last stages of construc- tion, several months before its opening to service. The successful performance during production, construction and actual loading tests permitted the introduction of proposed quality control criteria, testing procedures and construction specifications.

The CBP complex is now at the beginning of its fourth service year of accommodating exten- sive operations of caterpillar vehicles. Durin this period, annual monitoring of pavement con- dition and performance has been carried out.

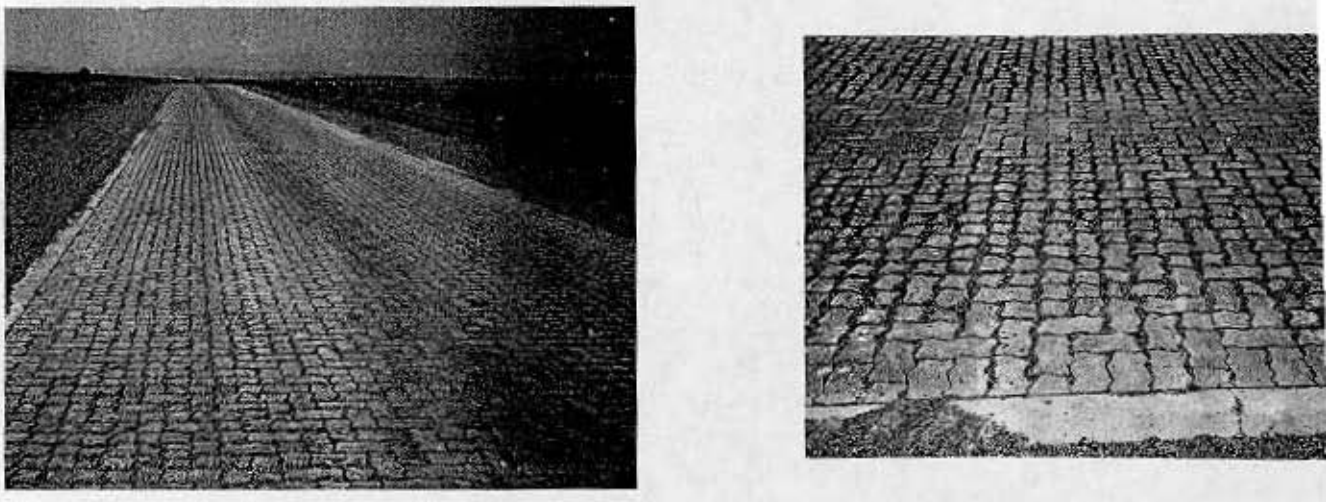
The behaviour of the CBP and its performance over time with three different types of cater- pillar loadings and operations was described. The development of failure modes in the three traffic zones and an analysis of the causes and deterioration mechanism were also presented

The following is a summary of the major trends and conclusions derived from the main findings presented in this paper:

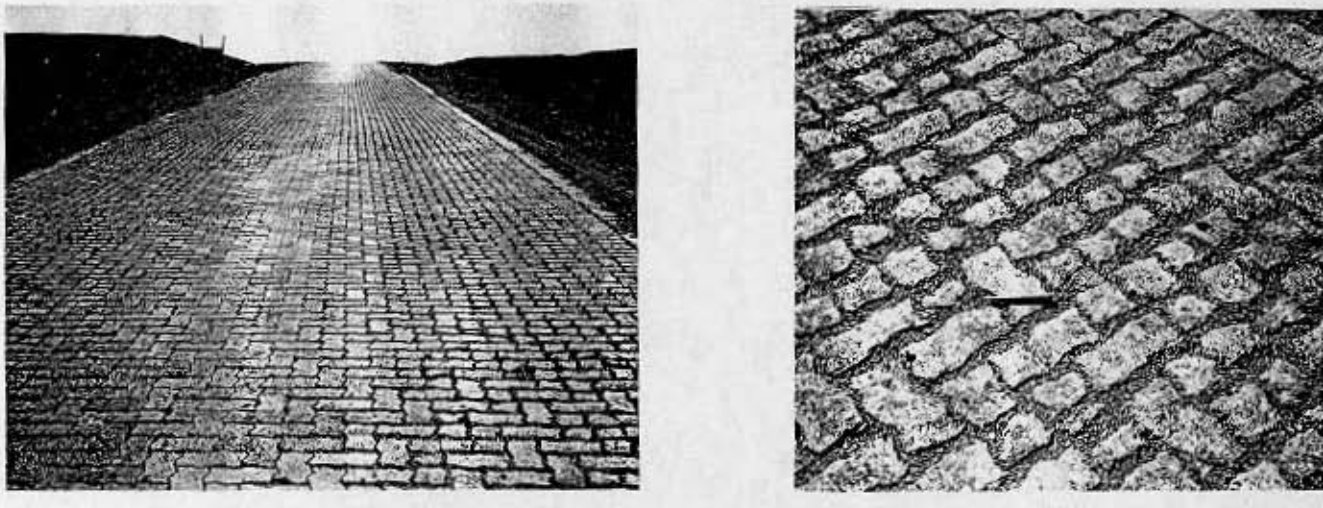
1. With proper pavement design, block productio and construction procedure, an interlocking concrete block pavement can provide a dur- able pavement to support both the slow and fast traffic of heavy caterpillar vehicles with rubber-padding chains;
2. Slow and turning movements of heavy cater- pillar vehicles with exposed metallic chains will cause abrasion and upper-corner breakage of the pavement blocks. The abrasion and corners breakage gradually develop with time, producing a widening of the upper joints between blocks. After three years of service, the thickness of the block still maintains its interlocking effect; thus the pavement remains stable and monolithic without any settlement, rutting or horizontal movement of the block
3. Fast movement of heavy caterpillar vehicles with exposed metallic chains will cause excessive abrasion and breakage of entire blocks. This abrasion and breakage may create the loss of the interlocking potenti of the pavement, causing the loss of bearin capacity and developing settlement, rutting and local failure of the entire block pave- ment;
4. Based on the three-year performance, CBP found to be unsuitable for operating heavy caterpillar vehicles with exposed metallic chains. On the other hand, CBP is quite suitable and durable for any heavy pneumati vehicles and heavy caterpillar vehicles wit rubber-padded chains.



a. July 1985



b. July 1986



c. November 1987

Figure 7: Typical road and pavement condition during service in access roads for heavy caterpillar vehicles with exposed metallic chains.



a. a spot of excessive abrasion and breakage.



b. development of settlement or rutting.



c. development of local entire pavement failure.

Figure 8: Typical example of the development of local pavement failure at the end of the access road.

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