EVALUATION OF THE THICKNESS OF JOINTS IN TRANSMISSION OF STRESS AND DISPLACEMENTS IN AN EXPERIMENTAL PANEL OF ICBP

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SUMMARY

This paper describes laboratory research on a physical model of Interlocking Concrete Blocks Pavement – ICBP – to determine stress transmission through the structure down to the foundation soil. The model was an experimental panel built at the Geotechnical Laboratory of COPPE/UFRJ (Graduate School of Engineering/Federal University of Rio de Janeiro – Brazil). Load cells and a crack activity meter were used. Several combinations of parameters for testing were adapted: block thickness (40, 60, 80 and 100mm), sand cushion thickness (50 and 75mm before compaction), block configuration (herringbone, parquet and stretcher or linear) and block form (rectangular and indented). Load was applied by a ten-ton capacity hydraulic jack acting on the pavement surface trough a round still plate (9cm diameter and 254.34cm^2 area). Thicknesses of joints were 2 and 5mm. Thickens of blocks, thickens of joints, and degree of interlocking influence stress transitions and surface displacements.

Keywords: interlocking concrete block pavements, experimental panel, load cells, crack activity mater, load spreading.

1. INTRODUCTION

The study of the structural behavior of pavements takes advantage of instrumentation and physical modeling to improve pavement design. Measurements made with sensors inserted into pavement layers permit monitoring of pavement degradation under traffic and climatic actions.

There is not yet available a reliable mathematical model of interlocking concrete blocks pavements (ICBP) subject to traffic loading. The following structural parameters should de considered: blocks thickness, block forms, configuration of blocks surfacing, thickness of sand cushion, nature of foundation material and joints widths. These parameters were adapted in the experimental panel of physical modeling built at the Geotechnical Laboratory of COPPE/UFRJ, in Rio de Janeiro, Brazil.

2. LITERATURE REVIEW

Shackel (1990) studied the permanent deformation of several ICBP structures using a traffic simulator. In that research he studied several combination of block thickness (60, 80 and 100mm), block

configurations (herringbone, parquet and stretcher or linear), block form (indented and rectangular) thickness of sand cushion (40, 70 and 100mm).

Shackel (up cit.) presents the following conclusions:

- Pavements having herringbone configurations performed better, i.e. showed smaller permanent deformation caused by simulator traffic; pavements of stretcher configuration showed greater permanent deformation (in the traffic direction);
- Pavement with dentated paving units perform better than rectangular or slightly curved form in regard to permanent deformation in wheel paths; the dentated pavers showed smaller horizontal deformation;
- The thickness of blocks (in the range of 60 to 100 mm) showed smaller permanent deformation;
- Permanent deformation for sand cushions of 40 to 70mm received small deformations; 100mm thick sand cushion deformed four times as much the 70mm thick sand layer.

Muller (2005) describes measurements made in a field panel under heavy traffic with the installation of load cells in sand cushions and in the interface of cemented base and bedding sand in an experimental stretch of ICBP. This experimental stretch was constructed in the access of trucks of the cement plant of HOLCIM S.A. in the city of Cantagalo, Rio de Janeiro, Brazil. The pavements consist of blocks with different thicknesses (40, 60, 80 and 100mm) and a 50mm thick bedding sand layer for the four stretches.

The results obtained by the load cells installed in experimental sections under truck loads having a double wheel axle of 10,330kg and with 12,020kg total load:

- In the 40mm blocks test the cells registered the passage of rear axle and the front one while the others tests registered only the rear truck axle.
- Thicker blocks decrease the pressure transmitted to the load cells.

3. DESCRIPTION OF THE LABORATORY PANEL

3.1 Previous Research

The panel was built by Saramago (2002) in order to study the influence of compaction in soil reinforcements at retaining walls. This “test box” belongs to the section of physical modeling in the building “Willy Alvarenga Lacerda” – Geotechnical Laboratory of COPPE/UFRJ.

The box is 2m wide, 3m long and 1.5m high with reinforced concrete walls. The walls have the interior face coated with polyethylene plates made with ultra-high molecular weight, UHMW 1900. The internal lateral faces and floor are painted with a thin layer of silicone grease and coated with a plastic sheet. This procedure aims to minimize friction between quartz sand grains and the wall faces, to become similar to a plane deformation state. To avoid mechanical damage to the plastic sheet, it was coated by a geosynthetic material. Figure 1 shows the test box used by SARAMAGO (2002).




Figure 1. Shows the test box used by Saramago (2002)

3.2 Loading System for ICBP Testing

Load are applied with a hydraulic jack exerting 98kN (10tf) onto a steel plate having a 9cm radius with 254.3cm^2 area (similar to contact area of a pneumatic tire). Although the plate rigidity much higher than the tire, the metallic plate was chosen because it was available in the Geotechnical Laboratory.

The reacting system adopted was the same used by Saramago (2002). He used a 300 kg reacting steel beam. The setup details are shown in Figure 2(a). Applied load was measured by a load cell inserted between the hydraulic jack and the steel plate. Loading applied pressure was 0.56Mpa or a little more. Five loading and unloading were applied. With this reacting system the applied loads could reach up to 8tf, if necessary.

3.3 Load cells application into the pavement

After load cell calibration, they were installed at the interface of the bedding sand and quartz sand foundation (subgrade). Load cells were placed at 10cm center to center. They were identified as "center" (of plate), "10" and "20." (Figure 2-b)




(a) (b)

Figure 2. (a) Load system for ICBP testing; (b) The tree load cells positioned

3.4 The ICBP Tested

The foundation soil used in the experimental panel was made of quartz sand, normally used for the strengthened reinforced soils tests, according with SARAMAGO (2002). This choice was made because its has a high internal friction, is well graded and is commercially available.

The foundation base of sand was compacted first. A plastic sheet was inserted between the base and bedding sand to prevent contamination. Then the sand bedding layer was distributed at 50mm thickness and not disturbed after installation. Finally, the blocks were placed.

The experimental panel has a superficial area of $6m^2$ and due to the great number of assemblies; it was decided to divide the superficial area into two and to construct the ICBP with two blocks shapes, rectangular and dentated, for each experiment. These paver shapes could be studied with the bedding sand. Figure 3 shows a cross section of the setup.

After placing the blocks, they were compacted with a vibratory plate. As Carvalho (1998) notes in Brazil, the compacting must be carried onto two steps:

- **Initial Compacting** performed after the blocks placed. This flattens the blocks and begins compaction of the bedding sand. It also allows the bedding sand to penetrate between the blocks and help produce interlock. The vibratory plate should be passed over the surface at least two times in each direction.
- **Final Compaction** performed after joints are filled with sand which also helps interlock. The same compaction equipment should be used with the vibratory plate passing over the surface four times in each direction.

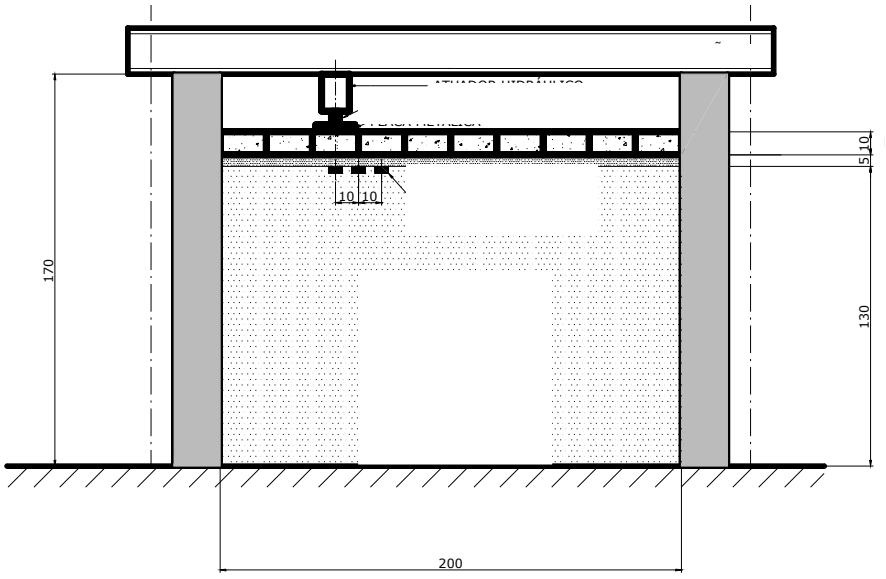


Figure 3. Experimental panel of ICBP

According with Shackel (1990) and Carvalho (1998), traffic contributes to completing the consolidation of the joint sand and stabilizing the surface against permanent deformations. Therefore, a different sequence of compaction was used than as described above. To simulate the traffic passing over the pavement and different compaction energy, the following sequence was performed:

- **Initial compaction** was done after the block were placed for 15 minutes passing the vibratory plate in all the directions;
- **Compacting and filling joints** was done in three 5 minutes stages, totalizing 15 minutes. Before each stage, the sand destined to the filling the joints was distributed on the pavement, then passing the vibratory plate in all the directions;

- **Final compaction** was done in a 30 minute period, divided in two 15 minutes stages to help stabilized the surface against permanent deformations.

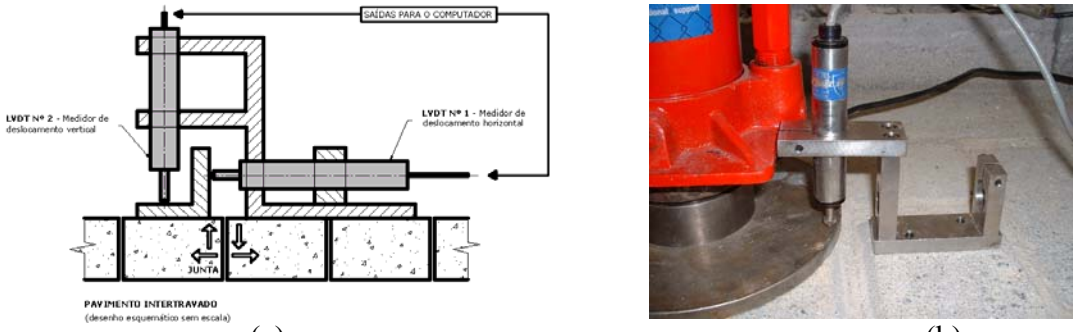
According to Muller (2005), this sequence of compacting was of great importance for stabilizing the tensions transmitted in the experimental panel base, mainly the initial compacting carried out after placing the blocks, for a 15 minutes period, with the vibratory plate passing in all directions. While the compacting and filling joints and the initial compacting stabilizes the surface against permanent deformations, these compactions influence the stabilization and distribution of the transmitted tensions. Therefore, the compaction sequence carried great importance for the reducing and stabilizing the plastic deformations in the experimental panel.

4. MEASUREMENTS OF SURFACE DISPLACEMENTS

For the determining the displacements between the blocks of the interlocking pavement, "Crack Activity Meter" (CAM) was used, represented in Figure 4(a). This was developed by the National Institute for Transport and Road Research of the CSIR, to measure displacements, horizontal and vertical, between cracked walls. The displacements are measured by LVDTs. The first LVDT installed in the horizontal position measures the relative displacement in its direction and the second LVDT installed in a vertical position measures the relative displacements in the vertical direction between the cracked walls (Vilchez, 2002).

In our case, using the CAM was used to measure displacements between two blocks the LVDT was located above the steel plate, responsible measuring tension applied to the pavement surface. The equipment was supported on a lateral block that didn't receive the efforts generated for the plate directly. The Figure 4(b) presents the CAM device located on the pavement. To accomplish vertical displacement experiments, the following stages were executed:

- The system of reaction and application of the shipment is mounted;
- Circular plate is adjusted to prevent a lateral block not to suffer any type of surface request;
- The CAM is placed, with the LVDT adjusted in the vertical position, above a block that is not suffering shipment;
- The LVDT is located on the circular plate;
- The shipment is applied and becomes fulfilled the readings.



(a) (b)

Figure 4. (a) CAM as modified by VILCHEZ (2002), (b) Testing vertical displacement

A sequence of five loading and unloading cycles was applied to a maximum pressure of about 0.6MPa. Measurements made:

- Total displacement after first loading;

- Elastic displacement from the first loading;
- Total plastic displacement after fifth loading;
- Elastic displacement of a fifth loading.

5. VARIATION OF THE THICKNESS JOINTS

The behavior of the tensions transmitted from surface to base and the surface displacements in an interlocked pavement was tested. Joints thicknesses between two concrete blocks varying from 2.0mm to 5.0mm were used for comparison to results. There were eight experiments performed that verified the compaction influence in the 80mm thickness blocks in the linear or stretcher pattern, and in the rectangular and dentated block shapes.

Plastic spacers, used in ceramics, helped guarantee the joint thicknesses for these tests. Figure 5 shows the spacers placed between the blocks to guarantee consistent joint thicknesses.

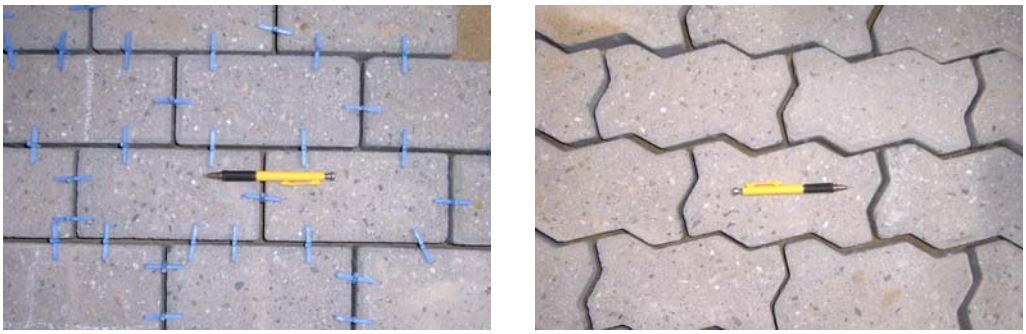


Figure 5. ICBP having 5mm thickness joints

It was noticed in these experiments that the interlocking between the blocks was prejudiced. The displacement between the neighboring blocks was noticed clearly, mainly harming the rotational and horizontal interlock. Figure 6 shows the displacement between the blocks.

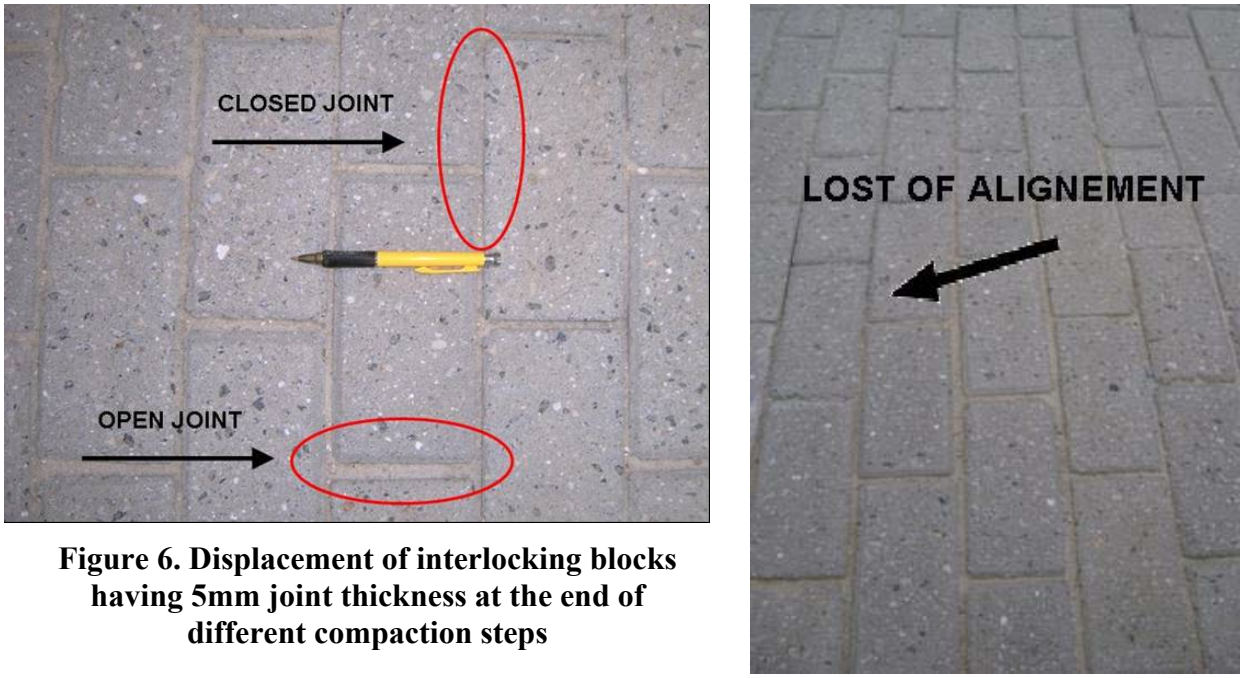


Figure 6. Displacement of interlocking blocks having 5mm joint thickness at the end of different compaction steps

6. EVALUATION OF STRESS DISTRIBUTION

Comparisons with thickness variation between concrete blocks were performed. Two graphs elaborate the transmitted differences in tensions at various stages of compaction. Figure 7 presents these transmitted tensions in the 80mm thickness blocks with dentated pavers in the stretcher pattern and the Figure 8 shows the transmitted tensions in 80mm thick blocks with the rectangular pavers in the stretcher pattern.

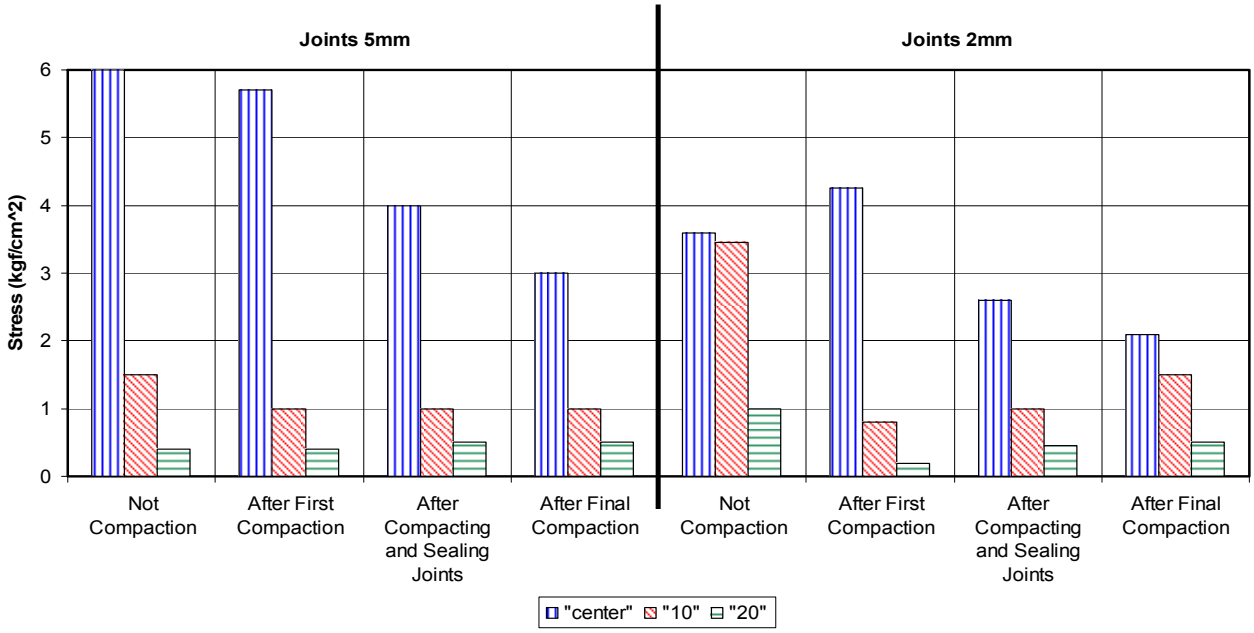


Figure 7. Comparison of stress distribution with joints thickness – 2mm and 5mm; blocks 80mm thickness, stretcher configuration and dentated pavers

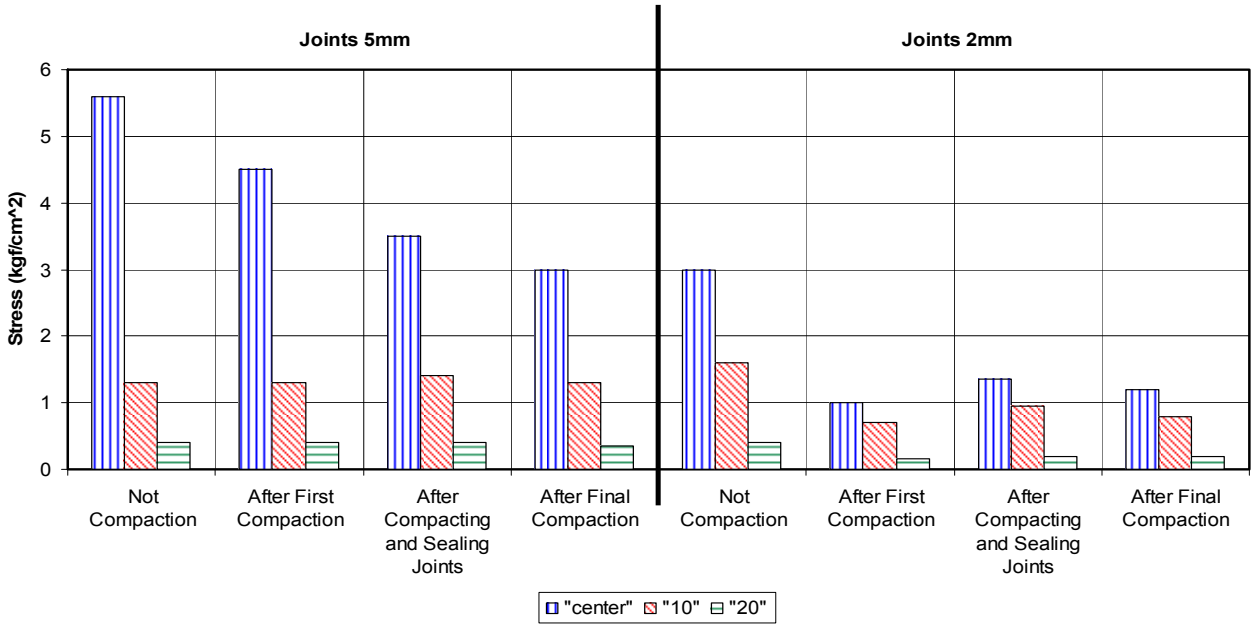


Figure 8. Comparison of stress distribution with joints thickness – 2mm and 5mm; blocks 80mm thickness, stretcher configuration and rectangular pavers

First of all, there are two general observations valid for both blocks forms – dentated and rectangular:

1. Interlock and joint thickness are important parameter of stress distribution. With no interlock there is no lateral spreading of stresses which concentrates under the plate center.
2. Smaller joints thickness (2mm) permits stress distribution horizontally.

Two specific observations depend on the block shapes, either dentated or rectangular.

3. For dentated blocks (Figure 7) with 5mm joint thickness, the stress transmitted at centerline are 100%, 95%, 66% and 50% of the stress applied to the loading plate, corresponding to the four compaction steps: non-compacted, and the three steps mentioned in Section 3. For the 2mm joint thickness the corresponding values are: 60%, 70%, 43% and 35%.
4. For rectangular blocks (Figure 8) with 5mm joint thickness, the values are: 93%, 75%, 58% and 50%; for the 2mm joint thickness are: 79%, 41%, 33% and 28%.

7. RESULTS OF SURFACE DISPLACEMENT MEASUREMENTS

Comparisons of the variation of the joints thickness between the concrete blocks are elaborated on two graphs. They show the differences between the displacements in accordance with the evaluations described in Section 4. Figure 9 presents the displacements between the blocks with 80mm thickness with dentated blocks. Figure 10 shows the displacements between the rectangular blocks with 80mm thickness.

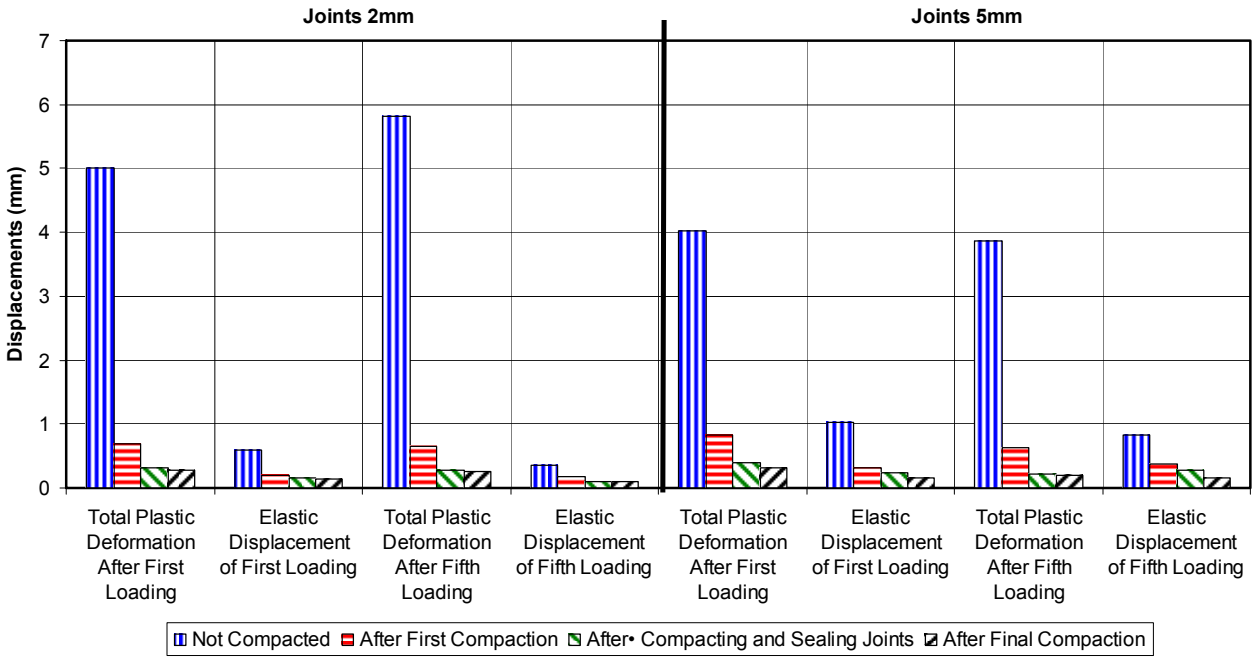


Figure 9. Influence of compacting and the thickness of the joints on the displacements of 80mm thick dentated blocks

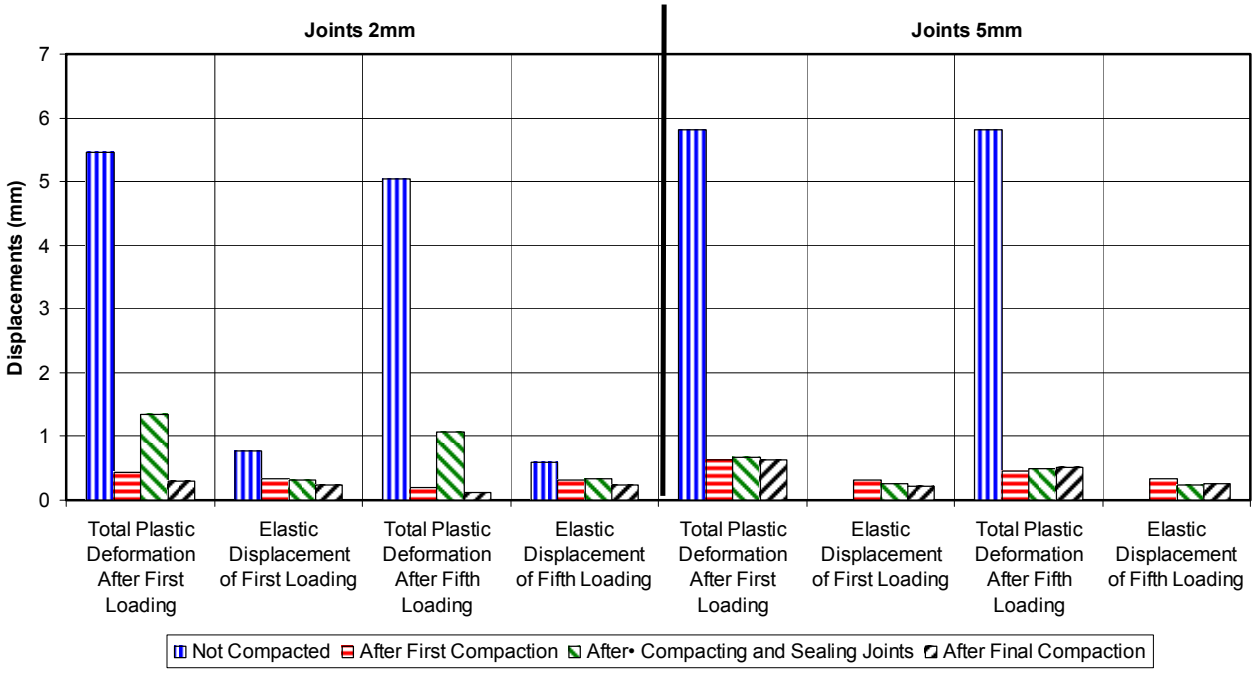


Figure 10. Influence of compacting and the thickness of the joints on displacements with rectangular 80mm thick blocks

It maybe concluded that joint thickness did not influence displacement values. Total plastic deformation is about 0.7mm for dentated blocks and 0.2mm for rectangular blocks after the initial compaction. After final compaction they are respectively 0.3mm and 0.2mm. All these displacement values are very small.

8. CONCLUSIONS

1. The stress distribution measurements with load cells permits interpretation of the structural behavior of interlocking concrete blocks pavements;

2. Compaction procedure seems effective in reducing the stress transmitted to the quartz sand foundation soil. Other compactions did not have significant influence reducing tension transmissions, but they served to demonstrate that the higher transmitted tensions tend to toward stabilization.

3. Interlock depends on joint thickness. It is an essential feature for stress transitions and for absorption of stress by these interlocking concrete blocks pavements;

4. The sequence of compaction performed in the experimental panel was effective to stabilize plastic deformation.

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