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DEFLECTION BASIN MEASUREMENTS AND SEASONAL STRUCTURAL BEHAVIOUR OF INTERLOCKING CONCRETE BLOCK PAVEMENTS IN A URBAN NORTHERN CONTEXT

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Note: The following is the notation used in this paper: (.) for decimals and ( ) for thousands.

Summary

In Quebec, the use of concrete blocks as surfacing material in urban roads is limited because no design method adapted to cold regions is available and some urban interlocking concrete block pavement projects have not really well performed. Indeed, the structural behaviour of this type of pavement in cold regions is not well known, as it has not been studied much yet.

The results presented form part of a research project which aims to determine and optimize design criteria for interlocking concrete block pavements in urban northern context. This project includes initially a study of equivalent modulus of "concrete blocks + bedding sand" system in order to design interlocking concrete block pavements with typical flexible pavement design methods. Thereafter, a laboratory validation will allow testing different interlocking concrete block pavement structures. The performing laboratory pavement structures will be tested in-situ in different cities of Canada in order to verify and validate their global behaviour in field conditions. Finally, the project will allow the development of a design model for interlocking concrete block pavements in municipal northern context.

The proposed paper will present Falling Weight Deflectometer (FWD) tests performed in order to measure deflection basins for interlocking concrete block pavements located in Québec City. The deflection tests results will allow understanding and verifying the behaviour differences according to base types (granular material and stabilised with bitumen), season (fall, winter and spring) and traffic (a highly circulated industrial boulevard, a highly circulated principal avenue, and a main street with an average traffic). The deflection basins for the interlocking pavements show an important inflection point which clearly indicates that the interlocking concrete block pavements have a different structural behaviour and which confirms that the development of specific design criteria for interlocking concrete block pavements in urban northern context is necessary.

1. 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 bedding sand. 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 paving as surfacing material remains low in Québec. Until now, the use of concrete block pavement has not been the object of many studies which take into account specificities of urban northern context. Thus, Université Laval, in collaboration with the cities of Québec and Montréal as well as the companies Permacon, Transpavé, Bau-Val (Techmix) and Techniseal, undertook a research project whose main objective is to determine and optimize design criteria for roads surfaced with interlocking concrete blocks.

2. RESEARCH SIGNIFICANCE AND OBJECTIVE

According to a study completed by Shackel (2003), the production and the use of interlocking concrete pavements are increasing in North America since the seventies. Nevertheless, this type of pavement is still not very common in Québec. A large part of the literature coming from a northern context (Northern Europe and Japan) deals with the wear of interlocking concrete blocks due to studded tires which are not often used in North America. Besides, very few studies were made on the structural behaviour of this type of pavement. Until now, there is no specific interlocking concrete pavement design method in Québec. The cities of Montréal and Québec proposed technical specifications for the placing of interlocking concrete pavement laid on bedding sand. However, it appears that design and placing are major performance criteria.

The main objective of the global project is to validate solutions that are both economical and adapted for the design of durable and performing interlocking concrete pavements. These solutions will have to be integrated in a global model that can be generalized. The achievement of this research project will be possible through the five following objectives:

- To determinate equivalent elastic modulus of different “concrete blocks – bedding sand” systems and to test them with a previously developed numerical model.
- To define appropriate road structures for each “concrete blocks – bedding sand” systems and to test them using classic design models that consider a continuous pavement layer and decreasing elastic modulus values from top to bottom of the pavement structure.
- To validate in a laboratory the structural behaviour of interlocking concrete blocks pavements using a laboratory load and climate simulator.
- To validate the structural behaviour of the most performing interlocking concrete pavement in real conditions by the construction of interlocking concrete roads in some Québec municipalities.
- To elaborate a global model that can be generalized for the construction of roads paved with interlocking concrete blocks in a northern context.

The first step was an evaluation of the seasonal structural behavior of interlocking concrete block pavements. Tests of FWD were realized to obtain deflection basins for interlocking concrete block pavements in urban northern context. These tests allow to understand and verify the behaviour differences between several structure pavements according to the base layer, the season and the type of road or traffic.

3. TEST PROGRAM

3.1 Pavement structures

A field test program was designed to study the seasonal structural behaviour of interlocking concrete block pavements in a urban context. Deflection basins of four road sections (a highly

circulated industrial boulevard, a highly circulated principal avenue, and a main street with an average traffic) were measured with Falling Weight Deflectometer (FWD) tests during two years. The pavement structure of each road section is shown at Figure 1 and is given in Table 1. All the pavements studied and tested have a good structural performance and show very low rutting.

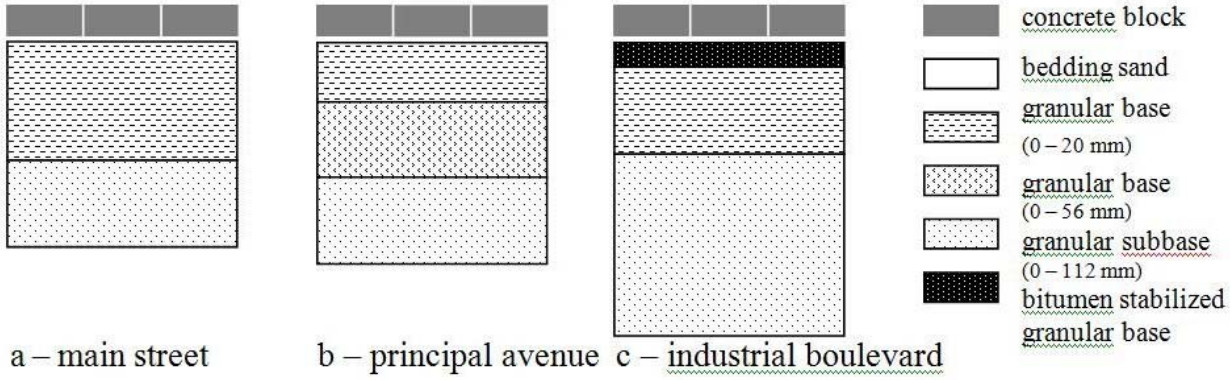


Figure 1 –Pavement structures of each type of road tested.

Table 1. Thickness layers of pavement structures.

MAIN STREET		PRINCIPAL AVENUE		INDUSTRIAL BOULEVARD	
LAYER	**THICKNESS (mm)**	**LAYER**	**THICKNESS (mm)**	**LAYER**	**THICKNESS (mm)**
Concrete block	100	**Concrete block**	100	**Concrete block**	100
Bedding sand	20	**Bedding sand**	15	**Stabilized bedding sand**	15
Granular base (0 – 20 mm)	400	**Granular base (0 – 20 mm)**	225	**Bitumen stabilized granular base**	125
Granular base (0 – 112 mm)	300	**Granular base (0 – 56 mm)**	275	**Granular base (0 – 20 mm)**	300
		Granular base (0 – 112 mm)	300	**Granular base (0 – 112 mm)**	600

3.2 Parameters

The parameters of the study are:

- 3 types of urban roads – a highly circulated industrial boulevard, a highly circulated principal avenue, and a main street with an average traffic.
- 2 types of base course layer - a granular base and a bitumen stabilised granular base.
- 3 seasons:
  - Fall when the bearing capacity of the road is the highest.
  - Winter which corresponds to a frozen road with a high rigidity.
  - Spring, season during which the thawing occurs and the bearing capacity of the road decreases.
- 3 load values for the FWD tests – 40, 50 and 60 kN.

4. RESULTS

4.1 Deflection measurements

The FWD used in this study is the PRI 2100 of Carl Bro which is an equipment of the civil engineering department of Université Laval (See Figure 2). A test with this equipment allows to recreate the mechanical solicitation which corresponds to a heavy vehicle on the pavement and to measure the pavement deflection. This test is a non-destructive test.



Figure 2. Falling Weight Deflectometer (FWD) PRI 2100 of Carl Bro.

This FWD is a trailer with an application load mechanism and a removable beam with geophones which is put down on the surface pavement for each test. The load is applied with a standard falling weight dropped on a circular plate of 300 mm diameter from a height which depends on the aimed load. The load application lasts about 30 min. Nine (9) geophones are used to measure the pavement deflection, the first one is located exactly in the centre under the load plate and the eight (8) others are located on the removable beam, at 0.20, 0.30, 0.45, 0.60, 0.75, 0.90, 1.0 and 1.50 m from the centre of the plate. Figure 3 shows a diagram of the deflection measurements with the FWD.

4.2 Deflection analysis

In a FWD test, the deflection measurement allows to determine a half of a deflection basin (See Figure 3). Many variables of the deflection basin help to study the structural behaviour of the pavement. The first variable is the deflection measured directly under the loading plate called D0, the maximum deflection. In the neighbourhood of the loading plate, the first geophones are indicators of the top of the pavement structure (the first 200 mm) that is to say the surface layer and the top of the base layer. The farthest geophones are indicators of the bottom of the pavement

structure that is to say the subbase layer. In Figure 3, the indexes which correspond to these two levels in the pavement structure are:

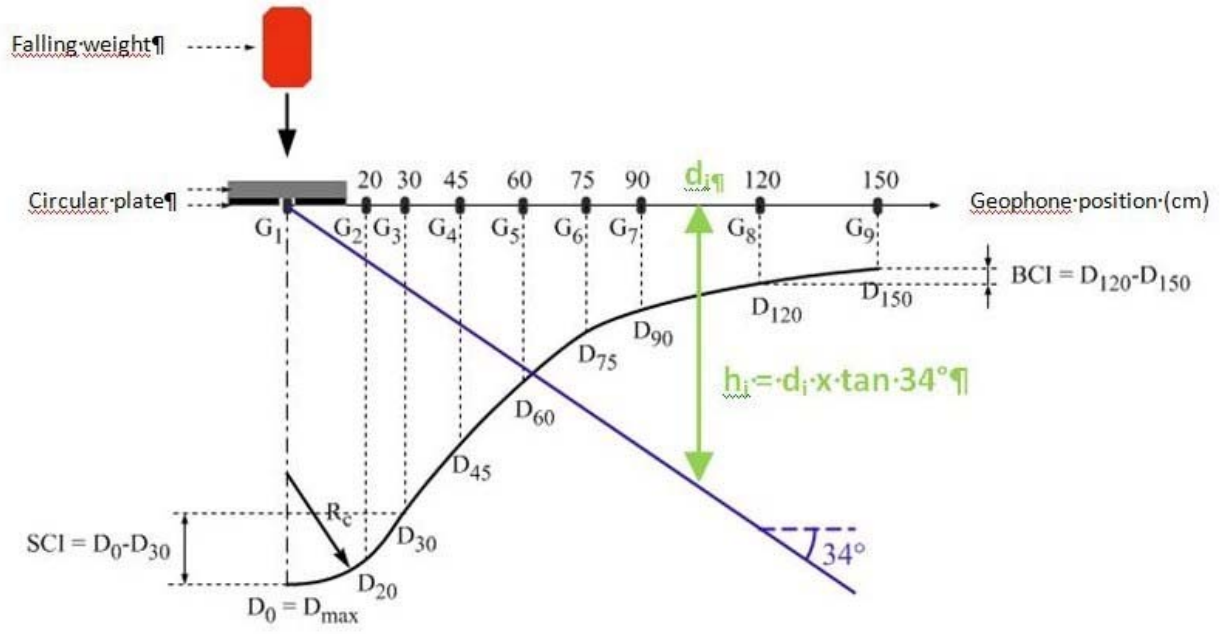


Figure 3 – Plan of the deflection measurements with the FWD.

SCI (Surface Curvature Index) = $D_0 – D_{30}$ [μm].

- D_0 is the deflection measured under the loading plate [μm].
- D_{30} is the deflection measured under the geophone G_3 [μm].

BCI (Base Curvature Index) = $D_{120} – D_{150}$ [μm].

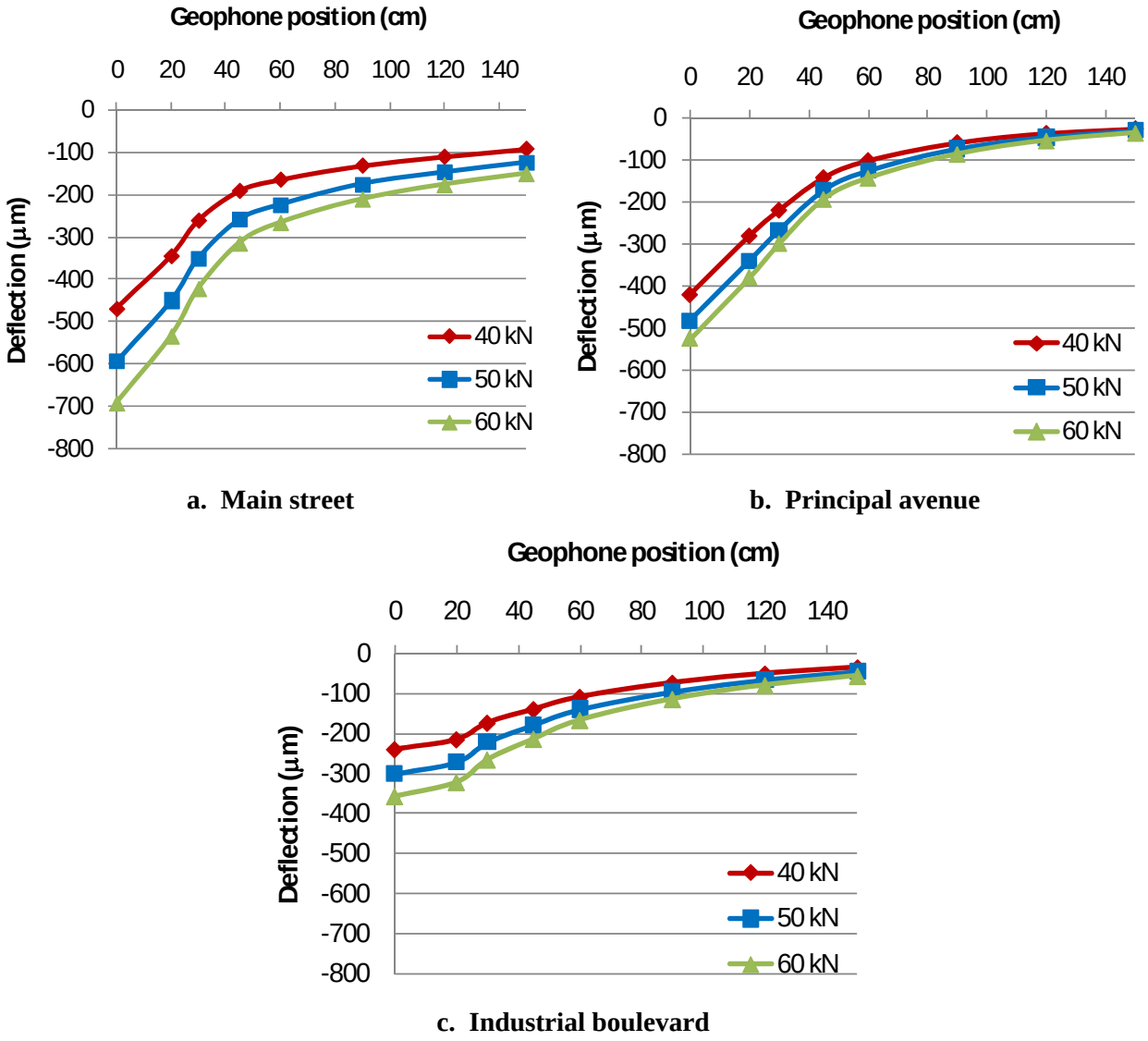
- D_{120} is the deflection measured under the geophone G_8 [μm].
- D_{150} is the deflection measured under the geophone G_9 [μm].

Moreover, the geophones are vibration sensors. The shock wave penetrates the soil with an angle of 34° and it is possible to calculate the deflection at different levels in the pavement according to the geophone positions or to the distance from the centre of the loading plate (See Figure 3):

- $h_i = d_i$ x tan 34°.
- h_i is the depth in the pavement structure.
- d_i is the geophone position or the distance from the center of the loading plate.

4.3 Results according to the load applied

In order to eliminate the seasonal parameter, the results presented on Figure 4 are those of the fall deflection measurements that are to say when the bearing capacity of the pavements is the highest. The Figures 4a, 4b and 4c clearly show that the deflection measurements increase with the load applied from 40 kN to 60 kN independently of the pavement structure and the type of the road. This observation confirms the fact that the structural behaviour (deflection) of the pavement is directly function of the mechanical solicitation (load).



a. Main street

b. Principal avenue

c. Industrial boulevard

Figure 4 – Deflection basins according to the applied load measured in fall.

In order to analyze deeply, theses deflection basins, SCI and BCI were calculated. Figure 5 shows SCI and BCI indexes calculated with the fall deflection measurements when pavement is at its highest bearing capacity. For each type of pavement structure, there is no real significant difference between BCI indexes calculated for any applied load. This implies that for interlocking concrete block pavements, the bottom of the pavement structure, that is to say the subbase layer, is not a significant layer for their structural behaviour. On the other side, SCI indexes calculated are significantly dependant on not only the applied load but also the type of pavement structure. The industrial boulevard, with its bitumen stabilised granular base, gives lower SCI indexes than the two other types of pavement structures whatever the applied load. For those structures, both present a standard granular base. Results show that for this type of base course layer, thickness is an important factor. Indeed, the thinnest structure (main street) is more influenced by the applied load.

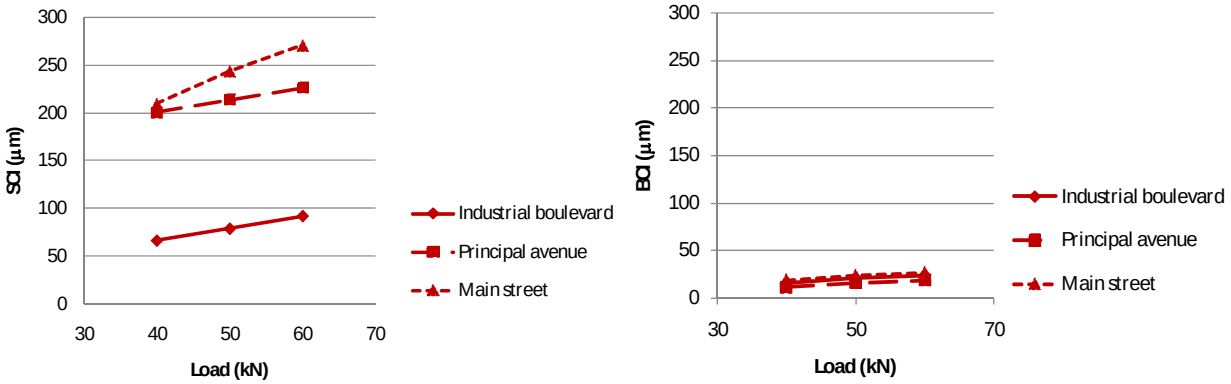


Figure 5. SCI and BCI indexes calculated according to the applied load (measured in fall) for each type of pavement structure.

4.4 Results according to the structure pavement and the season

For the next figures, to simplify, only the deflection basins measured for an applied standard load of 40 kN (half of a standard simple axle) are represented. Figure 6 show deflection basins measured according to the pavement structure. For each type of pavement structure, the lowest deflections are measured in winter when the roads are frozen and have a high rigidity and the highest are measured in spring during the thawing of the pavement when the bearing capacity of the roads decreases.

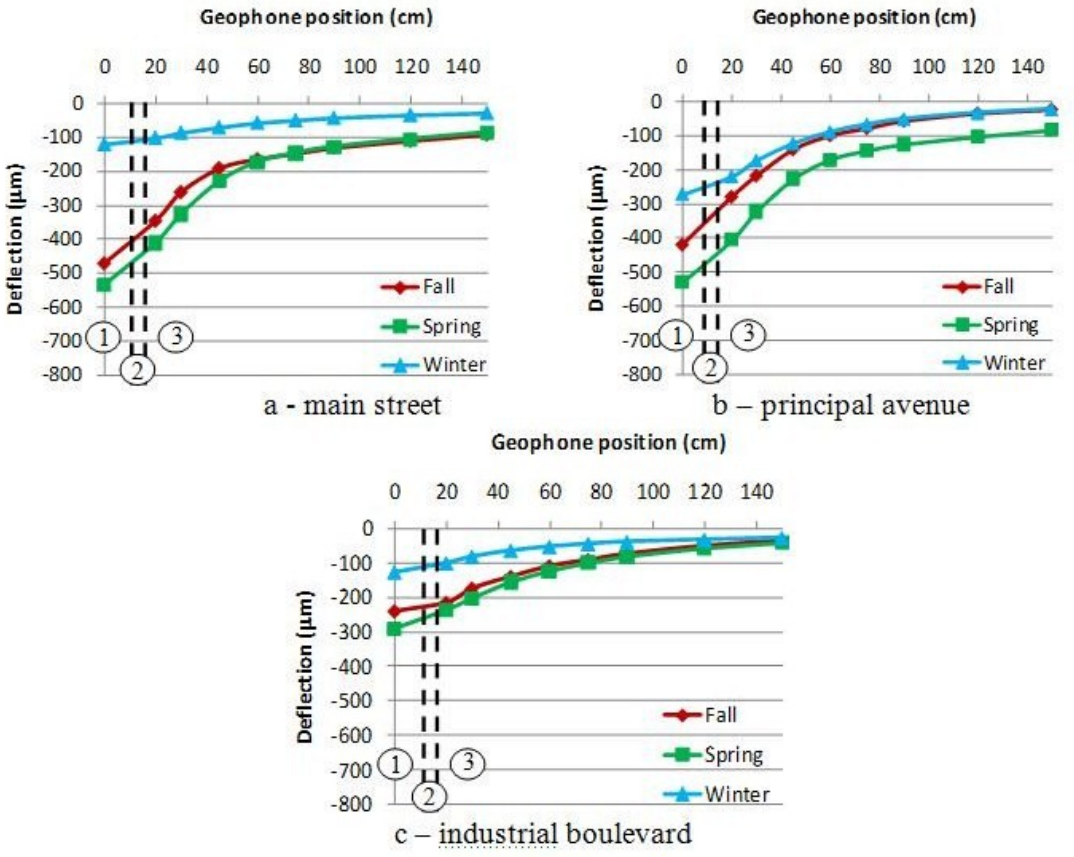


Figure 6. Deflection basins measured for an applied load of 40 kN according to the pavement structure.

The deflection basins for all the pavement structures have an important inflection point which clearly indicates that the interlocking concrete block pavements have a specific structural behaviour. From the deflection basins at Figure 6, the areas which correspond to the concrete blocks (area 1), the bedding sand (area 2) and the top of the base layer (area 3) can be determined with the formula hi = di x tan 34°. Thus, the inflexion point is located for the three types of roads in the first layer of the base course. The deflection basins show an important inflection point which clearly indicates that the interlocking concrete block pavements have a different structural behaviour. This observation allows confirming that the design criterion of strain at the bottom of the surface layer is certainly not appropriate to the interlocking concrete block pavements. This criterion could probably be replaced by the vertical strain at the top of the base course and/or in the base course.

Figure 7 shows deflection basins measured according to season for the three types of road. The inflection point could be observed more easily in spring and in fall than in winter because of the high rigidity of the structure during this season. The lowest deflections are measured in winter (See Figure 7c) for the main street and the industrial boulevard with D0 values equal to 120 m and 127 m respectively. The principal avenue presents a D0 value of 273 m certainly because of its thin first granular base (0 mm to 20 mm) layer.

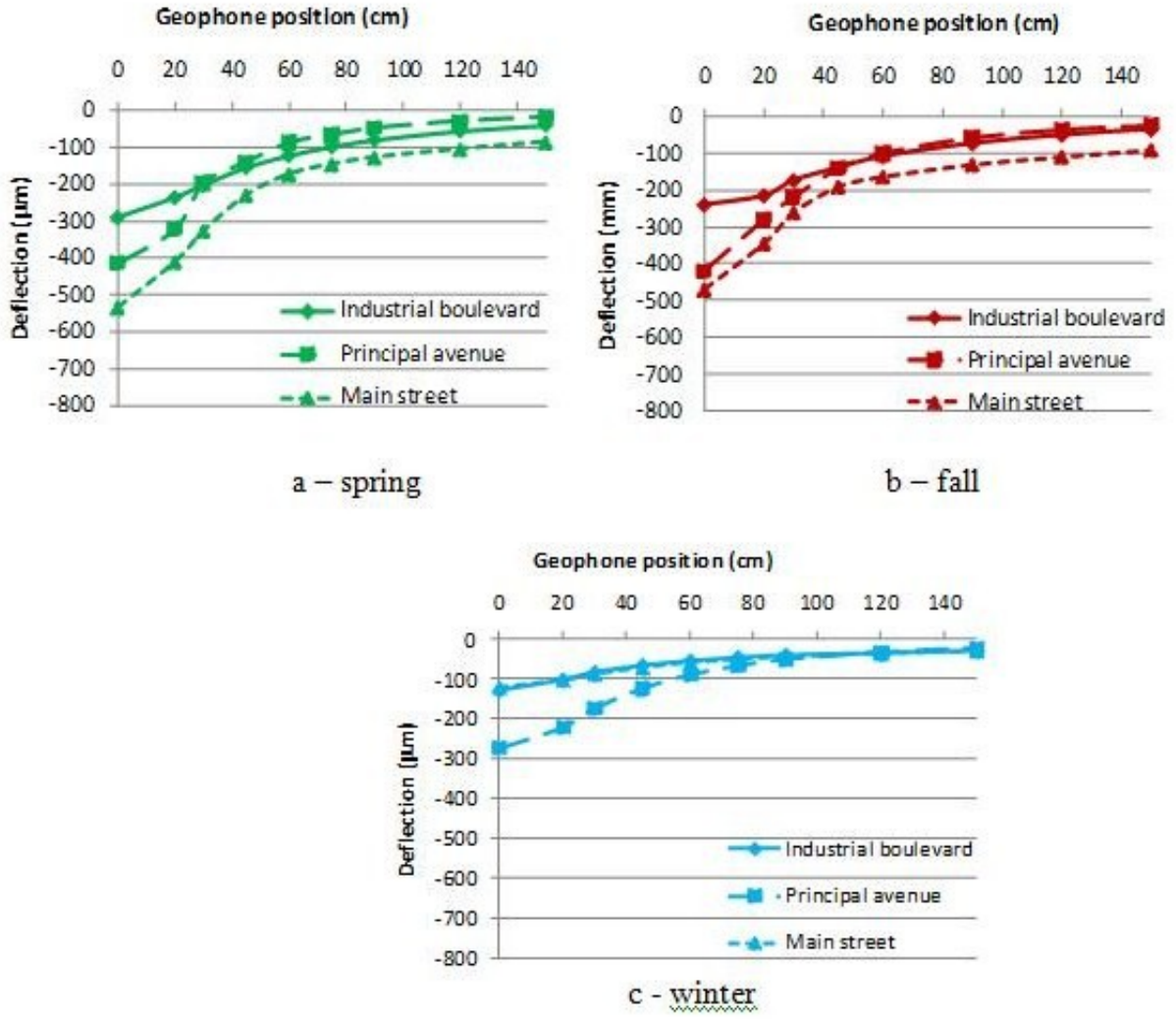


Figure 7– Deflection basins measured for an applied load of 40 kN according to the season.

The differences of deflection values between the different types of pavement structures are emphasized in spring (See Figure 7a). The structural behaviour of the pavements is a function of the thickness of the structure and of the type of base layer. The main street with a thickness of 820 mm and a standard granular base layer gives the highest value of D_0 (531 µm) whereas the principal avenue with a thickness of 915 mm and a standard granular base layer, presents a value of D_0 equal to 413 µm. The lowest value of D_0 (290 µm) is measured for the industrial boulevard with a thickness of 1.14 m and a bitumen stabilized granular base. These results clearly indicate that the deflection value D_0 decreases by half if the structure pavement is thicker and the first layer of the base course is stabilized. The same tendency is observed for the measurements of the fall season.

5. CONCLUSION

Some conclusions can be drawn from the field experimental results obtained. First of all, from the deflection measurements, it can be concluded that:

- The structural behaviour of the interlocking concrete block pavements is directly linked to the mechanical solicitation.

- The subbase layer is not a significant layer for the structural behaviour of the interlocking concrete block pavements.
- For structures with a standard granular base, thickness is an important factor.
- For each type of pavement structure, the lowest deflections are measured in winter when the roads are frozen and have a high rigidity and the highest are measured in spring during the thawing of the pavement when the bearing capacity of the roads decreases.
- In spring and in fall, the deflection value D_0 decreases by half if the structure pavement is thicker and the first layer of the base course is stabilized.
- The deflection basins show an important inflection point located for the three types of roads in the first layer of the base course.

Besides, the results presented from this field study confirm that the interlocking concrete block pavements have a different structural behaviour and the development of specific design criteria for interlocking concrete block pavements in urban northern context is necessary. In this way, the design criterion of strain at the bottom of the surface layer could certainly be replaced by the vertical strain at the top of the base course and/or in the base course.

6. REFERENCE

SHACKEL, B., 2003. The challenge of concrete block paving as a mature technology, Proceedings of the 7th International Conference on Concrete Block Paving (PAVE AFRICA 2003).