Evaluation of Interlocking Concrete Pavement Performance

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Abstract

Road pavement surfacings are now an intrinsic part of the development and personalization of municipal public areas. Through its use of form, colour, and texture, interlocking concrete pavements provide an answer to concerns in urban design. Nevertheless, the use of interlocking concrete pavements by cities in the province of Québec remains low. Little is known about the structural behaviour of this type of pavement since only few studies have focused on this topic. This research project aims at the determination of criteria for the design of interlocking concrete pavement in northern environments. For this purpose, parameters linked to performance of this type of pavement have been identified and the experience with interlocking concrete pavement as road surfacing in Québec has been reviewed. This was followed by a laboratory evaluation of the concrete blocks and sandy bed behaviour.

Many parameters seem to affect the performance of interlocking concrete pavement. The assessment of the importance of these parameters required an evaluation of the use of interlocking concrete pavement as surfacing material in Québec. An evaluation of nine sites in Québec City, six in Montréal, and three in Longueuil, yielded to the identification of the main parameters linked to the degradation of interlocking concrete pavements in urban context: pavement, joints and sandy bed. This assessment has enabled pinpointing of the problems associated with this type of pavement and to identify the causes of failures as well as the reasons behind the success of existing sites, in particular, the key role of the sandy bed. An experimental program was carried out in laboratory, which consisted in verifying and quantifying the relative importance of these significant parameters using cyclic testing on systems consisting of two types of concrete blocks laid on sandy beds of different thicknesses and mineralogical sources.

INTRODUCTION

Roads surfaced with concrete blocks are considered to be flexible pavements for which bituminous concrete is replaced by interlocking concrete blocks laid on a granular bed known as the sandy bed. Interlocking concrete pavements cover an increasingly wide range of applications, essentially in urban areas. These applications bring together, among others, pedestrian walkways, sidewalks, service stations, intersections, bus lanes, port zones, parks, and automobile and airport parking lots.

This wide field of applications can be explained by the many technical, aesthetic, and economic advantages offered by this type of pavement. Despite its many advantages, the use of concrete block pavement as surfacing material remains low in Québec. Until now, the use of concrete block pavement has not been the object of studies accounting for Québec's specificities. Thus, Laval University, in collaboration with the cities of Québec and Montréal as well as the companies Transpavé, Permacon, Techni-Seal, and Techmix, undertook a research project whose main objective was to determine and optimize design criteria for roads surfaced with interlocking concrete blocks.

At the end, it was necessary to identify the key parameters linked to the performance of this type of pavement, to assess the use of concrete blocks as surfacing material in Québec, to establish the causes of failures and the reasons behind successful case studies, and to carry out laboratory tests to study the behaviour of the concrete blocks/sandy bed system for different types of blocks and sandy beds.

BACKGROUND INFORMATION AND IDENTIFICATION OF PARAMETERS AFFECTING THE PERFORMANCE OF IINTERLOCKING CONCRETE BLOCK PAVEMENTS

The performance of interlocking concrete block pavements is directly influenced by its various components and its characteristics. The components of this type of pavement are the concrete blocks, the sandy bed, the joint-filling material, the header blocks, the base layer and subbase layer. Figure 1 presents a typical representation of an interlocking block pavement.

In service, the performance of interlocking concrete block pavements is affected by several factors influencing the main components of this type of pavement: the concrete blocks, the sandy bed, the joints, and the base layer.

The blocks

Four main parameters affect the performance of blocks. They are the shape, the thickness, the pattern, and the strength of the blocks.

Shape

In the case of vertical loads, the shape of blocks has no significant influence on the performance of pavement. However, it is at a paramount importance to control horizontal loads.

Thickness

Increasing the thickness of blocks reduces strains, deflections, as well as the stress transferred to lower layers.

Pattern

There are many ways of laying down the blocks, the most common of which are the broken line, herringbone, and chevron patterns. It seems that the best performance is obtained with blocks laid in herringbone pattern and that this benefit is more important if the road is exposed to horizontal loads.

Strength

Québec standard specification NQ 2624-120 requires a compressive strength of 45 MPa or more for concrete blocks.

Sandy bed

The sandy bed is the essential element of roads paved with concrete blocks and it is one of the main causes for its failure. Its purpose is to provide a uniform support to blocks in order to avoid the concentration of stresses (an important source of damage), to fill the bottom part of joints to ensure the interlocking of blocks, to constitute a barrier to the propagation of cracks, and to contribute to the distribution of stresses resulting from wheel loads. In order to achieve its role, the sandy bed must exhibit the following properties: to be easily compactable, not susceptible to frost, able to fill joints, resistant to mechanical damage, and self-draining.

Thickness

The thickness must be 30 mm ± 5 mm.

Gradation

The sandy bed is generally a sand whose maximum particle size is 5 mm. Studies pointed at the danger associated with a large amount of particles passing the 75 μm sieve (Cook and Knapton, 1992). In Canada, the trend is to eliminate all particles passing the 75 μm sieve (due to frost problem).

Particle shape

Some studies show that sands having angular particles are more stable after compacting and present a higher internal angle of friction (Shackel, 1980a). On the other hand, Cook and Knapton (1992) have shown that the bedding sand is the cause of some damage observed in the United States and in England. Indeed, sands with angular grains break more easily under the effect of traffic loads.

Water content during compaction and in service

Shackel (1980b) suggested that the sand should have a water content of 6% while Miller-Cook (1980) suggest a content between 6 and 8%. According to Beaty (1996), it also seems that the sand must have an uniform water content in order to allow for change in volume during compaction.

Resistance to mechanical damage

After having studied the causes of pavement failures under heavy loads, Lilley and Dowson (1988) concluded that the most important property of sand used for sandy beds is its aptitude to bear repetitive loads without breaking. Therefore, sand containing quartz and feldspath, which are more resistant to mechanical damage, are better suited for the laying of blocks.

Joints between blocks

Two main characteristics of joints are likely to affect in-service performance of roads paved with concrete blocks. These are their width and their mechanical strength.

Width

To avoid the pumping of sandy bed material through joints, the maximum recommended width of joints is 2 to 6 mm.

Mechanical strength

According to Panda and Ghosh (2001), shear and expansion stresses are the main criteria in selecting sand for joints. This study shows that the best sand for these joints is one with coarse angular grains (quarry sand) likely to resist shear.

Base layer

The main factors influencing the performance of the base layer are the type of material used and the thickness of the base layer. With respect to the thickness, the variation in elevation of its finished surface must be very low. In fact, a high variation can cause variations in thickness of the sandy bed, which could become a cause of future failure. Strains, deflections, and stresses in the base layer decrease considerably with the increase in thickness of concrete blocks. For an optimal solution, the quality and thickness of the base layer must be compatible with the thickness of blocks. It appears that materials used for the base layer of bituminous concrete road pavement can be used effectively for concrete block pavement. These materials are granular materials (crushed stone), stabilized granular materials, lean concrete, and even bituminous concrete. The choice of material depends essentially on the climate.

Permeability

One of the main concerns related to the use of concrete blocks as road pavement in a northern environment is the water infiltration through the joints which is very damaging for base and subbase layers. For this reason, it is recommended to provide an adequate slope (transversal profile) for water draining purposes and to reduce the permeability of joints, or, even better, to seal them.
Ishai et al. (1999) has shown that the choice of sand grading for the laying of blocks must take into account the mechanical strength and especially the water infiltration. Water infiltration can wash away the sand if the speed of flow is elevated which result in shifting of the blocks. The authors of the present paper have noticed that indented blocks (multidirectional blocks) remain better in place than rectangular blocks (unidirectional) under water infiltration or water flow at high speed. Tests carried out have shown that coarse particle sands (5 mm in diameter) are less susceptible to being washed away than finer particle sands.

In this section, it has been shown that many parameters affect the performance of interlocking concrete pavement. In order to assess the factors contributing to good performances in a northern environment, the use of concrete blocks as pavement material for several sites in the province of Québec was documented.

STUDY OF THE USE OF BLOCKS AS PAVING MATERIAL IN QUÉBEC

Identification of studied sites

Several test sites were identified in three different municipalities: Overall, 18 test sites were selected of which 9 were located in Québec City, 6 in Montréal, and 3 in Longueuil.
<u>Test sites in Québec City</u>
- Charest East– de la Couronne,
- de la Canardière – 3e avenue,
- Honoré Mercier, in front of the National Assembly,
- Masson – Musset,
- René-Lévesque – Cartier,
- René-Lévesque, Centre des congrès,
- René-Lévesque – des Érables,
- Saint-Jean – Sainte-Geneviève,
- Saint-Joseph East– de la Couronne.

<u>Test sites in Montréal</u>
- Clark – de la Gauchetière,
- Duluth - Berri,
- Jardin botanique, main road,
- Prince Arthur East – Hôtel de ville,
- Prince Arthur East - Laval,
- Verdun, in front of former City Hall.

<u>Test sites in Longueuil</u>
- Briggs - Chambly,
- De Gentilly - Chambly,
- Demix Plant 1 and 2.

Observations, measurements, and samplings

Evaluation on the various sites consisted of measuring rutting, the thickness of blocks, and the thickness of the sandy bed (5 measurements per site), the vertical and horizontal shift of blocks, the deterioration of joints, the shape of blocks as well as, bonding and blocking of blocks. Sample of the joint-filling material, the sandy bed and the base layer were also taken during the site visit.

Visual observations

The purpose of visual observation of the blocks was to evaluate the presence of scaling, the wear, and the type of failure. All of these observations are summarized in Table 1. It can be seen in Table 1 that no scaling of blocks was observed on the sites studied, which indicates a good behavior of blocks with respect to this type of damage. However, a large amount of wear was observed at the Masson/Musset, Duluth/Berri, Prince Arthur/Laval, and Demix Plant 1 and 2 sites. The main types of failures observed sporadically are corner breaks and breakage in two halves. The general aspect of the sites is good in most cases, except or René-Lévesque/Cartier and René-Lévesque/des Érables sites where severe rutting was observed.

Thickness of sandy bed

Table 2 presents the values for thickness of sandy bed measured at each site. The average value of thickness is the result of five measurements of the sandy bed thickness for a single site. According to the results presented, the average value of sandy bed thickness in Québec, is 30 mm with a standard deviation of 8 mm, which demonstrates a certain homogeneity of this parameter. However, in Montréal, the average value at the sites studied is 41 mm with a standard deviation of 33 mm showing a high level of variability in thickness of sandy bed. For example, the average thickness of the sandy bed at the Clark/de la Gauchetière site is 4 mm while it is 94 mm at the Duluth/Berri site. Finally, in Longueuil, results are similar to those in Québec with an average of 35 mm and a standard deviation of 12 mm.

Surface quality

Table 3 presents a summary of measurements and readings carried out on the surface of sites paved with concrete blocks from both the surface deterioration and the blocks characteristics points of view. It can be seen that only three sites present vertical shifting (Charest/de la Couronne, René-Lévesque/Cartier and René-Lévesque/des Érables), and that no horizontal shifting has been observed. Moreover, according to the results presented, it is clear that rutting is a type of damage that is frequent for this type of pavement, as 12 out of the 19 sites are affected by this type of damage. It should be noted that the joints are mostly damaged by trenching between them. It can be seen from Table 3 that the thickness of blocks appears to play a role in the development of transversal rutting. In fact it is possible to notice that the three sites presenting a maximum transversal rutting greater than 30 mm are covered by blocks of 80 mm in thickness or less. This represents a trend observed on the studied sites, however, more data is necessary to confirm this observation. Nevertheless, this observation is consistent with expectations, since thicker blocks accentuate the slab effect, increasing strength of the pavement. Moreover, in Figure 2, maximum transverse rutting is compared to blocks pattern using a histogram. It can be seen that, according to the results obtained, the herringbone pattern seems to be the least performing. In fact, 57% of the sites whose maximum transversal rutting exceeds 20 mm (arbitrary threshold for this analysis) were laid in a herringbone pattern. However, it would be necessary to collect more data to confirm this trend.

Rutting measurements

Table 4 presents, for each site, the maximum rutting value measured using a precision rut ruler. One value of elevation is taken every 100 mm in order to obtain the transversal and longitudinal profile of each site under consideration. It can be seen in Table 4 that the maximum rutting values vary considerably ranging between 0 et 60 mm. It should be noted that five sites present maximum rut above 20 mm, that is the René-Lévesque/Cartier, René-Lévesque/des Érables, Prince Arthur/Hôtel de ville, Demix Plant 1 and 2, and Jardin Botanique sites. The René-Lévesque/des Érables site presents the deepest ruts at 60 mm. As far as the maximum longitudinal distortions are concerned, no one exceeded 20 mm and the deepest distortion was measured at the Briggs/Chambly site in Longueuil. Figure 3 shows an example of the rut depth measurements. Depth “d” of the rut is the distance (Δ) between the deepest point of the rut and a straight line drawn above the crests on both sides of the rut.

Laboratory materials characterization tests

Base materials

Tests were conducted in order to measure the grading of base materials and to determine the value of certain parameters in terms of percentage of fine particles. From these results, it can be seen that the majority of base materials are equivalent to the Québec Ministry of Transportation (MTQ)'s MG-20. Aside from the Demix Plant site, where the base layer is a cement stabilized granular material, all other sites are built using unbound granular materials. Modified Proctor tests were carried out in order to determine the CBR value of base materials. Optimum water content and dry specific density ρ_d were determined and results are presented in Table 5. In this table, it can be seen that the W and ρ_d values do not vary much for the MG-20 samples. Therefore, assuming that these materials were placed at a dry specific density close to the Proctor density, this parameter seems of little interest in order to explain poor performance. CBR tests were done on base materials in order to verify that the base layer does not constitute a source of degradation of pavement, since these tests provide an estimate of the bearing capacity of a granular material. The CBR values obtained are presented in Table 6. Most of the results are found between 100% and 200%. It should be noted that the CBR value of the base material used at the Jardin Botanique site (76%) is a bit low and can partly explain a problem with this type of material.

Sandy bed materials

The percentage of fine particles in the sandy bed materials can be a source of pavement degradation in northern environments. A large quantity of fine particles in a granular material can make it prone to freezing, negatively affecting draining and making it more plastic. However, a low quantity of fine particles can improve granular stacking and thus improve the bearing capacity of the material, thereby improving the load capacity of the material. Gradation analysis by sieving and sedimentation were conducted in order to determine the percentage of fine particles and their size distribution. From the gradation curves obtained, the percentage of gravel (5 mm retained), the percentage of fine particles (passing 80 μm), and the percentage of particles below 5 μm were determined and the results are summarized in Table 7. It can be seen in this table that the percentage of fine particles in the sandy bed at the sites under study varied between 7% and 22%. Seven out of eighteen sites have more than 15% fine particles and most of them have more than 5% of particles below 5 μm, in other words nearly the size of clay particles. The granular materials whose grading is uniform are generally more likely to develop important permanent strains due to their instability. That is why maximum transversal rutting was compared with the uniformity coefficient (C_u) of sandy bed materials in Figure 4. The main observation drawn from the data presented is that nearly all of the sites showing poor rutting performance (a maximum transversal rut above 20 mm is used as a criteria for low performance) are among the sites having a relatively low uniformity coefficient compared with the overall number of sites. The good rutting performance of the three sites with lowest C_u (de la Canardière/3^e avenue, Honoré/Mercier et Prince Arthur East/Laval) is probably due to low percentages of fine particles and particles below 5 μm.

Joint-filling materials

Given the narrow width of joints between blocks, it was not possible to take samples of joint-filling materials on all sites. Moreover, where this was possible, the quantity of material sampled was insufficient to conduct a grading analysis. Maximum diameter values of particles and the percentage of particles passing the 80 μm sieve are given in Table 8. Maximum diameter values indicate that type 0-5 mm and 0-2.5 mm materials are usually used as joint-filling materials in practice. It is however possible to question the width of joints in which particles having a d_{max} of 10 mm were found (de la Canardière/3^e avenue, René-Lévesque in fron of the Centre des congrès, Duluth/Berri, Jardin Botanique, Prince Arthur East/Hôtel de ville, and Prince Arthur East/Laval). Nevertheless, sites having a large percentage of fine particles (Masson/Musset, René-Lévesque in front of Centre des Congrès, Jardin Botanique, Duluth/Berri and de Gentilly/Chambly) may display a lower permeability which can improve the performance of the pavement. However, a large quantity of fine particles may make the material plastic, depending on the mineralogy of these particles.

Analysis of results – Rutting Performance

For each site, the total number of heavy vehicles was estimated by multiplying the annual average daily traffic (AADT) of heavy vehicles by the age of the pavement. In Montréal and Verdun, AADT information was provided directly by these two municipalities. In Québec, the Réseau de Transport de la Capitale (RTC) was able to provide the number of buses traveling on each site per year. Very little information was available for Québec City. The combination of these two sources of information yields to an estimate of the ratio of the number of buses per year and the number of buses for all sites. This coefficient multiplied by the number of buses per year and by the age of the site gives an estimate of the total number of heavy vehicles having traveled each site. Results obtained are summarized in Table 9. It was not possible to obtain enough relevant information to estimate the total number of heavy vehicles in Longueuil. No criterion was found in the literature to establish threshold values for sites having a low, average, and good rutting performance. That is why threshold values used by the Québec Ministry of Transport for performance contracts determined for the construction of highways using bituminous concrete were used. These are presented in Table 10. These values being used for highways, they are stricter than values expected in an urban context since highway speeds are much greater than those on urban roads and the risk of hydroplaning is greater. Nevertheless, it could be appropriate to use these values since they represent a strict performance criterion for pavements. In this study, we used criteria specific for each individual measurement. As the sites evaluated could not be considered new constructions, the value of 12 mm at 7 years was used as a limit value marking the beginning of poor behaviour. It seemed reasonable to assume that the rutting value after construction of the sites was 0 mm. By drawing the maximum depth of rutting against the age of the pavement, it is possible to draw a straight line from 0 mm at age 0 that connects to the point 12 mm at age 7. Moreover, the Québec Ministry of Transport specifies that a rut depth of 20 mm as a typical terminal value at age 15 years. Therefore, a straight line was drawn between 12 mm-7 years and 20 mm-15 years. All data points falling above the line were considered to be representing poor performance. Another line was drawn using half of the values describes above i.e.: 6 mm at age 7 and 10 mm at age 15. This new line was used to separate sites having a good performance from sites having an average performance. The results of this analysis are presented in Figure 5. Using this figure, sites can be classified as having good, fair or bad performance from the point of view of structural rutting, which is the main performance criteria used in this study.

Sites having a good behaviour
- Verdun/Hôtel de Ville
- Duluth/Berri
- Prince Arthur/Laval
- De la Canardière/3ème avenue
- Charest/de la Couronne

All of these sites, except the Verdun/Hôtel de Ville and Duluth/Berri sites, have a sandy bed 35 mm thick (it was specified in the literature review that the thickness of the sandy bed should generally be 30 mm ± 5 mm) which could partly explain their good performance. It should be noted that the Verdun/Hôtel de Ville, Prince Arthur/Laval and Duluth/Berri sites are exposed to relatively low traffic given their age. This might be the explanation for their good performance. Moreover, in the case of the Charest/de la Couronne, Duluth/Berri and Verdun/Hôtel de Ville sites, the uniformity coefficient of the sandy bed is very high (124, 100, and 95). Granular stacking of these materials is therefore good and they are less likely to experience permanent strain.

Sites having an average behaviour
- Masson/Musset
- Saint-Jean/Sainte-Geneviève

These two sites have in common a beginning of joint degradation that could explain some of the poor performance. The average thickness of their sandy bed is relatively small (27 and 19 respectively). These two sites also experience heavy traffic which could explain their average behaviour.

Sites having a poor behaviour

- René-Lévesque/des Érables
- René-Lévesque/Cartier
- Saint-Joseph/de la Couronne
- Prince Arthur/Hôtel de Ville
- Jardin Botanique
- Clark/de la Gauchetière
- Honoré Mercier (in front of the National Assembly)
- René-Lévesque (in front of the Centre des congrès)
-

The poor performing sites have a sandy bed thickness generally within standards, except for the Clark/de la Gauchetière site where the sandy bed is very thin, and even non-existent. However, it was observed that these sites often have a sandy bed of irregular thickness. The poor behaviour of the Jardin Botanique site could be linked to the poor bearing capacity of the base material whose CBR value is only 76%. In all cases, with the exception of the Clark/de la Gauchetière and Jardin botanique sites, the uniformity coefficient of the base material is below 40. With the exception of the Clark/de la Gauchetière, Prince Arthur/Hôtel de Ville and Jardin botanique sites, these sites were submitted to relatively high traffic loads which can partly explain their poor performance. A common characteristic of all these sites, except Honoré Mercier (in front of the National Assembly), is the degradation of joints from a relatively advanced state to a very advanced state.

LABORATORY STUDY OF THE INFLUENCE OF SANDY BED

The sandy bed is a structural layer that is specific to interlocking concrete pavement. As a result, considering the few studies available for this type of pavement, the influence of sandy bed on performance has been carefully investigated in our study. Up until now, in this study, the influence of sandy bed was observed through data collected on site. In this section, laboratory tests were carried out to assess the influence of the thickness of sandy bed and the type of material used. Two thicknesses were tested, 25.4 mm (1'') and 50,8 mm (2''), and two types of materials were tested, a natural granitic sand and a limestone dust. Moreover, two types of concrete blocks, interlocked blocks 80 mm in thickness and rectangular blocks 100 mm in thickness were also examined.

Laboratory tests were conducted on a loading frame. The sandy bed used was compacted, to a water content of 5%, directly into a mould especially designed for these tests, until it reached the desired thickness after 300 cycles of loading corresponding to the energy equivalent to that of a compactor used in laying the blocks at job site. Three blocks, regular or interlocked, were then placed into the mould on the sandy bed, and the joint material, similar to the material used for the sandy bed was then put in place. A 40 kN load was applied at the center of the middle block. The time of loading was 0.1 second and the time of rest was 0.9 second. Cumulative permanent strain was measured at 3 points using a wall-thickness micrometer on the middle block (Figure 6) after the application of 100,000 cyclic loads. In order to compare the performance of each configuration, the average permanent strain on the middle block, (i.e. the one on which the load was applied) was calculated. Comparative results obtained are presented in Table 11.

It can be seen that the thickness of the sandy bed has a major influence on the permanent strain. For 100 mm thick blocks, increases in permanent strain of 81% and 120% were observed for limestone dust and granitic sand respectively when the thickness varied from 25.4 mm to 50.8 mm. As for 80 mm interlocked blocks, increases of 95% and 50% were observed for limestone dust and granitic sand respectively when the thickness varied from 25.4 mm to 50.8 mm. Table 11 shows the beneficial effect of interlocking. Indeed, when compared with regular blocks (100 mm in thickness), the interlocked blocks (80 mm in thickness) show a reduction in permanent strain for an identical material of the same sandy bed thickness, except in the case of the 25.4 mm-thick granitic sand where an increase in permanent strain of 38% was observed. In the three other cases, the decrease in permanent strain observed when interlocked blocks are used remains below 1 mm and varies between 6 and 11%. The type of material seems to be a factor to take into account since, in all cases; the lowest permanent strain is obtained for granitic sand. The plastic behaviour of the limestone dust may explain the results obtained. Nevertheless, granitic sand is an overall better aggregate for this type of application because of its better abrasion resistance which is due to its mineralogy (presence of quartz and feldspath). An example of permanent strain curves as a function of the number of cycles obtained for the tests carried out on regular blocks (100 mm thick) is given in Figure 7.

DISCUSSION AND CONCLUSION

According to data collected on existing roads, it was observed that the thickness of sandy bed often varies considerably, which can create problems with differential behaviour of pavement. This may result in frost heave and the formation of small indentations in the pavement, which can cause water puddling problems. In terms of bonding and thickness of blocks, the trends observed indicate a certain influence of these two parameters. Among the main degradations observed, the most frequent is rutting. This degradation may be the cause of several failures and it was difficult to identify a cause common to all observed sites. The performance of this type of pavement can also be analyzed using a deflection criterion which might provide interesting results. However, it is more complex and costly to measure deflections on site and therefore the rutting criterion was selected for simplicity purposes.

In general, the objective pursued in selecting several sites distributed in three different cities was to draw a general picture of the performance of interlocking concrete pavement and to identify the main parameters having an overall influence on the behaviour of this type of pavement in a northern environment. However, it is difficult to draw clear conclusions on the in-situ performance of concrete block pavements since too many variables are involved. Good or poor performance is generally related to a combination of factors and it is difficult to isolate the effect of each one individually. Nevertheless, a few trends were identified which could guide future research. Tests carried out on the cyclic loading press also confirm some of the observations made on site. Laboratory results have thus clearly shown the effect of the sandy bed thickness, of the interlocking of blocks, and of the type of material used as sandy bed and joint-filler on the performance of rutting in concrete block pavement.

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Table 1 - Visual observations at the test sites

City	**Sites**	**Visual observations**				
		Scaling	**Wear**	**Type of rupture**	**Other**	**General aspect**
Québec	Charest East/de la Couronne	No	Moderate	A few corners of blocks broken off	-	Fairly good
	de la Canardière/3e avenue	No	Moderate	A few corners at angle	Damage near drain inlets	Fairly good
	Honoré Mercier, in front of National Assembly	No	None	None	Joints parallel to the direction of traffic	Very good
	Masson/Musset	No	High	None	Presence of an indentation	Fairly good
	René-Lévesque/Cartier	No	Low	None	-	Deep rutting
	René-Lévesque, Centre des congrès	No	None	A few blocks broken in two or at the corner	-	Good
	René-Lévesque/des Érables	No	Moderate	A bit of breakage	Loss of materials	Deep rutting
	St Jean/Ste Geneviève	No	None	A few small corners broken	-	Good
	St Joseph East/de la Couronne	No	None	None	-	Very good
Montréal	Clark/de la Gauchetière	No	None	None	-	Very good
	Duluth/Berri	No	High	A few blocks broken in two or many more pieces	-	
	Jardin Botanique, main road	No	None	A few blocks broken in two	-	Fairly good
	Prince Arthur/Laval	No	Low to high	None	-	Very good
	Prince Arthur /Hôtel de ville	No	None	None	-	Very good condition
	Verdun, in front of former City Hall	No	Moderate	A few corners	Old pavement	Fairly good
Long.	Briggs/Chambly	No	None	None	Rutting	
	de Gentilly/Chambly	No	None	None	Rutting	
	Demix Plant 1 and 2	No	Moderate to high	A few broken blocks (intense traffic and turning)		

Table 2: Sandy bed thickness at existing sites paved with concrete blocks

Sites		Average thickness (mm)	Remarks
Québec	Charest East/ de la Couronne	33.4	Irregular
	de la Canardière/3^{e} avenue	24.4	Low
	Honoré Mercier, in front of Nat. Ass.	35	Very good
	Masson/Musset	31	Good
	René-Lévesque/Cartier	29	Good
	René-Lévesque, Centre des congrès	24.2	Low and irregular
	René-Lévesque/des Érables	46.6	Thick and irregular
	St Jean/Ste Geneviève	22.4	Low
	St Joseph East/de la Couronne	20.8	Low and irregular
Montréal	Clark/ de la Gauchetière	3.7	Nearly non-existent
	Duluth/Berri	93.8	Thick and irregular
	Jardin Botanique, main road	26.8	Irregular
	Prince Arthur/Laval	32	Acceptable
	Prince Arthur/Hôtel de ville	22.2	Low and irregular
	Verdun, front of former City Hall	68.8	Thick and irregular
Long.	Briggs/Chambly	50.6	-
	de Gentilly/Chambly	36.2	Thick
	Demix Plant 1	30	Irregular
	Demix Plant 2	22.5	Low

Table 3: Surface condition

Sites	Surface characteristics				Block characteristics	
	Vertical shift	**Horizontal shift**	**Rutting**	**Damage to joints**	**Thickness of blocks**	**Pattern**
Charest East/de la Couronne	Yes	Yes	Yes	Yes	76mm	Herringbone
de la Canardière/3^{e} Avenue	No	No	Yes	No joint-filler in some places	80mm	Herringbone
Honoré Mercier, in front of Nat. Assemb.	No	No	No	No	100mm	Broken straight line
Masson/Musset	No	No	Yes (low)	No surface joint remaining	80mm	Herringbone
R.Lévesque/Cartier	No	No	Yes (very deep)	A few worn joints	80mm	Herringbone
René-Lévesque, Centre des congrès	Yes	No	Yes	Very deep	100mm	Broken straight line
René-Lévesque/des Érables	Yes	No	Yes (very pronounced)	Yes	80mm	Herringbone
St Jean/Ste Geneviève	No	No	Yes (very low)	Deep	76mm	Broken straight line
St Joseph East/de la Couronne	No	No	Yes (very low)		100mm	In broken line

Table 3 (continued): Surface condition

Sites	**Surface characteristics**				**Block characteristics**	
	Vertical shift	**Horizontal shift**	**Rutting**	**Deterioration of joints**	**Thickness of blocks**	**Pattern**
Clark/ de la Gauchetière	No	No	No	Very deep and open		Grid
Duluth/Berri	No	No	Yes	Yes (very deep)	80mm	Herringbone
Jardin Botanique, chemin principal	No	No	Yes	Deep and full of dirt	76mm	Broken straight line
Prince Arthur East/ Laval	No	No		No	100mm	Broken straight line
Prince Arthur East/Hôtel de ville	No	No	Yes	A little	100mm	Broken straight line
Verdun, in front of City Hall	No	No		A bit deep	80mm	Fich bone
Briggs/Chambly	No	No	Yes	Yes	100mm	Grid
Gentilly/Chambly	No	No	Yes	Yes	100mm	Grid
Demix Plant 1 and 2	No	No	Yes	In highly solicited areas	71mm	Herringbone

Table 4: Maximum rutting values (transversal and longitudinal profile)

City	Site	Max. depth of transversal rutting (mm)	Max. depth of longitudinal rutting (mm)	
			External edge	Pavement axis
Québec	Charest East /de la Couronne	6	7	5
	de la Canardière/3^{e} avenue	9	0	10
	Honoré Mercier, in front of Nat. Ass.	13	0	-
	Masson/Musset	10	6	4
	René-Lévesque/Cartier	38	3	5
	René-Lévesque, Centre des Congrès	16	-	-
	René-Lévesque/des Érables	54	10	0
	Saint Jean/Ste Geneviève	10	0	0
	St Joseph est /de la Couronne	30	6	0
Montréal	Duluth/Berri	16	10	0
	Clark/de la Gauchetière	5	0	0
	Jardin Botanique, main road	31	7	10
	P. Arthur East/Hôtel de ville	4	5	0
	Prince Arthur East/Laval	22	5	8
	Verdun, in front of former City Hall	3	8	10
Long.	Briggs/Chambly	13	20	-
	de Gentilly/Chambly	12	-	-
	Demix Plant 1	26	4	0
	Demix Plant 2	26	-	-

Table 5 - Results of modified Proctor tests on base materials

City	**Site**	**W (%)**	**ρ_d (g/cm^3)**
Québec	Charest East /de la Couronne	7.5	2.27
	de la Canardière/3^e avenue	5.5	2.33
	Honoré Mercier, in front of Nat. Assembly	4	2.31
	Masson/Musset	4.8	2.19
	René-Lévesque/Cartier	5	2.32
	René-Lévesque, Centre des Congrès	5.7	2.30
	René-Lévesque/des Érables	5.3	2.32
	Saint Jean/Ste Geneviève	5	2.33
Montréal	Duluth/Berri	5.9	2.30
	Clark/de la Gauchetière	4.3	2.34
	Jardin Botanique, main access road	5.3	2.32
	Prince Arthur East/Hôtel de ville	6.2	2.30
	Verdun, in front of former City Hall	4.6	2.33
Lon.	Briggs/Chambly	4.7	2.28
	de Gentilly/Chambly	5.3	2.34

Table 6 - CBR values of base materials

City	Site	CBR (%)
Québec	de la Canardière/3^{e} avenue	130
	Honoré Mercier, in front of National Assembly	217
	Masson/Musset	152
	René-Lévesque/Cartier	116
	René-Lévesque/des Érables	159
Montréal Longueuil	Duluth/Berri	101
	Clark/la Gauchetière	297
	Jardin Botanique, main access road	76
	Prince Arthur East/Avenue de l'Hôtel de ville	-
	De Gentilly/Chambly	101

Table 7 - Gradation characteristics of sandy bed materials

City	**Site**	**≥5mm (%)**	**≤80µm (%)**	**≤ 5 µm (%)**
Québec	Charest East /de la Couronne	11.03	16.97	6.17
	de la Canardière/3^{e} avenue	14.97	7.16	2.33
	Honoré Mercier, in front of National Assembly	15.62	7.80	2.32
	Masson/Musset	16.45	9.97	3.84
	René-Lévesque/Cartier	3.72	13.7	4.21
	René-Lévesque, Centre des Congrès	9.5	15.86	7.22
	René-Lévesque/des Érables	12.1	11.01	3.88
	Saint Jean/Ste Geneviève	18.66	12.6	5.31
	St Joseph East /de la Couronne	7.22	12.15	3.23
Montréal	Duluth/Berri	1.11	20.43	7.61
	Jardin Botanique, main access road	8.58	15.72	7.37
	Prince Arthur East/Hôtel de ville	13.22	10.78	1.15
	Prince Arthur East/ Laval	10.6	9.8	1.19
	Verdun, in front of former City Hall	2.78	16.83	4.73
Long.	Briggs/Chambly	3.18	21.97	5.85
	de Gentilly/Chambly	3.67	19.19	7.51
	Demix Plant 1	0	12.76	4.03
	Demix Plant 2	4.99	11.3	3.13

Table 8 - Gradation characteristics of joint-filling materials

City	Site	D_{max} (mm)	Particles ≤80µm (%)
Québec	de la Canardière/3^{e} avenue	10	10
	Honoré Mercier, in front of National Assembly	2,5	14
	Masson/Musset	5	20
	René-Lévesque/Cartier	5	17
	René-Lévesque, Centre des Congrès	10	29
	René-Lévesque/des Érables	5	18
	St Joseph East /de la Couronne	5	14
Montréal Longueuil	Clark/de la Gauchetière	5	11
	Duluth/Berri	10	21
	Jardin Botanique, main access road	10	24
	Prince Arthur East/Hhôtel de ville	10	18
	Prince Arthur East/Laval	10	13
	Briggs/Chambly	5	19
	de Gentilly/Chambly	5	25

Table 9 - Estimation of heavy traffic by site

City	**Site**	**Year of construction**	**Age (years)**	**Total number of heavy vehicles**
Québec	Charest East /de la Couronne	1996	7	8607480
	de la Canardière/3^{e} avenue	1989	14	968772
	Honoré Mercier, in front of National Assembly	1998	5	560200
	Masson/Musset	1995	8	4612800
	René-Lévesque/Cartier	1996	7	4370940
	René-Lévesque, Centre des Congrès	1994	9	10858320
	René-Lévesque/des Érables	1999	4	2497680
	Saint Jean/Ste Geneviève	1993	10	1709200
	St Joseph East /de la Couronne	2000	3	3688920
Montréal	Clark	2001	2	36500
	Duluth/Berri	1983	20	365000
	Jardin Botanique, main access road	2001	2	32850
	Prince Arthur East/Hôtel de ville	1994	9	25550
	Prince Arthur East/Laval	1996	7	76650
	Verdun, in front of former City Hall	1958	45	164250

Table 10 – Rutting performance contracts criteria for highways

	Grouping in 10 sectors	Any individual measure
At acceptance of work	< 5 mm	< 5 mm
At 7 years	< 8 mm	< 12 mm

Table 11 - Comparative results of cyclic loading tests

	Regular blocks (100 mm)		**Interlocked blocks (80 mm)**	
Thickness of sandy bed (mm)	25.4 (1’’)	50.8 (2’’)	25.4 (1’’)	50.8 (2’’)
Permanent strain(mm) **Limestone dust**	7.74	14	6.89	13.41
Permanent strain (mm) **Granitic sand**	4.57	10.04	6.32	9.47

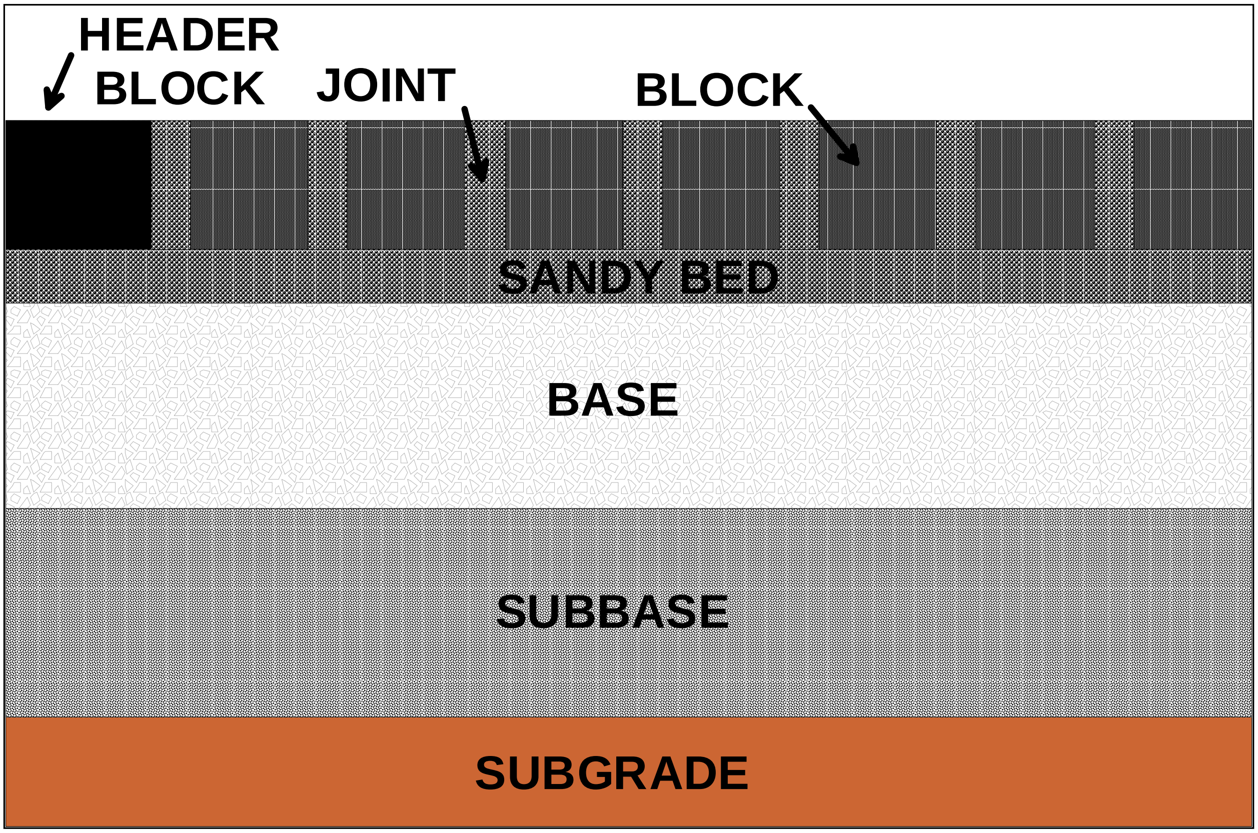


Figure 1 - Cross-section of an interlocking concrete pavement

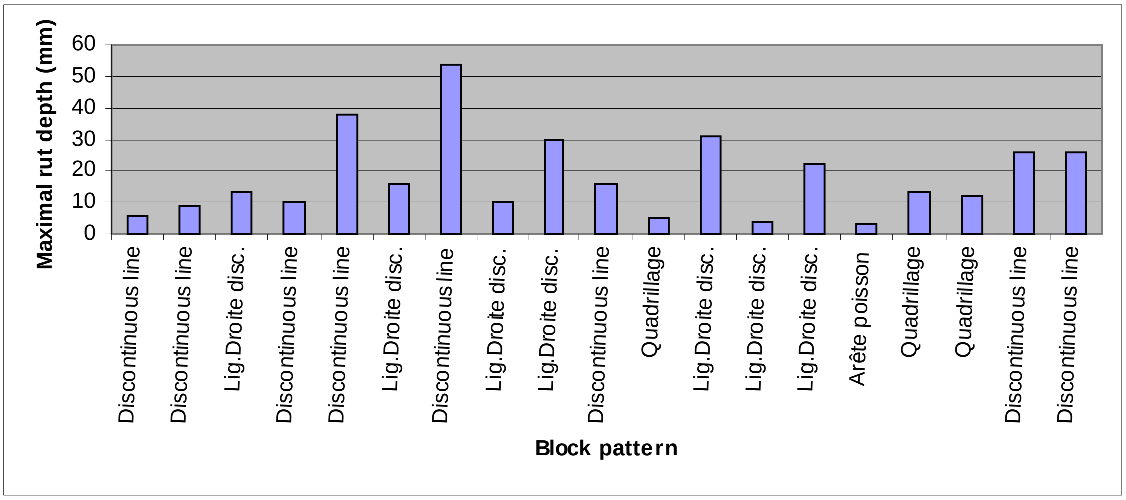


Figure 2 - Influence of block pattern on average maximum transverse rutting

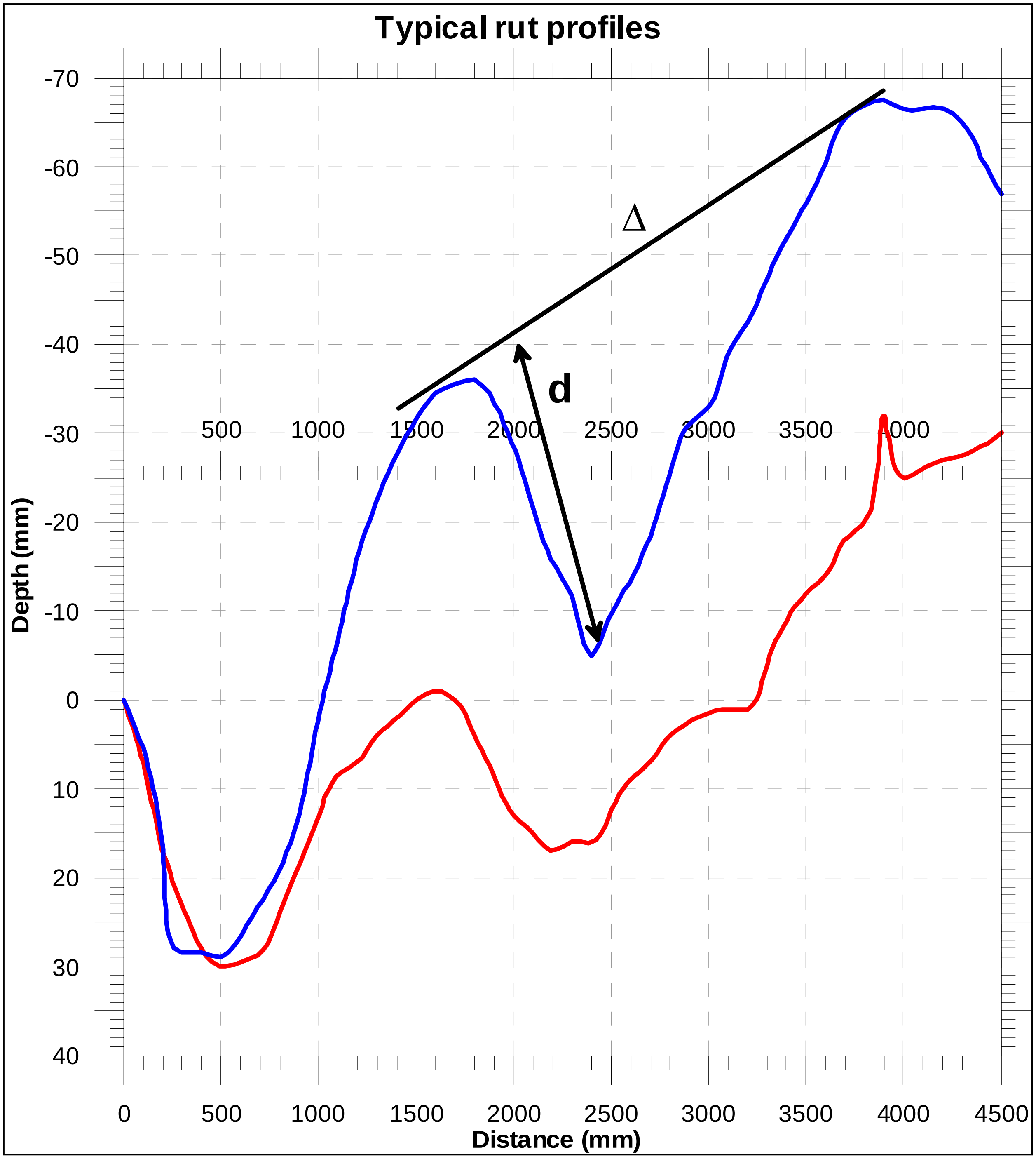


Figure 3 - Example of rut depth measurements

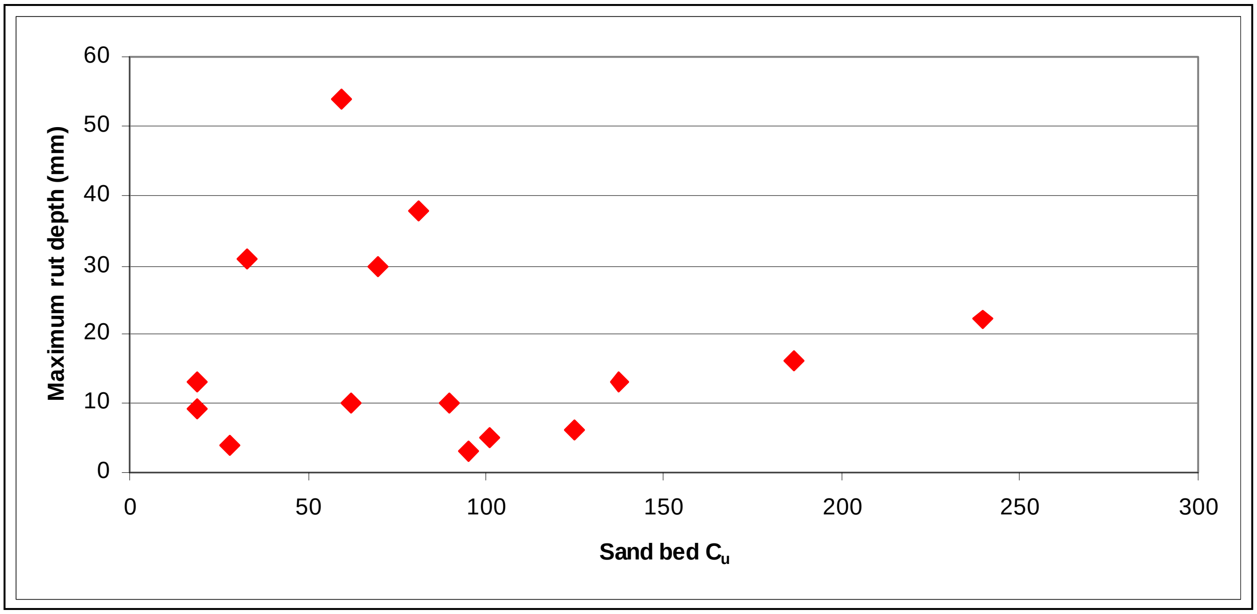


Figure 4 - Influence of C_u of sandy bed on maximum transversal rutting

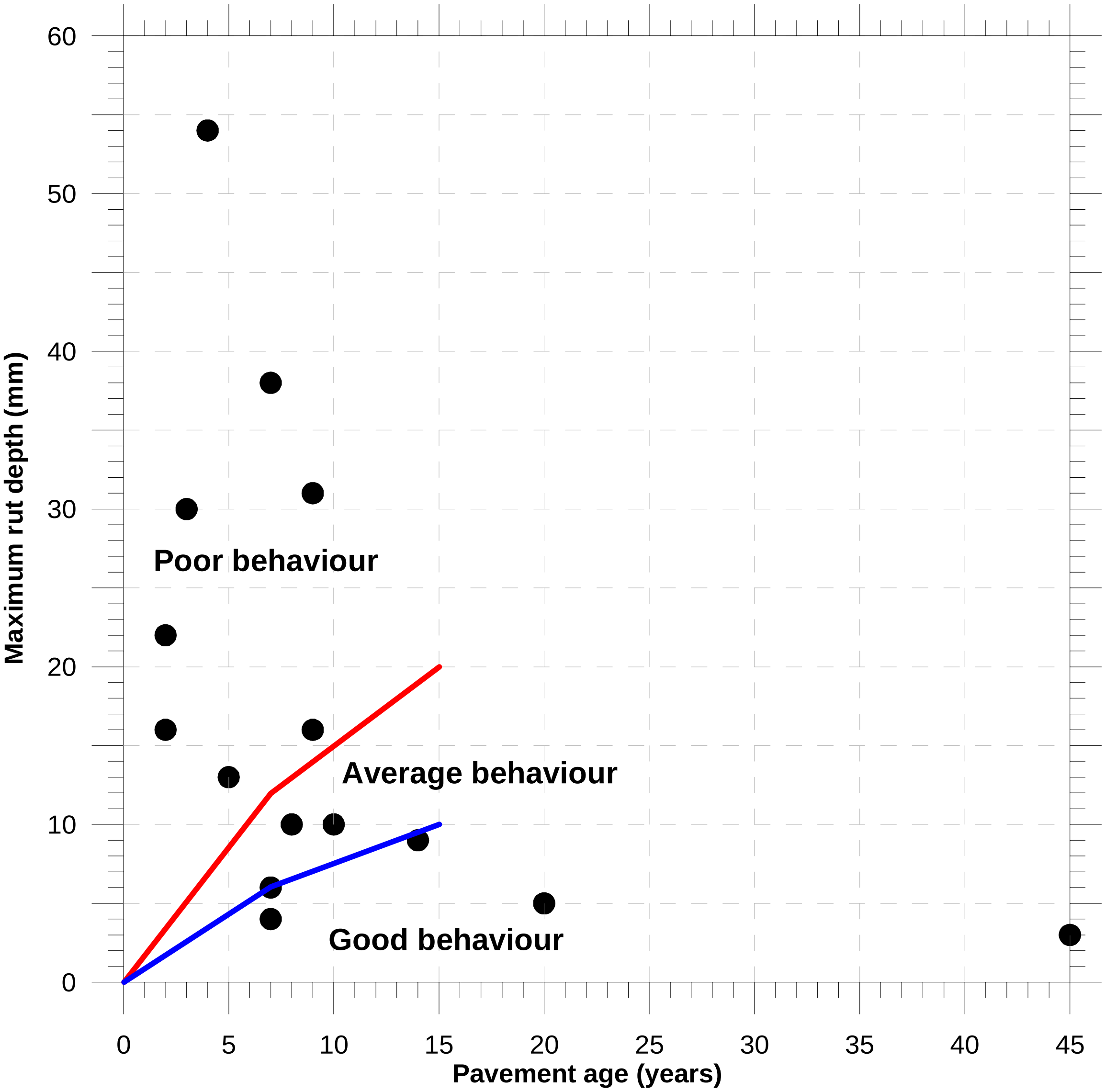
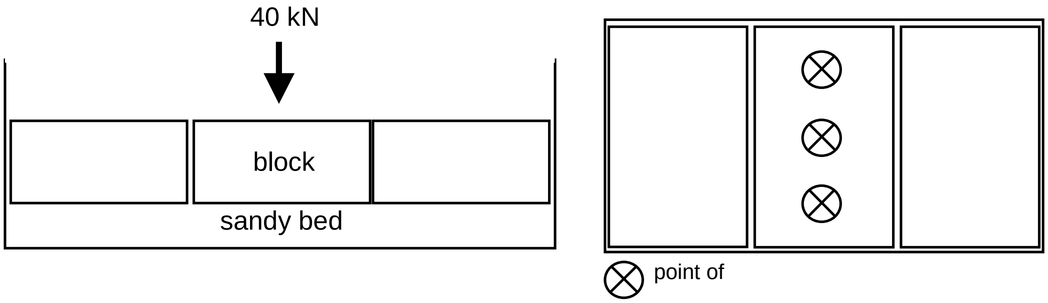


Figure 5 - Distribution of sites having a good, an average and a poor performance



Cross-section

Plan view

Figure 6 - Schematic representation of tests carried out in the laboratory

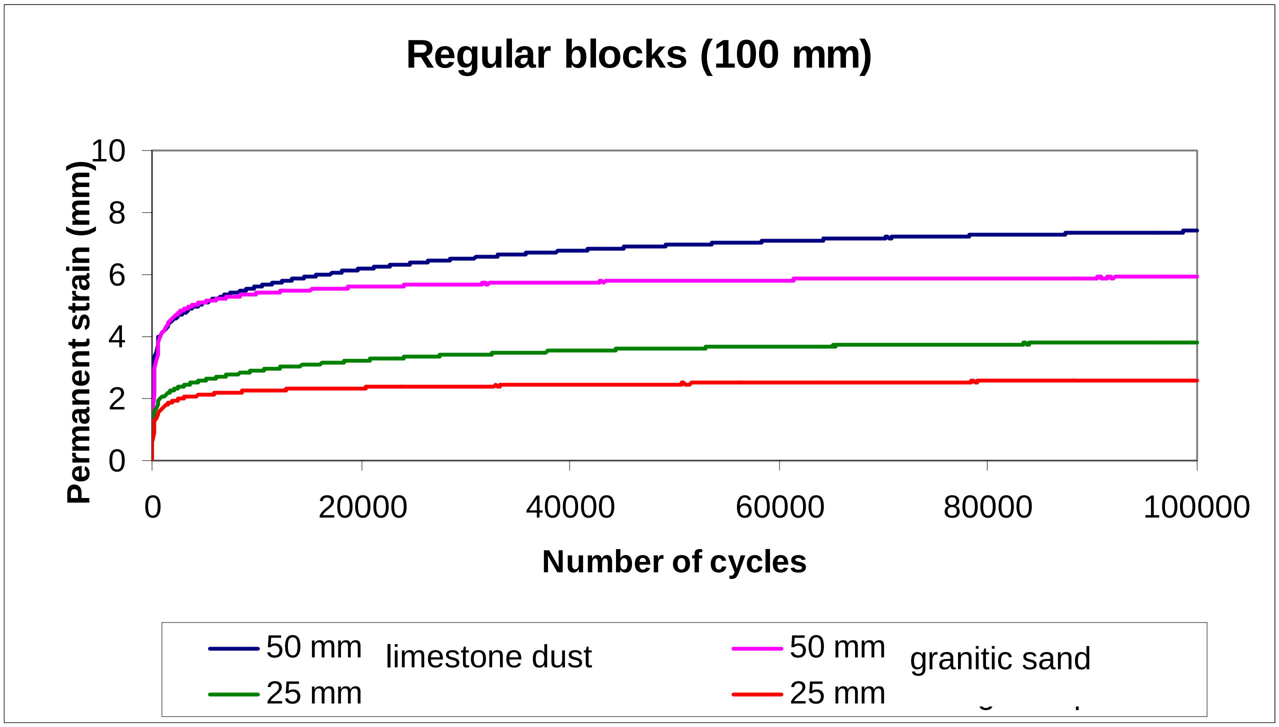


Figure 7 - Permanent strain as a function of the number of cycles of applied loads obtained during cyclic laboratory tests carried out on regular blocks (100 mm)