The behaviour of dynamically loaded sett pavings

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Summary

Dynamic load tests of various sett pavings will be made at the University of Technology of Dresden in cooperation with the Ruhr University in Bochum in 1993 and 1994. It is the aim of these investigations to determine the influence of

- various concrete blocks
- different beddings
- various jointing materials
- various pavements

on the load bearing behaviour of dynamically loaded pavement structures. Two tests were carried out wich should be unterstood as preliminary tests. The following paper contains the results.

1. Preliminary remarks

At Dresden University of Technology, already in the years of 1981 - 1985 investigations of sett pavings were made. These included the theoretical analysis of the load bearing behaviour of sett pavings by means of the multi-layers theory and plate bearing tests with various sett pavings (various types of sett pavings, various pavements) in the test stand at the department of Civil Engineering [1]. By these tests it was intended to get initial values for the theoretical calculations. As a result of these investigations it was stated that the paving layers behave in the same way, irrespective of the type of blocks and of the road base below. However, a minor improvement of the loading effect of the layer was stated in dependence on the layer thickness. Analysing all the tests and theoretical calculations it was found out, that a modulus of layers of

$E_1 = 500 \ldots 1000$ MPa

can be assumed for the paving layers. It was found as the most important statement that the bearing capacity of a sett paving is mainly determined by the foundation, less by the paving layer.

The findings described above were presented in writing at the conference in Auckland, New Zealand 1992 in greater detail [2].

The investigations made until now are confined to static tests. For obvious reasons, to scrutinize the statements, dynamic tests are required. Therefore, in 1993 and 1994, in cooperation with the Ruhr University in Bochum dynamic load tests of various sett pavings will be made which will be described in the following paper.

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 . The frame consists of steel sections (channel iron, height: 10 cm) allowing a total height of mounting of 70 cm above the hall floor. It is to be assumed that at this height, the influence of the rigid hall floor on the measuring results can be excluded.

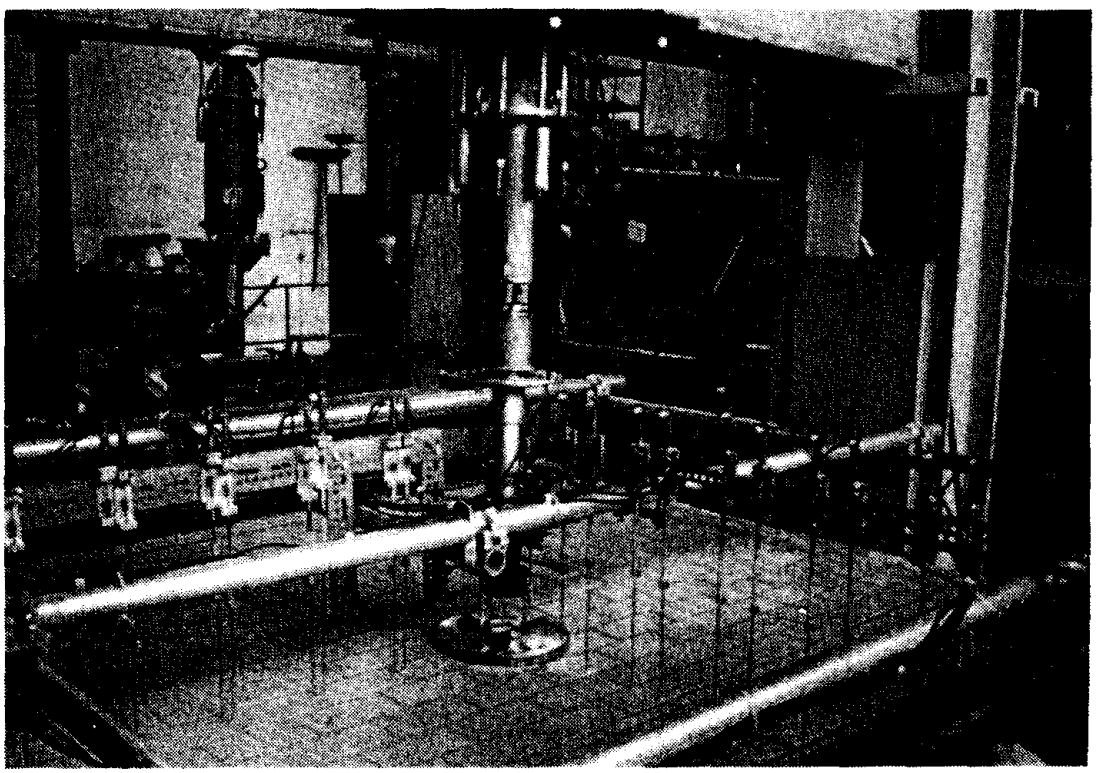

Fig. 1 Test stand

The loading system includes a hydraulic cylinder. By this cylinder, a repeated compression load of 5 ...100 kN at a frequency of 2...10 Hz is generated. 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. For the loading system, a steel portal is used as abutment situated at separate foundations. Hence, disturbing influences, such as superposition of vibrations on the test stand are excluded.

2.2 Measuring instruments, how to carry out the test

Tests are exclusively carried out to measure vertical deformations at the surface of the load axle and up to a distance of approx. 1.1 m from the load axle. Linear Variable Displacement Transformers (LVDT's) are applied, the scope of measurement of which is from 10^{-3} mm up to 20 mm. These LVDT's are mounted to a beam . The supports of which are outside the test stand. The measured values are registered by multichannel measuring converters and a PC with data interpretation programme. 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. The deformations on the loaded plate are recorded by four LVDT's evenly located on the periphery in a distance of 7.5 cm from the load axle. Beside the loaded plate, the LVDT's are placed radially to the load axle on the border of the sett paving in order to determine the movement of the stones (tipping, deformation) and the displacement of the stones (joint-to-joint movement). 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 Hz.

It is the aim of these investigations to determine the influence of

- various concrete blocks
- different beddings
- various jointing materials
- various pavements

on the load bearing behaviour of dynamically loaded pavement structures.

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The test programme intended is listed in the following table:

blocks	joint material	sett paving bed	wearing course
1. rectangular blocks	crushed sand 0/2	crushed rock 2/5	sandy gravel 0/32
2. interlocking blocks	crushed sand 0/2	crushed rock 2/5	sandy gravel 0/32
3. Uni-Coloc blocks	crushed sand 0/2	crushed rock 2/5	sandy gravel 0/32
4. rectangular blocks	natural sand 0/2	crushed sand 0/5	sandy gravel 0/32
5. interlocking blocks	natural sand 0/2	crushed sand 0/5	sandy gravel 0/32
6. Uni-Coloc blocks	natural sand 0/2	crushed sand 0/5	sandy gravel 0/32
7. rectangular blocks	crushed sand 0/2	crushed rock 2/5	crushed rock 0/32
8. interlocking blocks	crushed sand 0/2	crushed rock 2/5	crushed rock 0/32
9. Uni-Coloc blocks	crushed sand 0/2	crushed rock 2/5	crushed rock 0/32
10. rectangular blocks	crushed sand 0/2	crushed sand 0/5	sandy gravel 0/32
11. interlocking blocks	crushed sand 0/2	crushed sand 0/5	sandy gravel 0/32
12. Uni-Coloc blocks	crushed sand 0/2	crushed sand 0/5	sandy gravel 0/32
13. rectangular blocks/ stretcher bond	crushed sand 0/2	crushed sand 0/5	crushed rock 0/32
14. rectangular blocks/ hearing bond	crushed sand 0/2	crushed sand 0/5	crushed rock 0/32
15. interlocking blocks	crushed sand 0/2	crushed sand 0/5	crushed rock 0/32
16. Uni-Coloc blocks	crushed sand 0/2	crushed sand 0/5	crushed rock 0/32

3. Results of previous investigations

So far, two tests were carried out which should be understood as preliminary tests. The following pavement construction was chosen:

First test

8 cm rectangular concrete blocks
3 cm bedding material made from crushed rock (2-5mm)
59 cm sandy gravel (0-16mm)

Second test

8 cm UNI-Coloc concrete blocks (angular blocks)
3 cm bedding material made from crushed rock (2-5mm)
59 cm sandy gravel (0-16mm)

These constructions were loaded as described above by 1 000 000 load cycles. Results of the tests are illustrated in the Figures 2 and 3 and listed in the Tables 1 and 2.

Summarizing, the following is to be stated with respect to the measuring results:

1. Sandy Gravel

0/16 sandy gravel were used. For these sandy gravel applied, by means of the Waterreplacementmethod density values of
ρ_d = 1.962 ...2.016 g/cm^3 were identified.

At very good compaction (E_{V2}/E_{V1} = 1.1...1.14) on two measuring points at the surface of the sandy gravel applied, modules of deformation were found using the plate bearing test according to DIN 18134

E_{V2} = 98 N/mm^2 and E_{V2} = 105 N/mm^2 .

We are of the opinion, that such values are efficient after about 100 000 load cycles (recompaction completed).

2. Rectangular blocks

- The permanent deformation in the load axle is 10.5 mm for 1 000 000 load cycles. The greatest increase will occur during the first 100 000 load cycles, this can be explained by recompaction phenomena.

- The reversible deformation in the load axle decreases by 0.5 mm for approx. 100 000 load cycles (area of recompaction) and stabilizes to about 0.45 mm at further loading.

- Between the LVDT X.2 (at a distance of 30.2 cm from the load axle) and X.3 (at a distance of 47.8 cm from the load axle)

we measured heavings. This phenomenon is caused by the behaviour of the unbound materials lying below and was already discussed in detail [1,3].

3. UNI-Coloc concrete blocks (angular blocks)

- The total permanent deformation in the load axle is 10.4 mm for 1 000 000 load cycles. Again, there is the greatest increase during the first 100 000 load cycles recompaction.

- The reversible deformation in the load axle is comparatively constant between 0.38 and 0.42 mm over the total period of loading.

- Up to about 600 000 load cycles, between the LVTD´s X.1 (at a distance of 29.7 cm from the load axle) and X.2 (at a distance of 33.4 cm from the load axle) the deformations become heavings (zero passage). From 600 000 up to 1 000 000 load cycles zero passage of the deformation line is displaced between the LVDT´s X.2 (at a distance of 33.4 cm from the load axle) and X.3 (at a distance of 45.3 cm from the load axle).

Comparing considerations of the two variants of construction

In the pavement constructions investigated there are minor differences between the reversible deformations and the permanent deformations in the load axle after 1 000 000 load cycles. However, it is stated that in case of the rectangular blocks the reversible deformations decrease to a minor extent in dependence on the remaining deformations at increase of the number of load cycles. With respect to UNI-Coloc blocks, this behaviour cannot be recognized.

Comparing the surface deformations of both constructions it is indicated that in case of the UNI-Coloc blocks a somewhat smaller deformation curve at the surface is formed, i.e. the granular layers below the concrete block layer are more strongly loaded.

Summarizing, it is stated, that by the measured deformations no serious differences of the loading behaviour of rectangular blocks and of the UNI-Coloc blocks are identified. In the investigations of plate bearing tests mentioned already [1,2] similar findings were made, however, for other forms of sett pavings.

Concluding, it should be paid attention to the fact that additional tests are required to substantiate the present findings.

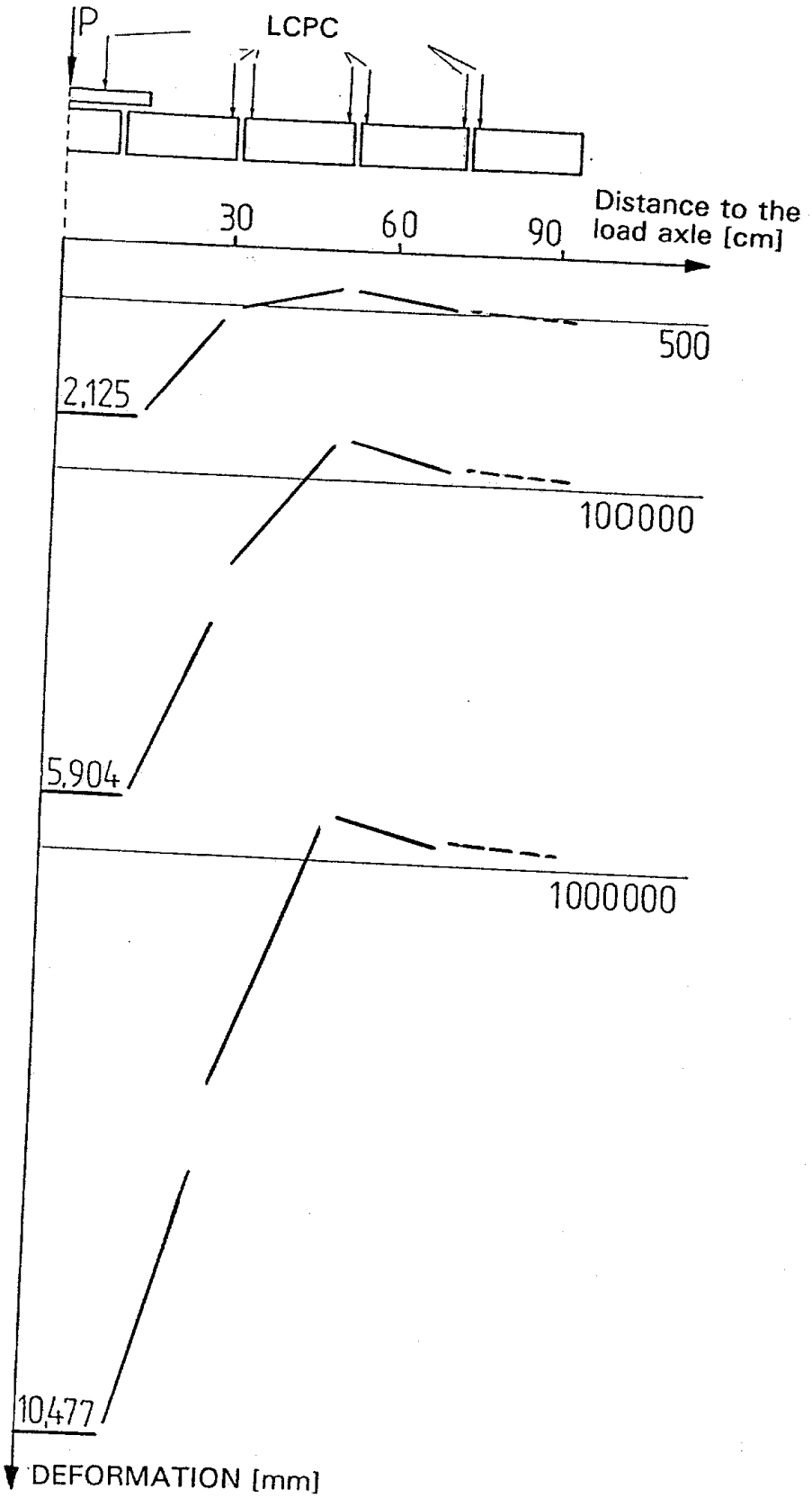
Tab.1: Measuring results of dynamic load tests on pavement with rectangular blocks

Rectangular Blocks		LVDT						
load cycle	kind of deformation [mm]	O.	x.1	x.2	x.3	x.4	x.5	x.6
	permanent	-2,125	-0,320	-0,067	0,351	0,341	0,076	0,08
500	total	-2,662	-0,563	-0,268	0,412	0,411	0,078	0,14
	resilient	-0,537	-0,243	-0,201	0,061	0,070	0,002	0,06
	permanent	-2,746	-0,679	-0,252	0,448	0,423	0,101	0,11
1000	total	-3,281	-0,943	-0,476	0,528	0,522	0,129	0,19
	resilient	-0,535	-0,264	-0,224	0,080	0,099	0,028	0,07
	permanent	-3,718	-1,265	-0,616	0,596	0,573	0,129	0,19
10000	total	-4,200	-1,530	-0,828	0,662	0,658	0,231	0,26
	resilient	-0,482	-0,265	-0,212	0,066	0,085	0,102	0,07
	permanent	-5,034	-2,131	-1,178	0,691	0,673	0,175	0,25
50000	total	-5,511	-2,392	-1,378	0,754	0,775	0,296	0,31
	resilient	-0,477	-0,261	-0,200	0,063	0,102	0,121	0,06
	permanent	-5,904	-2,703	-1,608	0,677	0,712	0,218	0,28
100000	total	-6,310	-2,915	-1,785	0,765	0,783	0,288	0,32
	resilient	-0,406	-0,212	-0,177	0,088	0,071	0,070	0,03
	permanent	-5,901	-2,707	-1,603	0,676	0,714	0,221	0,27
200000	total	-6,333	-2,917	-1,779	0,763	0,783	0,306	0,34
	resilient	-0,432	-0,210	-0,176	0,087	0,069	0,085	0,06
	permanent	-7,433	-3,714	-2,416	0,732	0,804	0,302	0,39
300000	total	-7,941	-3,961	-2,632	0,778	0,879	0,393	0,43
	resilient	-0,508	-0,247	-0,216	0,046	0,075	0,091	0,04
	permanent	-8,067	-4,077	-2,724	0,762	0,898	0,402	0,46
400000	total	-8,541	-4,325	-2,927	0,852	0,965	0,469	0,51
	resilient	-0,474	-0,248	-0,203	0,090	0,067	0,067	0,04
	permanent	-8,417	-4,482	-3,062	0,718	0,920	0,424	0,46
500000	total	-8,903	-4,663	-3,220	0,785	1,010	0,514	0,53
	resilient	-0,486	-0,181	-0,158	0,067	0,090	0,090	0,06
	permanent	-9,859	-4,819	-3,346	0,651	0,814	0,344	0,39
600000	total	-10,329	-5,046	-3,527	0,765	0,908	0,438	0,48
	resilient	-0,470	-0,227	-0,181	0,114	0,094	0,094	0,09
	permanent	-10,234	-5,021	-3,497	0,683	0,859	0,354	0,44
700000	total	-10,665	-5,219	-3,673	0,771	0,947	0,464	0,53
	resilient	-0,431	-0,198	-0,176	0,088	0,088	0,110	0,08
	permanent	-10,497	-5,637	-4,046	0,574	0,793	0,350	0,39
800000	total	-10,944	-5,835	-4,200	0,661	0,881	0,442	0,48
	resilient	-0,447	-0,198	-0,154	0,087	0,088	0,092	0,08
	permanent	-10,238	-5,437	-3,886	0,662	0,827	0,393	0,43
900000	total	-10,645	-5,642	-4,023	0,713	0,941	0,485	0,50
	resilient	-0,407	-0,205	-0,137	0,051	0,114	0,092	0,06
	permanent	-10,477	-5,642	-4,046	0,576	0,782	0,325	0,39
1000000	total	-10,932	-5,848	-4,206	0,645	0,896	0,439	0,48
	resilient	-0,455	-0,206	-0,160	0,069	0,114	0,114	0,09

Tab.2: Measuring results of dynamic load tests on pavement with Uni-coloc blocks

Uni-Coloc Blocks		LVDT						
load cycle	kind of deformation [mm]	O.	x.1	x.2	x.3	x.4	x.5	x.6
	permanent	-2,100	-0,121	0,111	0,295	0,046	-0,063	-0,043
500	total	-2,484	-0,327	0,154	0,360	0,100	-0,164	-0,104
	resilient	-0,384	-0,206	0,043	0,065	0,054	-0,101	-0,061
	permanent	-2,358	-0,184	0,134	0,353	0,071	-0,078	-0,048
1000	total	-2,700	-0,363	0,157	0,399	0,111	-0,119	-0,069
	resilient	-0,342	-0,179	0,023	0,046	0,040	-0,041	-0,021
	permanent	-3,542	-0,371	0,192	0,505	0,131	-0,020	-0,010
10000	total	-3,884	-0,553	0,232	0,586	0,192	-0,091	-0,091
	resilient	-0,342	-0,182	0,040	0,081	0,061	-0,071	-0,081
	permanent	-4,521	-0,697	0,152	0,535	0,141	-0,046	-0,015
50000	total	-4,907	-0,889	0,152	0,596	0,182	-0,091	-0,076
	resilient	-0,386	-0,192	0,000	0,061	0,041	-0,045	-0,061
	permanent	-5,313	-0,985	0,121	0,591	0,182	0,000	-0,043
100000	total	-5,773	-1,212	0,121	0,621	0,212	0,000	0,012
	resilient	-0,460	-0,227	0,000	0,030	0,030	0,000	0,055
	permanent	-6,435	-1,415	0,154	0,711	0,284	0,024	0,061
200000	total	-6,861	-1,653	0,154	0,766	0,321	0,098	0,117
	resilient	-0,426	-0,238	0,000	0,055	0,037	0,074	0,056
	permanent	-7,291	-1,832	0,060	0,728	0,320	0,122	0,087
300000	total	-7,730	-2,055	0,060	0,803	0,357	0,157	0,157
	resilient	-0,439	-0,223	0,000	0,075	0,037	0,035	0,070
	permanent	-8,229	-2,302	0,054	0,578	0,122	-0,019	0,016
400000	total	-8,663	-2,548	0,054	0,649	0,192	-0,054	-0,054
	resilient	-0,434	-0,246	0,000	0,071	0,070	-0,035	-0,070
	permanent	-8,615	-2,555	0,055	0,550	0,073	0,034	0,034
500000	total	-9,173	-2,807	0,055	0,620	0,189	-0,044	-0,083
	resilient	-0,558	-0,252	0,000	0,070	0,116	-0,078	-0,117
	permanent	-8,906	-2,720	-0,288	0,613	0,189	0,034	0,034
600000	total	-9,332	-2,914	-0,288	0,683	0,228	0,111	0,111
	resilient	-0,426	-0,194	0,000	0,070	0,039	0,077	0,077
	permanent	-9,270	-2,876	-0,277	0,693	0,228	0,111	0,073
700000	total	-9,699	-3,108	-0,277	0,771	0,267	0,150	0,150
	resilient	-0,429	-0,232	0,000	0,078	0,039	0,039	0,077
	permanent	-9,942	-3,308	-0,605	0,445	0,009	-0,035	-0,035
800000	total	-10,314	-3,526	-0,605	0,576	0,053	-0,078	-0,078
	resilient	-0,372	-0,218	0,000	0,131	0,044	-0,043	-0,043
	permanent	-10,270	-3,526	-0,689	0,489	0,009	-0,122	-0,078
900000	total	-10,663	-3,744	-0,733	0,533	0,053	-0,166	-0,122
	resilient	-0,393	-0,218	-0,044	0,044	0,044	-0,044	-0,044
	permanent	-10,380	-3,526	-0,606	0,576	0,096	-0,035	0,009
1000000	total	-10,816	-3,744	-0,606	0,664	0,140	0,053	0,053
	resilient	-0,436	-0,218	0,000	0,088	0,044	0,088	0,044

PERMANENT DEFORMATION ON THE SURFACE OF RECTANGULAR BLOCKS AT 500, 100.000 AND 1.000.000 CYCLES



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