# THE USE OF THE BEDDING LAYER AS A HORIZONTAL DRAINAGE MEDIUM IN CONCRETE BLOCK PAVEMENTS

**R. Yaron, J. Bensabat, I. Ishai**
Technion – Israel Institute of Technology
Haifa, Israel

**Abstract**

In certain situations a need arises to pave Concrete Block Pavements on impervious bases. Since the concrete block surfacing is highly permeable, water may accumulate in the bedding course between the concrete blocks and the impervious base. Analyzing the balance of water penetrating into and drained from the sand layer, reveals that using the conventional paving materials and procedures do not allow for a proper draining of the sand layer. The combined effect of an immersed sand layer and traffic loads can cause damages to the pavement due to pumping and loss of stability and shorten its service life. Some possible solutions to the problem were suggested, including surface sealing and changes in the bedding and joint sand aggregate gradations. Most of the solutions still need to be theoretically and experimentally investigated.

## 1. General

The hydraulic permeability of concrete block pavements to water is much higher than regular concrete or asphalt pavements. In rainy seasons significant amounts of water infiltrate into the lower layers of the CB (Concrete Block) pavement. When the base course under the sand bedding course is relatively impervious, water can accumulate in the sand and impair the durability of the pavement. Damages are caused to the CB pavement when the bedding layer is saturated, especially when combined with traffic loads ([1],[2],[3]). Engineering solutions must therefore be found in order to prevent water accumulation in the bedding course.

## 2. Concrete Block Paving on Bounded Bases

Building CBP (Concrete Block Pavement) on bounded bases of different kinds is frequently reported in the literature. The main uses of bounded bases in concrete block paving are:

*A. Bounded Bases as Part of the Design Method*

Most of the accepted design methods for CB pavements (see [4], [5] among others) allow to incorporate a bounded base as part of the pavement structure. However, the main use of bounded bases is performed in areas of heavy or industrial traffic, where the level of

stresses exerted on the pavement is high. The use of bounded bases in cases of lightly trafficked areas is rarely done, especially due to cost grounds. Bounded bases are much more expensive than unbounded ones, even when the relative structural value is taken into account.

According to experiments reported in [4], the behaviour of bounded bases in CBP is usually better than unbounded bases. It seems that especially in urban areas, where there are many devices (such as manholes and inspection chambers of various facilities) attached to the CBP and proper compaction of the base is difficult, the use of bounded bases may reduce the frequency of local failures of the pavement. This subject needs to be further investigated in the future.

*B. Concrete Block Paving as a Rehabilitation Method of Conventional Pavements.*

Relatively few articles ( for instance [6],[7],[8]) have dealt with the issue of using CBP for the overlaying of existing flexible and rigid pavements. In these cases the surface layers of the existing pavement become the base of the rehabilitated pavement. In cases where the existing pavement surface is distorted, there may be a need for a leveling layer to be paved under the sand bedding layer and the CB.

*C. Concrete Block Surfacing as a Final Stage in a Staged Paving Process.*

This paving method is usually adopted in new and developing areas. Due to architectural and other reasons, the roads and parking areas are planned to be eventually paved with concrete blocks. However the building and developing processes in the area may take several years, during which part of the area is already partly populated. Due to the high and irregular loading conditions that exist during construction (exceptionally loaded trucks, caterpillar vehicles, dropping building materials etc.), and especially due to the delayed construction of side elements (necessary to the stability of the CBP), the concrete block surfacing is delayed to the last stages of the construction [9]. In order to provide an acceptable level of service in the meantime, the roads and parking lots are temporarily paved with a bounded surface layer. Close to the end of the construction work, development works are finished, the interim surface layer is repaired and the concrete blocks and sand course are overlaid.

## 3. The Issue of Water Infiltration into Concrete Block Surfaces

Contrary to conventional asphalt and concrete pavements, which are practically impervious, concrete block surfaces are much more susceptible to water infiltration. The rates of water penetrating the CBP are especially high at the first period of service of the pavement. In time, the joints between the blocks are gradually filled with fines (originated by the moving traffic, water that percolates through the joints and driven by the air), thus reducing the infiltration capacity of the CBP.

One of the main factors that affects the permeability of CBP to water is the permeability of the sand used during construction to fill in the joints. Fig. 1 describes the gradation of some sandy materials used to fill the joints. According to the draft of the Israeli standard regarding CBP [10], pure sand is used, while according to [11] (recomendations adopted by the South African and Australian standards) the sand should contain 5-10% fines (passing no. 200 sieve). Hazen

equation [12] is successfully used in order to estimate the hydraulic permeability of sandy materials:

$$K = C_1 * (D_{10})^2 \qquad [3.1]$$

Where:

| | | |
|---|---|---|
| K | - | The permeability coefficient of the material in cm/sec. |
| $C_1$ | - | An empirical coefficient (1/cm*sec) ranging between 100 to 150. |
| $D_{10}$ | - | The size of which 10% of the aggregates in the joints sand are smaller |

According to the Hazen equation, the hydraulic permeability of the above mentioned joint sand materials ranges between 2.2 X 10-2 cm/sec for the Israeli sand to 3 X 10-3 cm/sec for the sand mentioned in [11]. It should be mentioned that Hazen equation is meant to be used for pure sands, so the hydraulic permeability values for materials that contain fines might be overestimated.

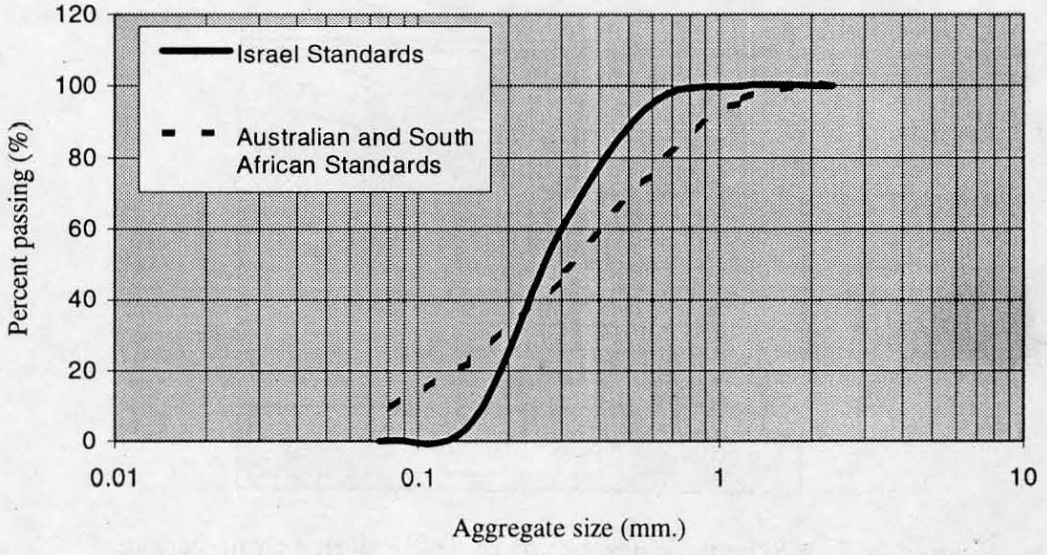



Figure No. 1: Joint sand aggregate gradations according to different standards.

Assuming that the sand course is not flooded, the water discharge infiltrating the CB surface can be estimated using Darcy's law:

$$Q = S * K_j * I_j / 100 \qquad [3.2]$$

Where:

| | | |
|---|---|---|
| Q | - | The rate of water penetration to a unit area of the concrete block surface ($m^3/sec/m^2$). |
| S | - | The ratio of joints area to the total area of the pavement ($m^2 / m^2$). |
| $K_j$ | - | The permeability coefficient of the joint sand (cm/sec). |

$I_j$ - The gradient of water flow in the joints (m/m).

The value of $I_j$ can be approximated by (see Fig. 2):

$$I_j = H / L \sim 1.0 \qquad [3.3]$$

Where:

H - The difference between the level of the water flowing on the surface and the bottom of the concrete blocks.

L - The length of water flow path in the joints.

Assuming that the depth of the water flowing on the surface is not greater than a few millimeters (a very reasonable assumption, except for limited places and time periods), and taking into account the height of the concrete block (6-10 cm.) and the block phases (3-5 mm.), the value of $I_j$ will usually be in the range of 1.0-1.1 and may be approximated as 1.0.

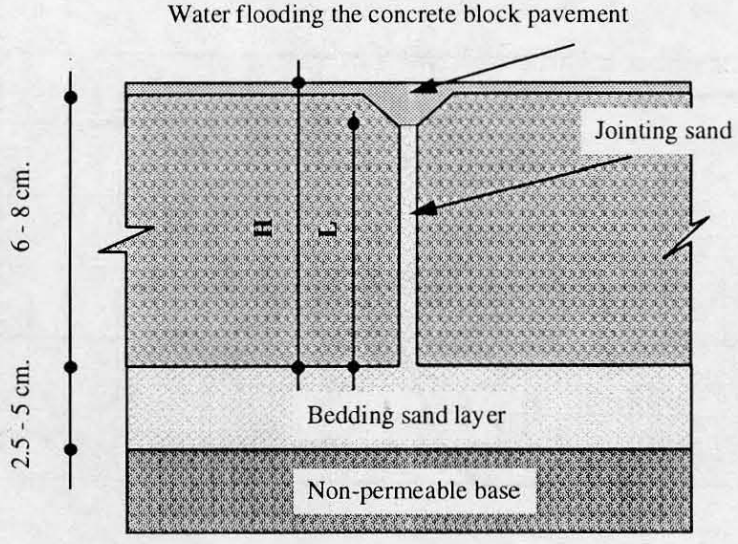



Figure No. 2: A Schematic description of a CBP during a rain period.

The above method allows the assessment of water penetration into the CBP. From the analysis it is clear that the depth of water on the surface has only a minor influence on the rate of infiltration. The rate of water infiltration is mainly controlled by the hydraulic permeability of the joint sand and the width of the joints. When the bedding layer is flooded (a phenomenon that has negative effects on the durability of the pavement), the gradient of water flow will be lower, the rate of water infiltration will be reduced and in some cases seepage problems may arise.

Some laboratory tests were conducted in order to evaluate the amounts of water infiltration into a CBP, under varying surface cross slope conditions. The main conclusion of the research presented in [13] is that water infiltration into a new CBP can amount to 30-35% of the total rainfall. Changes of the surface cross slope in the range of 1-5% had only minor effect over the rate of water infiltration. The use of an acrylic based sealer caused a 50% reduction in the surface permeability, but the sealing conditions were far from being ideal.

According to the authors of this article, the analysis of the laboratory results in [13] should be re-evaluated. The attempt to assess the rates of water infiltration into the pavement in proportion to the surface water flow or total rainfall, seems to be imprecise. In properly drained surfaces, water piling is rarely observed, and a few millimeters of water do not change significantly the rate of water penetration. Whenever there is free water in the vicinity of the joints (which means all during the raining period), water infiltrates into the surface. The rate of water infiltration is governed by the lower value of either the rain intensity or the permeability of the CB surface. Therefore, the analysis of water infiltration into the CBP should take into consideration long periods of rain and not only storm events.

The above conclusion may be illustrated on the basis of the data given in [13]. For 10/20 cm. concrete blocks and an average joint width of 2.6 mm. (as given in [13]), the relative joints area is:

$$S = ( 20.26 \text{ X } 10.26 - 10 \text{ X } 20 ) / ( 20.26 \text{ X } 10.26 ) = 3.7\%$$

If about 33% of the sprinkled water penetrates the surface and the "rain" intensity is (according to [13]) 45 mm./hour, then the rate of water infiltration is approximately 15 mm./hour. Using the above data and equations 3.2 and 3.3, it is possible to backcalculate the theoretical coefficient of permeability of the joint sand:

$$K = 100 * Q / ( S * I ) = 100 * ( 0.015 / 3600 ) / ( 0.037 * 1.0 ) = 1.15 \text{ X } 10^{-2} \text{ cm/sec}$$

Using equation 3.1 and the aggregate gradation of the joint sand as given in [13], the water permeability of the joint sand is:

$$K = 100 \text{ X } D_{10} \text{ ^ } 2 = 100 \text{ X } 0.023 \text{ ^2} = 5.3 \text{ X } 10^{-2} \text{ cm/sec}$$

Since the Hazen equation was calibrated for pure sands and the above material contained 2% fines (passing 200# sieve), it can be assumed that the real permeability of the joint sand was lower than $5.3 \text{ X } 10^{-2}$ cm/sec. Consequently, it seems reasonable that the monitored rate of water infiltration was consistent with the theoretical rates predicted by the sand permeability. The above leads to the conclusions that reducing the runoff from 45 mm/hour to 15 mm/hour or changing the slope of the surface will not significantly change the amounts of infiltrating water.

Additional infiltration experiments are reported in [14], where existing CBP were examined. Table 1 depicts the main results of that research, during which runoff coefficients under changing raining conditions were studied.

Similar conclusions as the above may be drawn by analyzing the results given in Table no. 1. For low rain intensities (0-7 mm/hour), the rate of water infiltration is also low (1.7-2.6 mm/hour). For higher rain intensities the rates of water infiltration reached values that are close to the infiltration capacity of the surface, which were about 4 mm/hour for the "Plaza" site and about 7 mm/hour for the "Junction" site. A further raise in the rain intensity had no significant influence on the amounts of water infiltration. On the other hand it is clear that when the rain intensity is lower than the surface infiltration capacity, the rain intensity dominates the rate of water infiltration.

Table No. 1: Results of experiments on runoff coefficients in CBP [14]

| Site | Range of rain intensity | Average rain intensity | Average runoff | Average rate of infiltration |
|---|---|---|---|---|
| | mm/hour | mm/hour | % | mm/hour |
| "Plaza" | 0-7 | 3.5 | 51 | 1.7 |
| | 7.1-15 | 11 | 63.3 | 4.0 |
| | 15.1-30 | 22.5 | 79.4 | 4.6 |
| "Junction" | 0-7 | 3.5 | 13 | 2.6 |
| | 7.1-15 | 11 | 41.8 | 6.4 |
| | 15.1-30 | 22.5 | 66 | 7.6 |

Using equation 3.2 on the assumed surface infiltration capacity of 4 to 7 mm/hour [14] results in backcalculated permeability values of 3-6 $*10^{-3}$ cm/sec in the joints sand (the value of S was about 3.5%). These permeability values are relatively lower than the expected values (according to the sand aggregate gradations) and may reflect the anticipated permeability reduction during the CBP service life.

Another research [15] was conducted in order to study the permeability of CBP surfaces to different kinds of fluids, with and without a sealing operation. The results have shown that using a polymeric sealing material practically rendered the CBP practically impervious. This result is entirely different than the result given in [13], where the sealing action reduced the permeability by only 50%. The opposing results may be due to the use of a different sealing material and different sealing procedures.

## 4. The Gradation and Characteristics of the Sand Bedding Course.

In certain situations, such as the rehabilitation of existing pavements with CBP, the sand bedding layer under the concrete blocks performs as a horizontal drainage facility. Using the bedding layer as a draining medium alters the required properties of the sand. Achieving high permeability coefficients in the bedding sand will decrease the flooding potential and the chances of shortening the service life of the CBP. Using the bedding layer for horizontal drainage requires the provision for adequate slopes of the base course and a subsurface drainage collecting system.

Beaty [16] brings up the issue of aggregate gradation of the bedding sand in conventional CBP. Most standards (such as US Corps of Engineers, ASTM, NCMA, BS 6717, Aus. C&CA, the Israeli standards and more) requires the use of aggregates with a maximum aggregate size of 5 mm. 50% of the sand pass 1.18 mm. sieve and 0-15% pass 0.15 mm. sieve. In the Netherlands coarser aggregate gradation is used. The maximum aggregate size is 8 mm. and a large part of the sand is in the size of 2-5 mm.

Another research [17] defines analytic aggregate gradations for the bedding sand layer. The well graded sandy material should, according to [17], follow the equation:

$$p=100*(d/D)^n \qquad [4.1]$$

Where:

| | | |
|---|---|---|
| p | - | Percent passing size d sieve |
| d | - | Sieve size in mm. |
| D | - | The size of the maximum sized aggregate in mm. |
| n | - | The value of exponent of the equation |

According to [17], an exponent value in the range of 0.45-0.6 results in sand mixtures that have high stability and relatively low permeability values. When the value of n is in the range of 0.7-1.0, lower but satisfactory stability is obtained and the permeability coefficients are much higher. Exponential coefficients that are lower than 0.4 or higher than 1.0, are not recommended. Figure no. 3 describes the aggregate gradation of some of the commonly used bedding sand materials in addition to the gradation of analytically derived materials as described in [17].

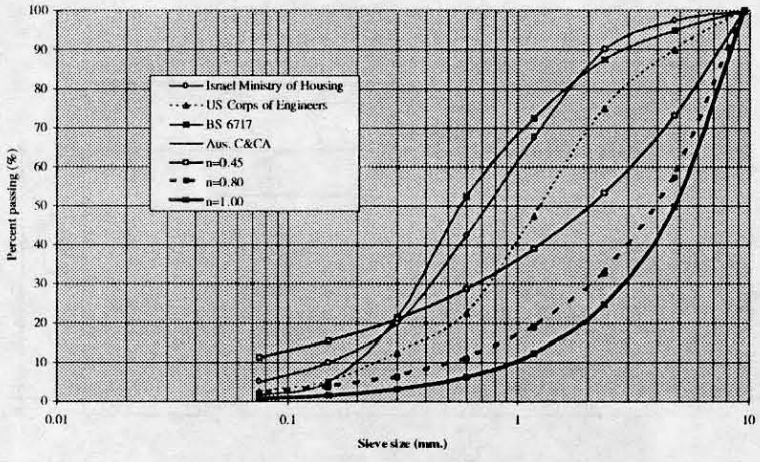



Figure No. 3: Aggregate gradation of some analytical and commonly used bedding sand materials ([10],[16],[17]).

Figure no. 4 depicts the permeability values of different sand mixtures according to the Hazen equation. The permeability values are in the range of 0.017 cm/sec (for the sand mixture recommended in Israel) to 1 cm/sec (for the coarse sand mixture mentioned in [17]).

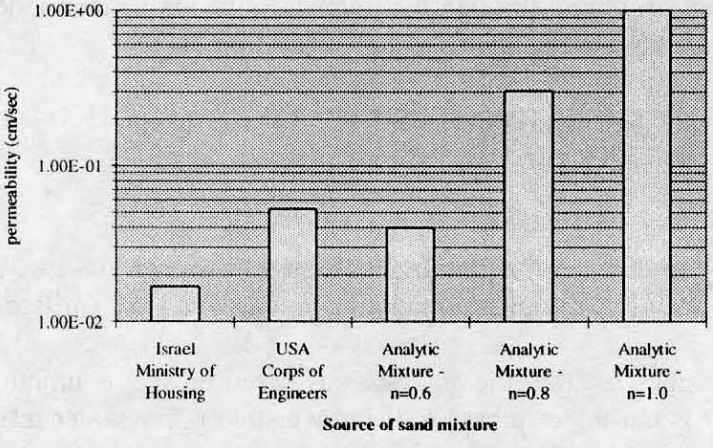



Figure No. 4: Bedding material Permeability estimates according to the Hazen equation

## 5. The Horizontal Drainage Capacity of the Sand Bedding Course.

When the base course under the CBP is impervious, the water infiltrating into the pavement will be horizontally drained through the sand bedding layer. The water will flow according to the slopes of the base course, up to the location of the subsurface drainage system.

The analysis of water flow in the sand bedding layer will be done by examining a strip of CBP as illustrated in Fig. 5. The strip has L/1 m. dimensions, where the L represents the maximum expected flow distance of water in the bedding course down to the location of the subsurface drainage system. For the sake of simplicity, a constant base slope is assumed. The analysis equated the amounts of water infiltration into the CBP with the water discharge of the bedding course.

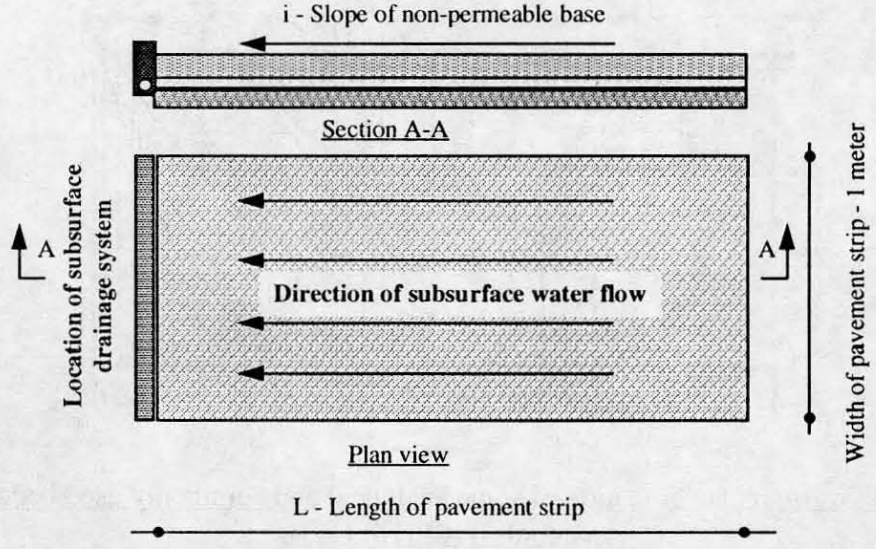



Figure No. 5: Schematic description of subsurface flow pattern in a CBP bedding layer

*A. Evaluation of Water Infiltration into the CBP*

The rate of water infiltrating through the joints into the above mentioned strip of CBP will be computed on the base of the analysis made in section 3:

$$Q_p = Q * 1 * L = S * K_j * I_j / 100 * L \sim S * K_j * L / 100 \qquad [5.1]$$

where:

$Q_p$ - The rate of water infiltration into the CBP strip ($m^3$/sec)
$Q$ - The rate of water infiltration into a unit area of CBP ($m^3$/sec/$m^2$)

It should be reemphasized that the analysis was based on the assumption that the water in the bedding layer is not under pressure, thereby enabling free water infiltration through the joints.

*B. Maximal Water Discharge Drained by the Bedding Course.*

The water that penetrates the CBP flows in the bedding course according to the slope of the underlying impervious base. The maximal discharge that can be drained through the sand is based on analyzing a vertical section of the sand course close to the subsurface drainage collectors. The analysis assumes a condition of steady state flow and though it is relatively simplistic (similar to that reported in [18]), good assessments of water discharges may be obtained. The computations assume that the sand layer is practically flooded, which means that the phreatic surface coincides with the bottom of the concrete blocks. This assumption will yield the maximal discharge through the section in non pressurized free water flow. The maximum water discharge through the sand layer of a 1 m. CBP strip is computed by Darcy's law:

$$Q_d = K_b * I_b * 1 * H_b / 10^4 \qquad [5.2]$$

Where:

$Q_d$ - The maximal possible water discharge in the sand layer of the CBP strip ($m^3$/sec)
$K_b$ - The permeability of the sand in the bedding course (cm/sec)
$I_b$ - The slope of water flow in the sand layer
$H_b$ - The thickness of the bedding course (cm.)

Equating the rate of water infiltration into the CBP strip ($Q_p$) with the maximal drainage capacity of the bedding layer ($Q_d$), enables the computation of the value of: L - the maximal possible draining distance in order to avoid the flooding of the bedding course.

$$L = K_b * I_b * H_b / (100 * S * K_j) \qquad [5.3]$$

As can be seen in equation 5.3, the density of the subsurface drainage collectors decreases when the bedding sand permeability gets higher or the slope of the subsurface water flow increases. A reduction in the maximal possible value of L occurs when the openings of the joints become wider or when the joints sand become more permeable.

Checking the maximal drainage length according to the usual sand gradations and conventional geometric conditions yields practically unrealistic values of L. As an example the computation was done for the following values:

1. $K_b = 1.25 * 10^{-1}$ - Bedding sand permeability according to an analytic mixture with n=0.7. This material has a coarser gradation than in most usually used mixtures (cm/sec)
2. $I_b = 0.03$ - The slope of the subsurface water flow
3. $H_b = 3$ - The thickness of the bedding layer (cm.)
4. $S = 0.04$ - Assumed ratio of joints area to total pavement area
5. $K_j = 4 * 10^{-3}$ - Assumed value of joint sand permeability, as obtained by analyzing the experiments reported in [14]

The maximal drainage length for the above conditions is:

$L = 1.25*10^{-1} * 0.03 * 3 / ( 100 * 0.04 * 4*10^{-3}) = 0.70$ m.

The value of L should govern the decision on the distance between subsurface drainage collectors. Under the above conditions, the computed value of L is far smaller than a reasonable minimum distance (from engineering and economic point of view) of about 7 to 10 meters.

The above analysis emphasized the problematic situation that may arise in CBP covering an impervious base. A too long subsurface drainage distance may lead to a saturated bedding layer, which may cause (combined with the action of wheel loads) to pumping problems and to a serious decrease in the durability of the CBP.

## 6. Possible solutions to the Problem

Some actions may be taken in order to avoid the damages caused by overflowing the sand bedding layer in a CBP with an impervious base:

A. Using finer sands that include higher percentage of passing #200 sieve, to fill the joints between the concrete blocks. Even small amounts of fines may significantly decrease the permeability of the material and thus reduce the amounts of water infiltration into the CBP. Addition of other materials such as lime or Bentonite was also examined in the past [4].
B. Sealing the joints with special sealing agents. The literature contains different results of the efficiency of the sealing action to cut down water penetration into the CBP. Using the right sealing materials and proper application might prove to be very effective.
C. Changing the gradation of the sand in the bedding layer. High permeability coefficients may be achieved by using a coarser graded material, while still maintaining the mechanical stability of the sand.
D. The addition of a pervious layer (such as an open graded asphaltic mixture) above the impervious base. The high permeability coefficients of this additional layer and its thickness will substantially increase the draining capacity of the CBP. The main problem in this solution is its cost, since in most cases the additional layer is not structurally needed. An supplementary geosynthetic might be needed in order to avoid sand penetration into the open graded pervious layer.
E. In new pavements that require a bounded base, use may be made of open graded mixtures that are pervious enough to allow the water to penetrate the deeper layers of the pavement. Only when some of the previously mentioned solutions are found efficient, an impervious bounded base can deliberately be used in order to prevent water penetration into the subgrade.

## 7. Summary

In certain situations a need arises to pave CBP on impervious bases. Since the concrete block surfacing is highly permeable, water may accumulate in the bedding course between the concrete blocks and the impervious base. Analyzing the balance of the water fluxes penetrating into and drained from the sand layer reveals that using the conventional paving materials and procedures does not allow for a proper drainage of the sand layer. Inappropriate drainage of the infiltrating water can cause serious problems to the pavement's stability and durability. Further research is needed in order to better understand the behaviour of CBP under

conditions of rain and to provide engineering and economically sound solutions to ensure dependable and reliable pavements.

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