DYNAMIC LOAD BEARING TESTS ON BLOCK PAVEMENTS

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Summary

In 1993/94 dynamic tests on block pavements were carried out on a 1:1 scale at the Chair of Road Construction at the Technical University of Dresden. The pavements were stressed with a sustained depression pulsating stress (approx. 0.7 N/mm^2, 1 mill. load cycles) via a load plate, made of steel and with a diameter of 30 cm. The elastic and plastic deformation were measured during the period of dynamic load and in addition to it measures were taken for static loads. The pavement types varied according to the shape of the paving stones (UNI-COLOC, interlocking stone and rectangular stone), the jointing and bedding material (natural sand, crushed sand, chippings) and the base (sandy gravel 0/32 and crushed rock 0/32).

The following significant conclusions derived from all the results:

1. The base has a considerable influence on the plastic deformation behaviour of the block pavements.

2. The shape of the paving stone can reduce the value of the permanent deformations.

3. The joint filler, the paving bed and the pattern have a remarkably low influence on the deformation behaviour.

4. No direct correlation has been made between plastic and elastic deformation.

5. No unequivocal connection could be made between the preliminary tests, e.g plate bearing test according to DIN 18134, and the determination of the value of density and the deformation behaviour of pavements under dynamic load.

Using the results from the test statements could be derived for the application of block pavements.

1. Introduction

In modern road construction, roads structures with paving layers are used for all types of traffic areas. Though rectangular block pavement and interlocking concrete block pavement to a large extent was used especially in the past 20 years, the load bearing behaviour under traffic load is unclear. At Dresden

University of Technology, from 1981 - 1985 static loading tests on sett pavings were made, the findings of which have been published already at the New Zealand [1] Conference. However, in literature it is pointed out that load bearing efficiency of the interlocking concrete block pavement only becomes clear when dynamically loaded.

Under directive of the Federal Ministry of Transportation and in a joint assignment with the Ruhr University of Bochum, the performance of a concrete block pavement under a dynamic load had to be tested. Therefore an experimental site was built at the Technical University of Dresden, Germany, which allows the application of dynamic and static loads to concrete block pavements.

A road construction is exposed to weather and traffic. The exposure to traffic is mainly a dynamic load. In addition, a horizontal stress develops through driving, breaking, and radial forces.Important is the vertical load. The lifespan of the road construction is determined by its percentage of heavy traffic use. This can be relatively well simulated in a test.

Various pavements should be subjected to a pulsating compressive loading which is comparable with a road traffic load. The behaviour of different pavements should be evaluated by the surface deformation in the area of the load as well as in the area of the pavement surface up to the distance of approximately 1.2 m (4 ft.). The various pavements were distinguished in regard to the paving stone shape, the joint, bedding and base material. Furthermore, links to the results of the conventional tests (plate bearing tests, degree of compaction, grain size distribution of the individual road construction materials) should be established.

2. How the tests were carried out

2.1 Test stand

The test stand is located in an experimental test hall of Dresden University of Technology (Fig. 1). The ground plan dimensions of the test stand are 2.5 * 2.5 m^2 .

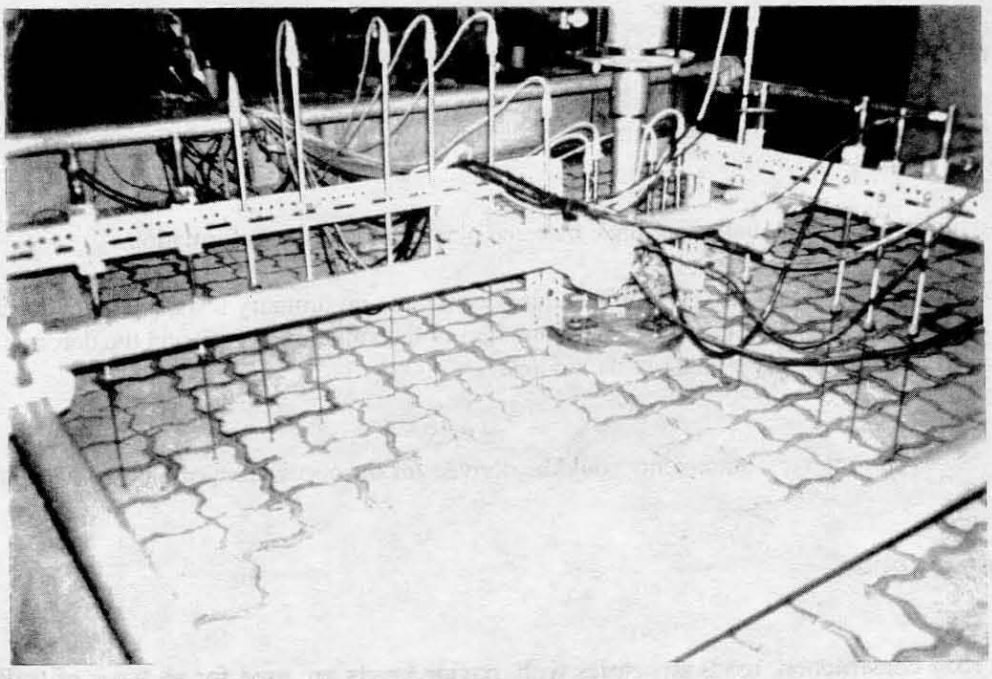


Fig. 1: Test stand

Tests are carried out to measure vertical deformations at the surface in the load axle and up to a distance of approx. 1.2 m from the load axle. Linear Variable Displacement Transformers (LVDT's) are applied. The dynamic deformations during the permanent load tests are measured as well as the static deformations at interruption of the permanent load following prescribed load cycles. Static values are registered in order to determine the different behaviour of the structures at static and dynamic loads. You will find a detailed description of the test stand in the Proceedings on the Workshop in Oslo 1994 [2].

In all the tests, the reversible and the permanent deformations have been determined after 1.000, 10.000, 50.000, 125.000, 250.000, 375.000, 500.000, 625.000, 750.000, 875.000 and 1.000.000 load cycles when dynamically loaded. In addition, at 0, 1.000, 10.000, 50.000, 125.000, 500.000 und 1.000.000 load cycles the static deformations were measured.

The repeated compression load of the sett paving applied in the test is between 5 and 50 KN. The load frequency was stated by 4,5 Hz. The structure is loaded by a steel plate of a diameter of 30 cm and of a thickness of 2.5 cm in the middle of the test field. The deformation at static load was measured at the same minimum and maximum stresses of 5 and 50 kN.

Putting in the individual structure layers, at various measuring points, plate bearing tests according to DIN 18134 [3] and density determinations according to DIN 18125 - F64 [4] applying the densitometer method were carried out. The aim was to find out relations between the results of these tests and the results of permanent load tests.

2.2 Materials used

Rectangular blocks and interlocking blocks (UNI -blocks) were selected which are often used in road construction. Furthermore, UNI-COLOC-blocks were used which when compared with the other two types of blocks are of a considerably greater bearing area. UNI - blocks and UNI-COLOC-blocks are interlocking blocks. Shapes and dimensions are listed in Table 1.

In addition, the following base-, bedding- and filling materials were included into the investigations:

base materials:	sandy gravel 0/32; crushed rock 0/32
bedding materials:	crushed sand 0/5; stone chips 2/5
filling materials:	crushed sand 0/2; natural sand 0/2

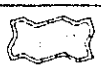
name	shape	length [cm]	width [cm]	height [cm]	bearing area [cm^2]
rectangular block		20,0	10,0	8,0	200
interlocking block (UNI-stone)		22,5	11,0	8,0	ca. 250
interlocking block (UNI-COLOC-stone)		22,5	22,5	8,0	ca. 375

Table 1: Dimensions of concrete paving setts

In Fig. 2, the principal construction methods with a sandy gravel base course is seen. The thickness of the sandy gravel layer is 39 cm in pavements with a crushed rock base course of 20 cm (tests no. 10 - 16 Table 2).

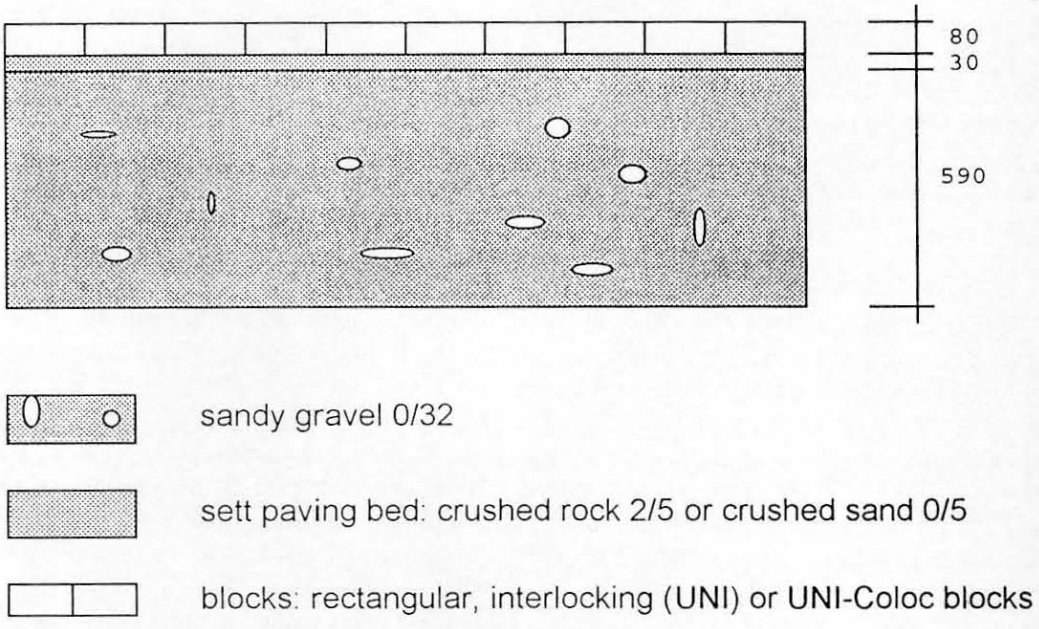


Fig. 2: Concrete Block Paving with base material: sandy gravel

2.3 Test program

For the test program, see Table 2. The name of the tests included in the last column of this table is used in the description of the results in chapter 3.

3. Test results

3.1 Plastic deformation at the surface

In Fig. 3 , plastic deformations are shown taking the UBSK test as an example. In the first joint next to the loaded plate, a distinct displacement of the paving stones against each other appears. The displacement tends toward zero already above the second block next to the load area. Distanced approx. 45 cm from the centre of the load, the deflection is transformed into a slight lifting. The lifting is 1/10 - 1/1000 mm and does not depend on the number of load cycles. When compared with the results of the other tests, it can be stated that there are no dependencies on the materials used in the orders of magnitude of the liftings. Therefore, in the following, we renounced to make further statements and explanations on the liftings observed, even when this phenomenon is assessed to be of significance for future considerations.

3.2 Elastic deformation at the surface

In their course, the elastic deformations at the surface are very similar in all the tests. In Fig. 4, the principal course is demonstrated taking the RBBS test as an example. Already in a distance of about 50 cm from the centre of the load, elastic deformations of 0,35 - 0,39 mm reduce to values of less than 9/100 mm. At dynamic measurements, elastic liftings were not found. The measured values expected for

the elastic liftings are very small (about 1/100 mm). Based on the software available for the determination of the deformations and for the measuring technique - at a load frequency of approx. 4,5 Hz - it was impossible to record the measured values in the range of liftings at the required accuracy.

No.	Paving stone shape	Joint filling	Bedding material	Base	Abbr.
1	Rectangular(L)	natural sand 0/2	crushed sand 0/5	sandy gravel 0/32	RNBK
2	UNI-STONE(F)	natural sand 0/2	crushed sand 0/5	sandy gravel 0/32	ANBK
3	UNI-COLOC(V)	natural sand 0/2	crushed sand 0/5	sandy gravel 0/32	UNBK
4	Rectangular(L)	crushed sand 0/2	crushed sand 0/5	sandy gravel 0/32	RBBK
5	UNI-STONE(F)	crushed sand 0/2	crushed sand 0/5	sandy gravel 0/32	ABBK
6	UNI-COLOC(V)	crushed sand 0/2	crushed sand 0/5	sandy gravel 0/32	UBBK
7	Rectangular(L)	crushed sand 0/2	crushed rock 2/5	sandy gravel 0/32	RBSK
8	UNI-STONE(F)	crushed sand 0/2	crushed rock 2/5	sandy gravel 0/32	ABSK
9	UNI-COLOC(V)	crushed sand 0/2	crushed rock 2/5	sandy gravel 0/32	UBSK
10	Rectangular(L)	crushed sand 0/2	crushed rock 2/5	crushed rock 0/32	RBSS
11	UNI-STONE(F)	crushed sand 0/2	crushed rock 2/5	crushed rock 0/32	ABSS
12	UNI-COLOC(V)	crushed sand 0/2	crushed rock 2/5	crushed rock 0/32	UBSS
13	Rectangular(F)	crushed sand 0/2	crushed sand 0/5	crushed rock 0/32	RFBBS
14	Rectangular(L)	crushed sand 0/2	crushed sand 0/5	crushed rock 0/32	RBBS
15	UNI-STONE(F)	crushed sand 0/2	crushed sand 0/5	crushed rock 0/32	ABBS
16	UNI-COLOC(V)	crushed sand 0/2	crushed sand 0/5	crushed rock 0/32	UBBS

Table 2: Overview of performed tests
F - herringbone pattern L - stretcher bond V - staggered clusters

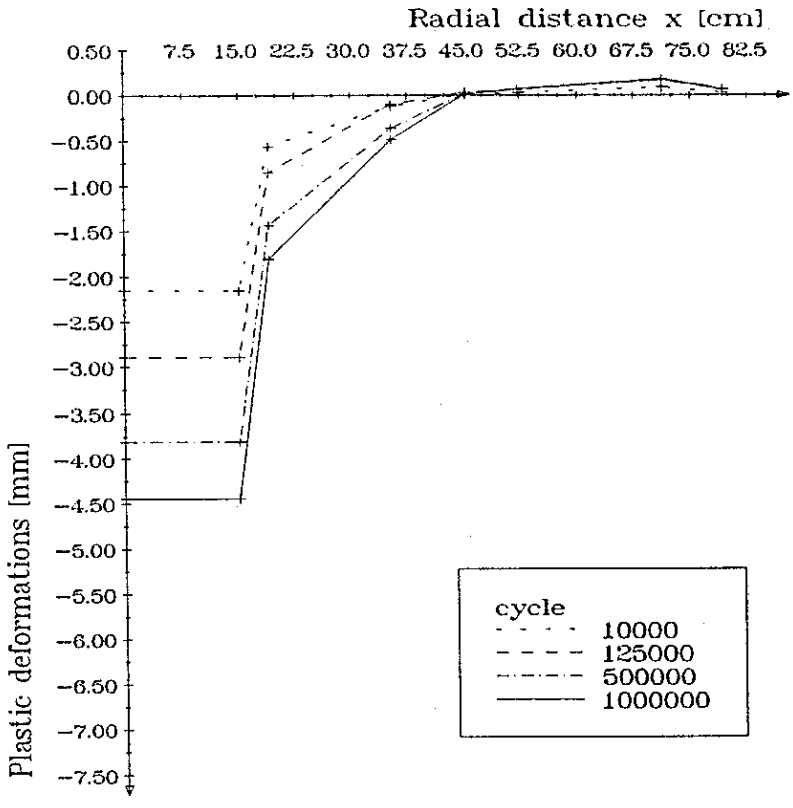


Fig. 3: Plastic deformations for UBSK

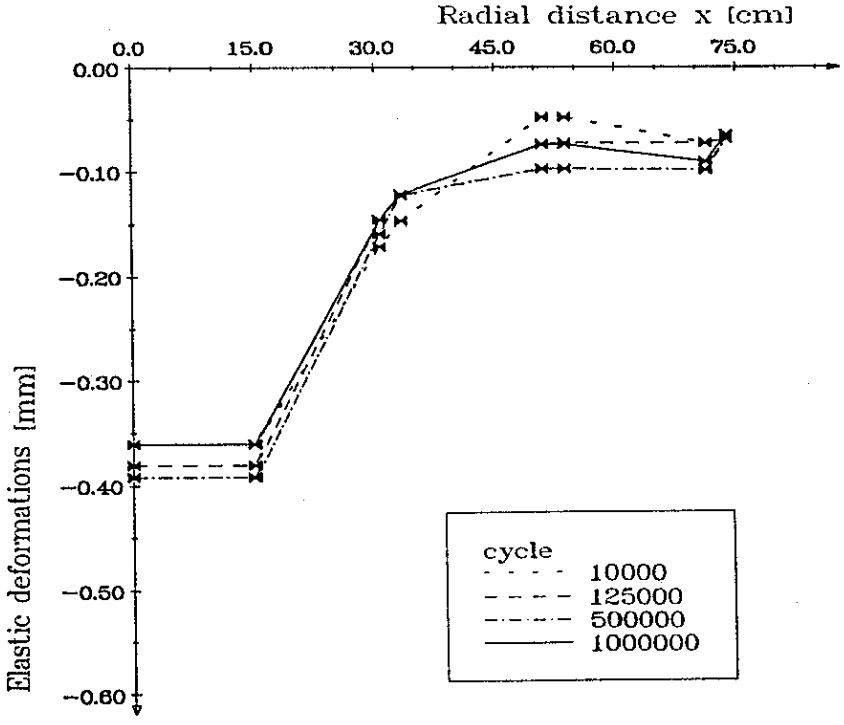


Fig. 4: Elastic deformations for RBBS

3.3 Elastic deformation in the load axis

In Fig. 5, the typical course of elastic deformations in the load axis is illustrated by means of the pavements with rectangular blocks (joint filling material: crushed sand 0/2; bedding material: crushed sand 0/5) on sandy gravel and crushed rock base course. The elastic deformations in the load axis are independent of the load cycle. In case of nearly parallel development of curves, the elastic deformations of pavements with a crushed rock base course are greater than those with a sandy gravel base course.

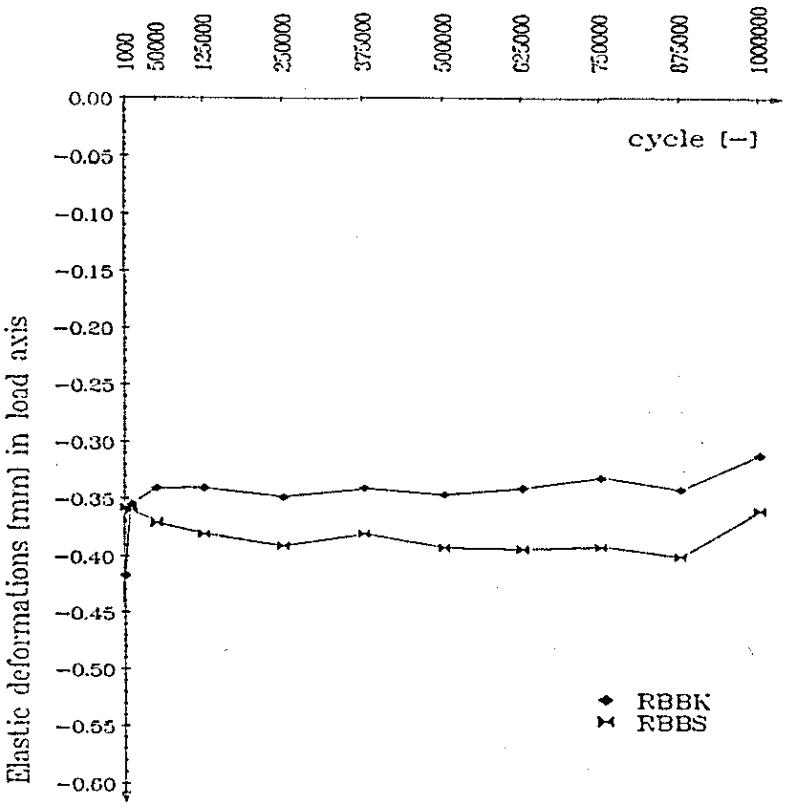


Fig. 5: Elastic deformations for RBBK/RBBS

In Fig. 6, the elastic deformations are illustrated in dependence on the load cycles for the RBBS/ABBS/UBBS pavements (variation of the blocks; joint filling material: crushed sand 0/2; bedding material: crushed sand 0/5; base course material: crushed rock 0/32). From the develmopment of the curves for the three different types of blocks, no general trends can be deduced. That means, that dimension of the appearing elastic deformations in the load axis is independent of the load cycles and of the block shape used.

3.4 Plastic deformation in the load axis

In Fig. 7, the development of plastic deformations in the load axis is shown for 1.000.000 load cycles for the same pavements as in the preceding investigations on the elastic deformations in the load axis (RBBS/ABBS/UBBS; see Fig. 6) and for three additional tests (RBBK/ABBK/UBBK). By this mode of illustration, the influence of base course materials (comparison of RBBK and RBBS, ABBK and

ABBS, UBBK and UBBS) and that of the shape of blocks (RBBK/ABBK/UBBK or RBBS/ABBS/UBBS) on the development of the remaining deformations can be shown.

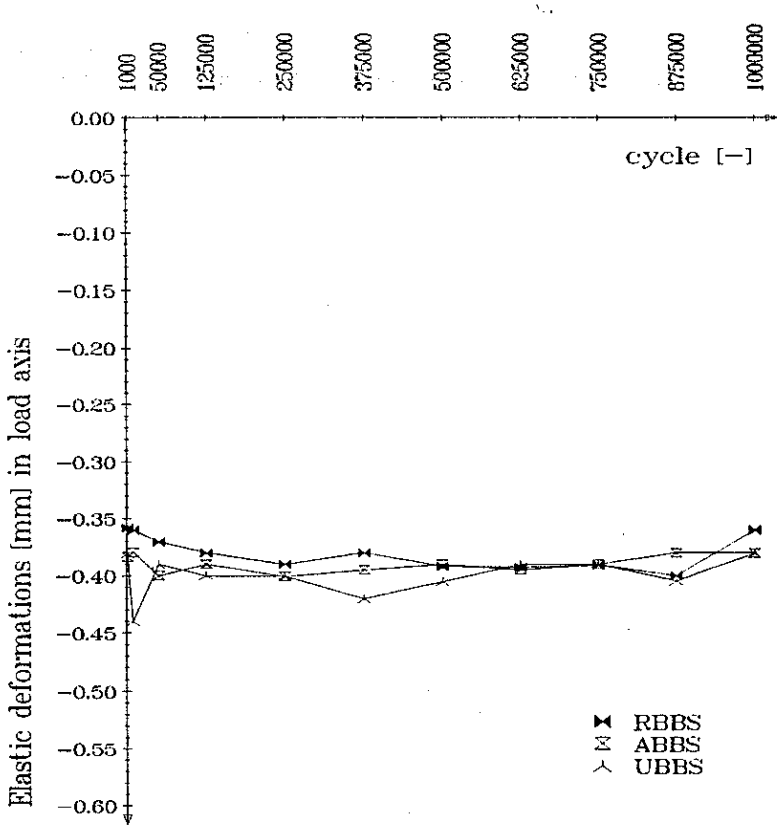


Fig. 6: Elastic deformations for RBBS/ABBS/UBBS

Plastic deformations in case of pavements with a crushed rock base course of about 20 cm are distinctly smaller than those of the variants with a sandy gravel base course. In case of UNI-COLOC-blocks, on principle, the smallest permanent deformations were measured. In case of UNI - interlocking blocks, medium deformations and, in case of rectangular blocks, greatest plastic deformations appear. In addition, in the structures with rectangular blocks, after the completion of postcompaction, there is a greater increase in the permanent deformation with the increasing number of load cycles. The difference of deformation of pavements with different shapes of blocks and a crushed rock base course is less than the value in case of pavements with a crushed sand base course.

4. APPLICATION CRITERIA

The evaluation and conclusion of all the tests showed that the bases as well as the shape of the stones have a significant effect on the load bearing capacity of a concrete block pavement under a dynamic vertical load. Both these criteria are arranged in a tabular form in relation to the permanent deformations drawn from 15 tests in order to find solutions for road construction applications.

The values from the Tab.3 are visualized in the graph in Fig.8. The dependence of the permanent deformation on the bases and the stone shapes is clearly recognizable after 1,000,000 load cycles.

The construction methods using a crushed rock base and UNI-COLOC stones or UNI-STONES display the smallest permanent deformation. For heavier traffic load applications these methods should be preferred to the other methods being tested.

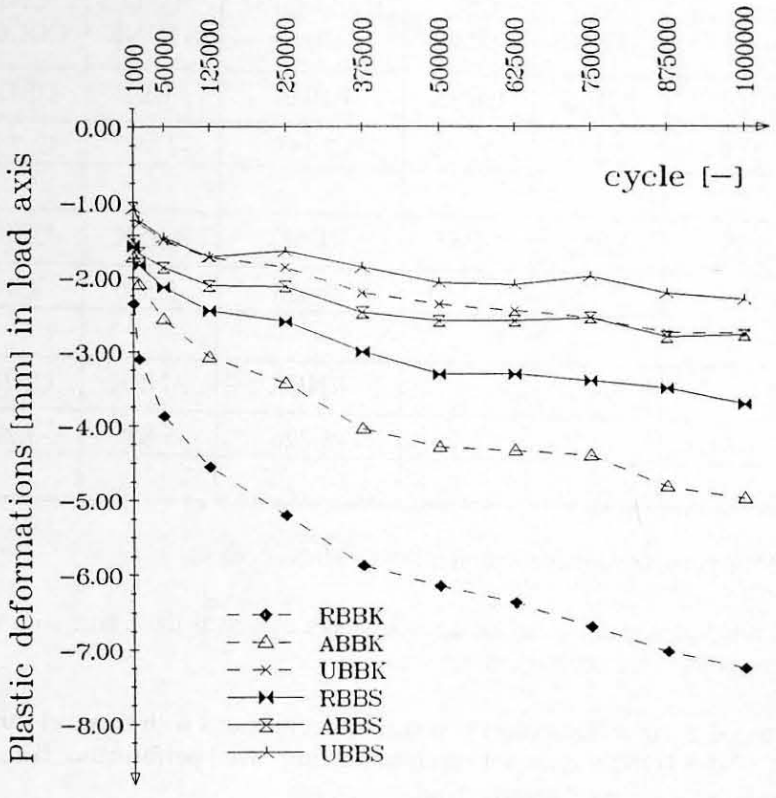


Fig. 7: Plastic deformations for RBBK/ABBK/UBBK and RBBS/ABBS/UBBS

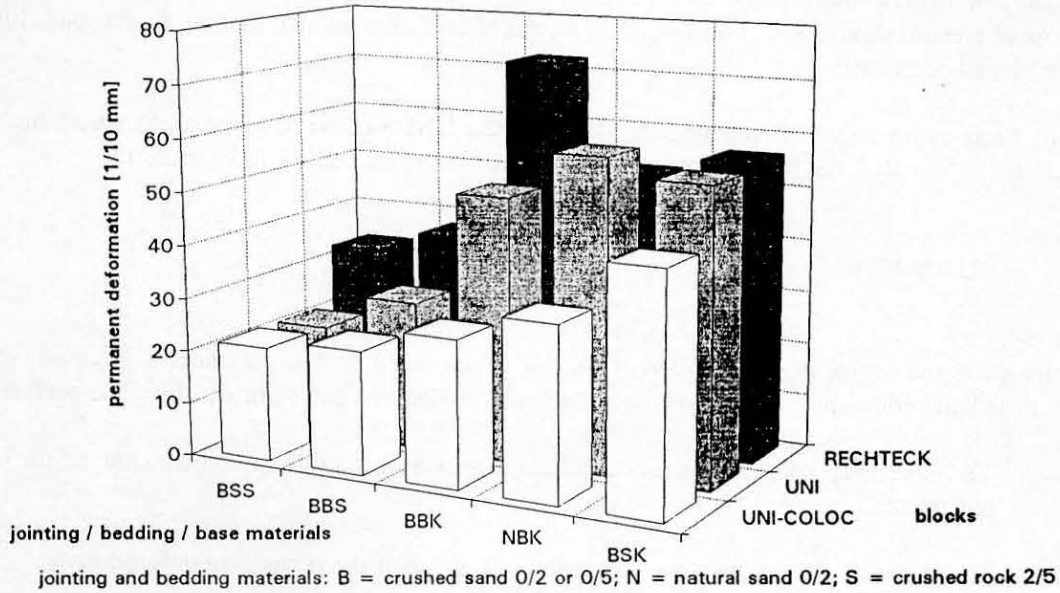


Fig. 8: Comparison of the permanent deformation of all tests

Base	Crushed Rock Base			Sandy Gravel Base		
	0/32			0/32		
Paving stone	Rectangular stone	UNI-STONE	UNI-COLOC	Rectangular stone	UNI-STONE	UNI-COLOC
Test	RBBS	ABBS	UBBS	RBBK	ABBK	UBBK
maximum permanent deformation [mm]	-3.715	-2.805	-2.304	-7.255	-4.980	-2.760
Test	RBSS	ABSS	UBSS	RBSK	ABSK	UBSK
maximum permanent deformation [mm]	-3.305	-2.120	-2.150	-5.625	-5.530	-4.445
Test	-	-	-	RNBK	ANBK	UNBK
maximum permanent deformation [mm]				-5.226	-5.870	-3.270

Tab.3: Tabular arrangement of the permanent deformation after 1 million cycles

The construction methods with a crushed stone base and rectangular stones as well as those ones with a sandy gravel base and UNI-COLOC stones show a medium deformation.

The largest permanent deformations occur while using the construction methods with a gravel sand base and rectangular stones. Use of UNI-STONES does not result in any improved performance here either. These pavements should be used solely for a light traffic load.

The load bearing capacity of each pavement can still be influenced- however not significantly- by the selection of a suitable filling and bedding material as well as the installation pattern. Nevertheless, the use of crushed sand as joint material and crushed rock as the bedding material is recommended for higher traffic loads. Since the use of crushed sand as joint filling material results in the higher internal friction, the complete filling of the joints should be assured.

Also, while using either the rectangular stones or the UNI-STONES in the areas where higher traffic loads are anticipated, the herringbone pattern over the stretcher bond is to be preferred.

5. SUMMARY

In this work the degree of deformation of various interlocking pavements under a dynamic vertical load was tested and compared. The following significant conclusions can be drawn from the performed tests:

1. The base has a determining influence on the permanent deformation behaviour of the block pavements.

2. The shape of the paving stone can reduce the value of the permanent deformations.

3. The joint material, the bedding material and the installation pattern have significantly less influence on the degree of deformation.

4. A direct relation between the permanent and the elastic deformation could not be determined.

5. A clear connection between the preliminary tests - plate bearing test (DIN 18134) and determination of the degree of compaction - and the deformation of the pavements under a dynamic load could not be established.

Based on the test results, conclusions could be drawn for the application of block paving methods. Additional tests - e.g. the influence of horizontal forces - will be required, so that additional recommendations regarding the economical use of block paving in road construction can be given.

All the results are included in detail in a research report published in a series of the Department of Road Construction at Dresden University of Technology, number 2 [5].

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