DEFORMATION BEHAVIOUR OF CONCRETE BLOCK PAVEMENTS UNDER VERTICAL AND HORIZONTAL DYNAMIC LOAD

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SUMMARY

This paper presents the results of research conducted at Dresden University of Technology (Germany), examining different influences on the horizontal deformation behaviour of concrete block layers under dynamic load. Full-scale dynamic laboratory tests on block pavements formed the basis of the investigation. In particular, the influence of different block shapes and sizes, layer patterns as well as bedding and jointing sands on the deformation behavior of concrete block layers was investigated. A maximum load of 66.4 kN was applied at an angle of 30° to the vertical axis to the test pavement. Up to 1 million load cycles were applied to the test pavement. The ground plan of the test section was a 5.0 m x 2.5 m rectangle with an overall thickness of 1.0 m. The dynamic load was applied to the concrete block pavement through a rubber layer. Therefore a circular steel plate was used. Analysis was based on the results of surface deformation measurements with displacement transducers. In addition, photogrammetry was used to investigate the horizontal deformation and torsion behavior of the blocks. From the results of the dynamic and static tests, it could be concluded that joint filling has a critical influence on the horizontal deformation behavior of block pavements. The results also led to the conclusion that the bedding material and block height have no substantial influence on the deformation resistance of block pavements, if their joints are completely filled. Regarding the block form, it was found that rectangular blocks offer the smallest resistance against horizontal deformation. Usage of interlocking blocks results in a clearly increased resistance against horizontal deformation.

1. INTRODUCTION

In the last few decades concrete block pavements were increasingly used in urban areas. They can be found in pedestrian as well as highly loaded areas. In Germany, concrete block pavements are used for low trafficked roads only. They are defined as carrying up to 3 million 10 t-standard axle within 30 years. Also concrete block pavements are commonly used for parking areas, bus lanes, shipping docks and industrial pavements.

Damages on concrete block pavements (horizontal and vertical displacements) can be observed frequently. They are mainly the result of insufficient pavement construction and by overloading the block pavement by heavy trucks. Hence, the concrete industry is trying to improve the performance of block pavements by minimizing displacement e.g. through developing advanced block forms. New block shapes with horizontally interlocking features are meant to ensure increased bearing capacity and deformation resistance of block pavements. Unfortunately, there is only limited experience on the deformation resistance of these new block shapes under realistic traffic load. This research focused on investigating the vertical and horizontal deformation behavior of concrete block layers under dynamic load using the results of full-scale laboratory tests.

2. TEST EQUIPMENT

At Dresden University of Technology full-scale laboratory tests were conducted by Lerch (2005) under constant climatic conditions (temperature, moisture content with the basecourse) to investigate the performance of various concrete block layers. The test section had a ground plan of 5.0 m x 2.5 m. A subbase material (sandy gravel) and a basecourse material (gravel) were placed in the test section in several layers (each 120 mm thick) and compacted using a vibrating plate. On top of the unbound granular layer (UGL) the bedding layer and finally the concrete blocks were placed (Figure 1). The total thickness of all layers added up to 1.0 m. The dynamic load (rigid load action) was applied using a steel loading plate with a diameter of 300 mm. An 8mm Rubber plate was placed between the steel plate and the pavement surface. One million stress pulses were applied on each test pavement at a frequency of 5.8 Hz. A vertical load of 57.5 kN (the permitted maximum wheel load in Germany) and a horizontal load of 34.5 kN (the equivalent to the forces during acceleration and deceleration of trucks, taking into account a friction coefficient of $\mu = 0.6$, $F_H=\mu*F_V=0.6*57.5$ kN=34.5 kN) were applied. A resulting load of 66.4 kN at maximum and 6.6 kN at minimum was applied to the surface of the test pavement by a hydraulic cylinder at an angle of 30° to the vertical axis (Figure 1). The steel plate was fixed on the blocks using steel pins to avoid slipping.

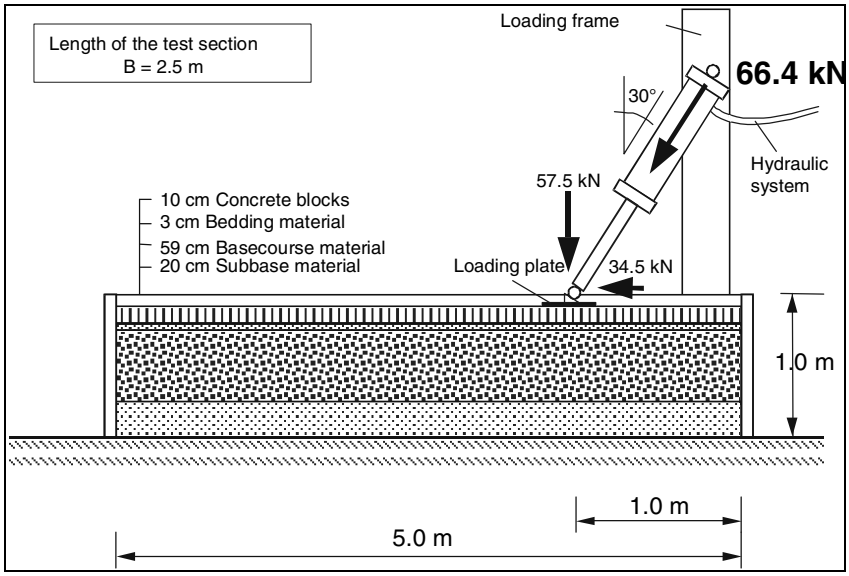


Figure 1. Elevation of the test pavement

To avoid any influence of the UGL on the horizontal deformation behavior of the block pavement the subbase and basecourse materials had equal properties for all conducted tests. For each test the bedding material and joint filling were replaced. The bedding layer was placed on the test section with a thickness of 45 mm (not compacted) and leveled using a straight edge. Afterwards the blocks were placed manually using a template creating 5 mm joints, which were then filled with dry unbound granular material before and after the compaction process.

3. CAPTURE AND ANALYSIS OF MEASURED VALUES

Using Linear Variable Differential Transformers (LVDTs) it was possible to measure the surface deformation of the pavement. The LVDTs (22) were fixed on a separated frame ensuring that the oscillation of the loading frame did not influence the measured values. Three of the LVDTs were used to measure the vertical deflection of the load plate, 15 to determine the horizontal displacements of blocks in the load axis and 4 to measure the horizontal displacements beside the load axis. The data was recorded in regular intervals.

Photogrammetry was used to investigate the horizontal deformation and the torsion behavior of the blocks. An area of 2.0 x 2.0 m in front of the load plate was captured.



1 Steel frame
2 Frame support
3 Concrete block pavement surface
4 Loading frame
5 Loading plate
6 LVDTs

Figure 2. Test section

4. TEST RESULTS

This section presents the results of this research. It examines the different influences on the horizontal deformation behavior of concrete block pavements under dynamic load. In particular, the influences of the different block shapes, block sizes, laying pattern as well as bedding and jointing sands were investigated. A horizontal deformation/displacement was only possible within the joints. The number of joints varied depending on block shape and size. For a better comparison of different block pavement arrangements, a specific horizontal deformation or displacement was calculated using Equation 1.

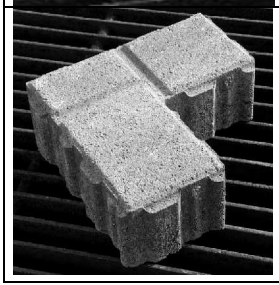
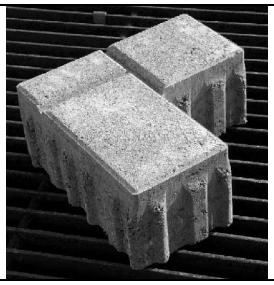
$$v_{s,i} = \frac{V_i}{\sum_{i}^{KR} B_F} * 1000\,[‰] \qquad \text{Equation 1}$$

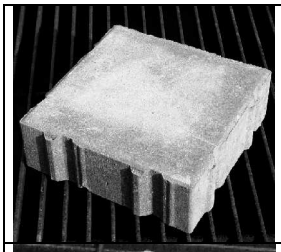
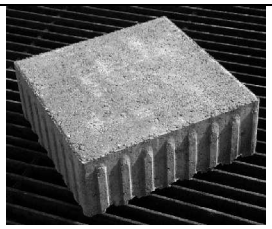
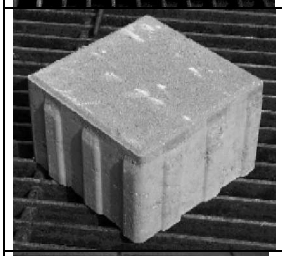
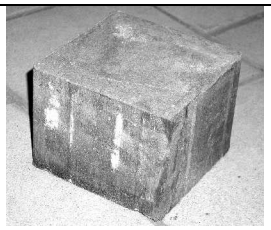
$v_{s,i}$ specific displacement on spot i [‰],
V_i absolute horizontal displacement on spot i [mm],
B_F width of the joints (5 mm) [mm].

4.1 Comparison of Block Shapes

The test results show that the block shape as well as the type of interlocking features has a significant influence on the horizontal deformation behavior of concrete block pavements. Figure 3 shows the maximum displacement in the load axis for block pavements always using crushed sand (0-5 mm) as joint and bedding material, but with different block shapes.

Table 1. Description of tested block shapes

Picture	Description and size	Picture	Description and size
	Rectangular block 200 x 100 x 60		Rectangular block 200 x 100 x 100
	Doppel-T-interlocking block 200 x 165 x 100		H+V-interlocking block 215 x 135 x 100
	L-interlocking block A 225 x 112,5(225) x 100		T-interlocking block 224 x 112(224) x 100
	R-interlocking block 225 x 112,5 x 100		F+B interlocking block 300 x 150 x 100
	L-interlocking block B 220 x 220 x 80		L-interlocking block B 250 x 250 x 100

	Square block A 250 x 250 x 80		Square block B/C 300 x 300 x 110
	Square block D 180 x 180 x 120		Square block E 160 x 160 x 120
	Square block F 300 x 300 x 120		

The F+B blocks (with interlocking features) showed the smallest horizontal displacements. When comparing different block shapes a significant scatter in the test results could be observed (Figure 3). Some of the large blocks showed huge displacements in single joints. However, because of the low number of joints the total horizontal displacement was low.

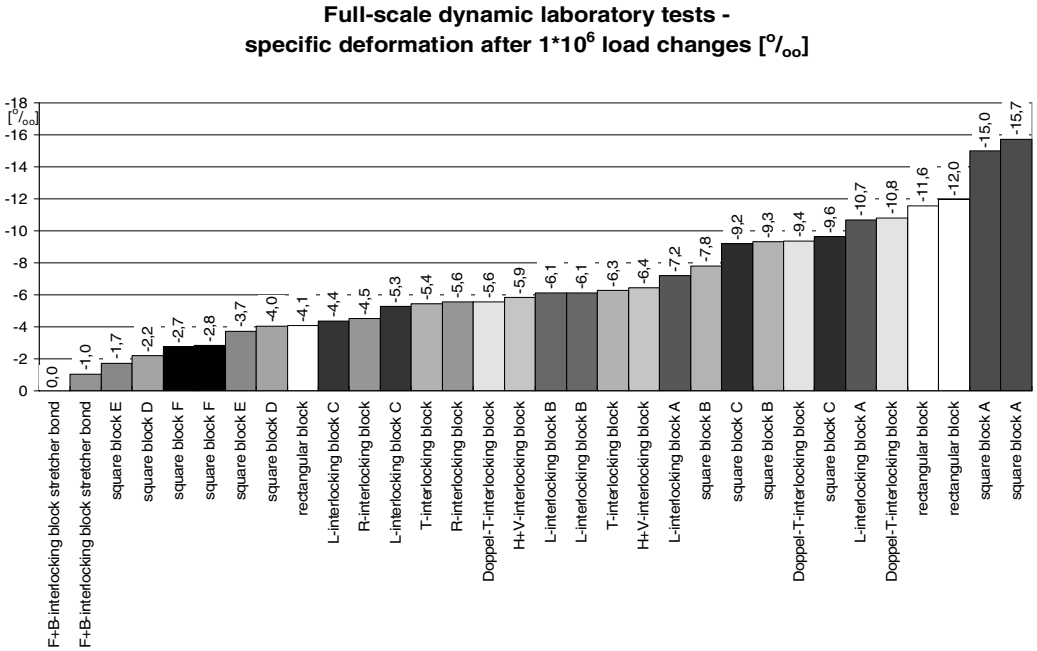


Figure 3. Specific horizontal displacements after 1 million load cycles – comparison of different block shapes

4.2 Comparison of Joint Filling Materials

To investigate the influence of different types of joint filling materials (natural sand 0-5 mm, crushed sand 0-2 mm and crushed sand/chip mix 0-5 mm) on the deformation behavior of the block pavement rectangular blocks 100 x 200 x 100 mm were used. Figure 4 shows the results of these tests. When comparing natural and crushed sand as joint filling materials smaller deformations were observed for natural sand. The cause of this behavior is the higher degree of compaction/density that can be achieved using natural sand as joint filling material. This again is a result of the lower friction between the single grains. The high amount of friction between the crushed sand particles avoids fully filled joints. The material formed bridges within the joint preventing a complete filling.

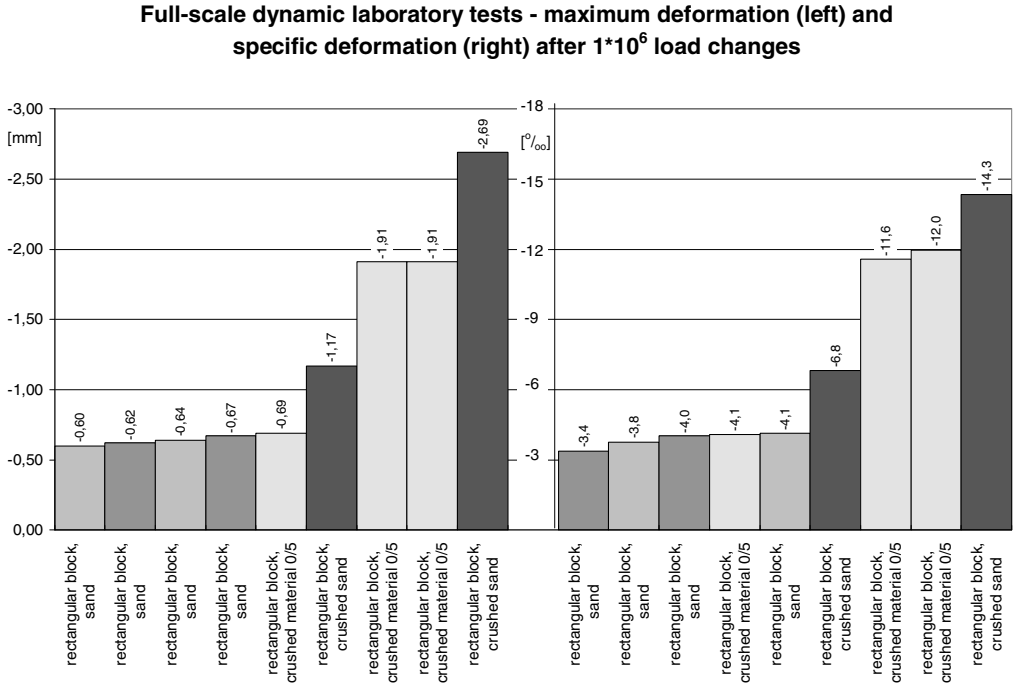


Figure 4. Maximum horizontal displacements (left side) and specific displacements (right side) after 1 million load cycles – comparison of joint filling materials (Lerch 2005)

4.3 Comparison of Laying Patterns

The influence of the laying patterns was investigated using rectangular blocks sized 100 x 200 x 100 mm and F+B blocks with interlocking features. Figure 5 shows the maximum horizontal displacements sorted by value. The test results demonstrate that continuous joints in the same direction as the load should be avoided (high displacements can be expected). Even in greater distance from the load plate a higher maximum horizontal displacement was observed for continuous joints. The displacements calculated using the photogrammetry method is illustrated in Figure 6.

The F+B blocks with interlocking features were tested using different laying patterns. Compared to the herringbone pattern the stretcher pattern induced a higher horizontal displacement. The cause is the higher amount of continuous joints. The results of the test using the herringbone pattern showed a small horizontal displacement in the load axis and a good load distribution over the pavement width.

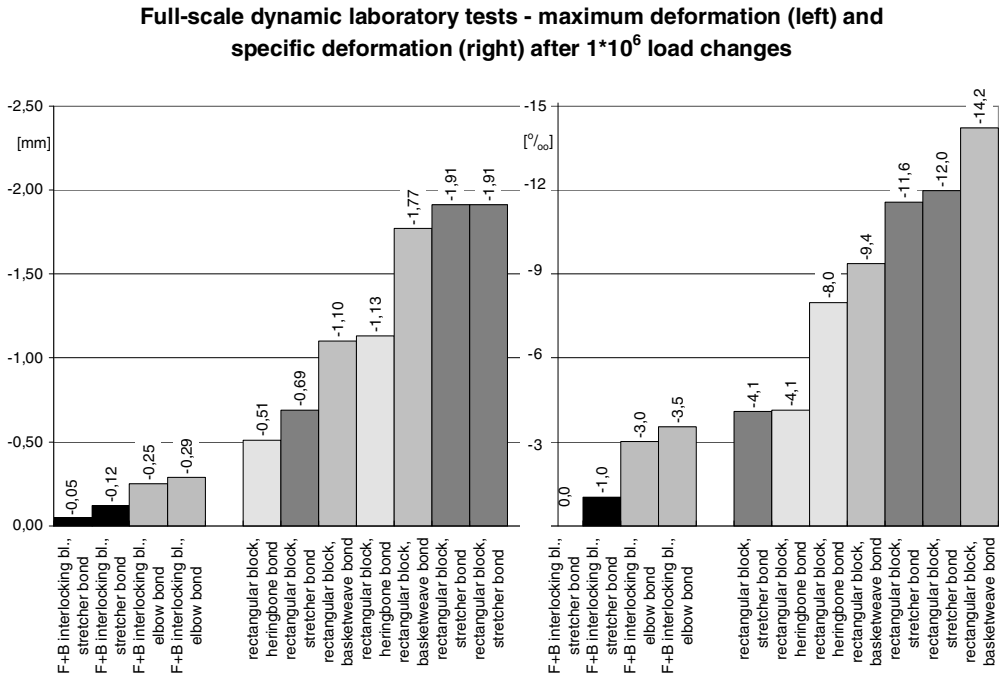


Figure 5. Maximum horizontal displacements (left side) and specific displacements (right side) after 1 million load cycles – comparison of different laying patterns (Lerch 2005)

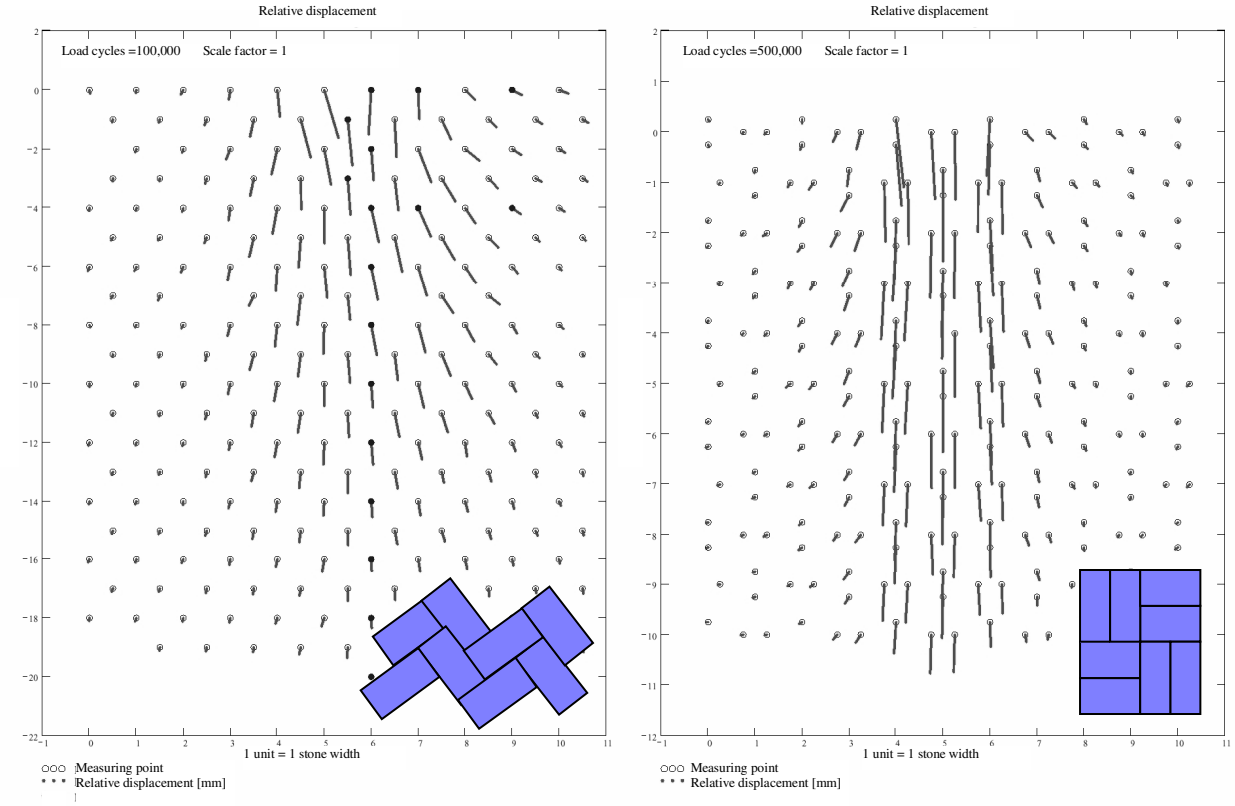


Figure 6. Photogrammetry diagrams for herringbone pattern and block pattern (Lerch 2005), the load was applied at the top of the figure

5. CONCLUSIONS

The aim of the investigation was the determination of several influences on the horizontal deformation behavior of the block layer. The investigation at Dresden University of Technology was carried out with accelerated dynamic tests on currently used block pavements in a 5.0 m x 2.5 m laboratory test environment. Different factors, like the joint material and width, the bedding material, the shape and thickness of the blocks and the laying pattern were alternated during the tests. A vertical load of 57.5 kN (the permitted maximum wheel load in Germany) and a horizontal load of 34.5 kN (the equivalent to the forces during acceleration and deceleration of trucks, taking into account a friction coefficient of $\mu = 0.6$) were applied.

The test results showed the major influence of the joint. Joint material and width as well as the degree of joint filling form a complex context. The compaction process of the joint filling material is different to that of other unbound pavement materials. It differs due to the absence of vertical superimposed compaction load. Therefore the joint filling material is not compacted but placed. The vibration of blocks and the deadweight of the filling material cause it to settle. Joint filling materials like natural sand 0-2 mm and crushed sand 0-2 or 0-5 are recommended. During the tests, natural sand reached the highest density, but because of the low friction between the grains it is very easily swept from the joints. For use with block pavements the first is in favor while the second is not.

The degree of joint filling has an important influence on load transmission from block to block. Below a filling degree of 75 % a higher vertical deformation of block layers can be observed. Empty joints lead to very high horizontal deformation of block layers. If the joints are fully filled, the thickness of the blocks and the bedding material has no influence on deformation resistance of the block pavement.

Furthermore, the test results showed that the shape of the blocks has a high effect on the horizontal deformation resistance. Pavements of concrete blocks with a four-sided bond showed a lower horizontal deformation compared to blocks with only two-sided bond. Rectangular blocks showed the lowest horizontal resistance. Block pavements using herringbone patterns have a very good load distribution and therefore high horizontal deformation resistance, while laying patterns using joints in the direction of horizontal load are unfavorable.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Lerch, T, 2005. Untersuchungen zum Verformungsverhalten von Pflasterbefestigungen unter simulierter horizontaler Last. (Investigation of the deformation behavior of concrete block pavements under simulated traffic loading), dissertation, Dresden University of Technology