Accelerated pavement testing on slab and block pavements using the New Mobile Load Simulator MLS10

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ABSTRACT: To optimize the thickness of slab and block pavements and also to test new large-format slabs an accelerated pavement test (APT) using the New Mobile Load Simulator (MLS10) was carried out in Austria from September to October 2010. The APT was an international cooperation with the Swiss Federal Laboratories of Material Science and Technology, Semmelrock Ebenseer and the Vienna University of Technology. The test field consists of seven different slab and block pavements, and some were instrumented with soil pressure cells and horizontal strain gauges in order to assess the primary response under the wheel load. For the APT the MLS10 used Goodyear super single tires with a wheel load of 65 kN. The test speed was 22 km/h and no lateral wandering and no application of water was used during the tests. After the construction of the test field as well as after the loading period deflection measurements with the Falling Weight Deflectometer (FWD) were performed. Also the deformation of the surface (rut depth) was determined periodically. The results of the APT are intended to evaluate the parameters for a developed Finite-Element Model (FEM) for slab and block pavements, which enables to simulate the whole superstructure, traffic loads and thermal stress. The FEM is the final tool to optimize the thickness of slabs and blocks for new formats and heavy traffic areas.

1 INTRODUCTION

Block pavements or slab pavements made of concrete or natural stones are mainly used for communal areas, where a variety in creation (shape, color, texture) is very welcome. Also the economically efficiency respectively the lifespan of the pavement is very important in such areas.

At bus stops or pedestrian precincts for example, which are also trafficked by delivery trucks, often high vertical and horizontal loads (braking and accelerating) occur. If the layers of the pavement superstructure were not properly designed, the pavement often suffers damage and as a result of this an expensive renewal is necessary. To avoid this in Austria pavements with blocks or slabs for areas with light or medium traffic loads were designed according to the Austrian regulation RVS 03.08.63 (FSV 2008a). In this regulation the thickness of the layers for the superstructure can be determined depending on a given design traffic load and a chosen pavement type. Also the maximum sizes and the aspect ratio for blocks and slabs are defined in this regulation. For heavy-duty trafficked areas, high traffic-loads and other formats individual structural designs are necessary.

To optimize the thickness of slab and block pavements for special areas of applications and also to design new large-format slabs a research project was started in December 2009. A new Finite-Element Model (FEM) was created and should be evaluated with the data of an accelerated pavement test (APT). The APT was carried out in Austria from September to October 2010 using the New Mobile Load Simulator (MLS10) from Switzerland.

This research project represented a challenge with no precedents for the partners involved and it was the first time an APT was executed in Austria on block pavements. The international cooperation involved two research institutes, Technical University Vienna (TU) and the Swiss Federal Laboratories of Material Science and Technology (EMPA), and Semmelrock Ebenseer Baustoffindustrie GmbH & CoKG (SEB), an international industry whose main activity is the development and production of concrete block pavers.

2 CONCEPT FOR ACCELERATED PAVEMENT TEST

2.1 *Layout, construction and instrumentation of the test sections*

For the APT seven different test sections were built in summer 2010 on a privately owned plot. TU and SEB designed and constructed the testing sites including measuring devices whereas EMPA provided and operated the MLS10 with the support of SEB.

Each test section was 6.40 m (21´) long and 5.0 m (16.4´) width for slab pavements and 4.0 m (13.1´) width for block pavements (Figure 1). The length of each test section was adjusted to the length between the corner jacks of the MLS10, because the machine should not stand on the pavement itself during the traffic simulation. All sections were surrounded with a concrete foundation to support the MLS10 and to fix the pavement. Because of the construction of the MLS10 (corner jacks) the maximum difference in height between the surface of the pavement and the foundation was limited to ± 20 mm (0.79´´). Also the test sections were built flat with no slope in longitudinal or cross direction.

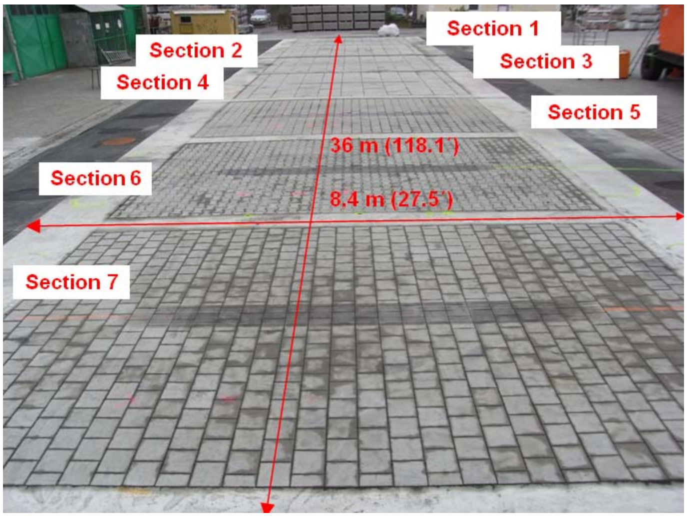

Figure 1. Layout of the seven test sections.

The superstructure of each test section was chosen according to the requirements in RVS 03.08.63 (FSV 2008a), depending on the calculated loading class (Tab. 1). For laying pattern a stretcher bond was selected for each test section. Bedding sand 2/4 mm, jointing sand 0/2 mm and 0/4 mm, base materials 0/63 mm and 0/32 mm and porous concrete C16/20 were chosen according to the requirements in regulations RVS 08.18.01 (FSV 2009) and RVS 08.15.01 (FSV 2008b).

Table 1. Superstructures of the test sections.

Test section	Thickness cm	Pavement layer	Instrumentation
1	18	Slab 100/50 cm (40/20”)	
	3	Bedding	
	20	Unbound base course	
	30	Frost protection	
	-	Subgrade	
2	18	Interlocking slab 125/62.5 cm (50/25”)	6 strain gauges
	3	Bedding	
	20	Unbound base course	2 pressure cells
	30	Frost protection	
	-	Subgrade	2 pressure cells
3	14	Interlocking slab 125/62.5 cm (50/25”)	
	3	Bedding	
	20	Unbound base course	
	30	Frost protection	
	-	Subgrade	
4	12	Interlocking slab 125/62.5 cm (50/25”)	6 strain gauges
	3	Bedding	
	20	Unbound base course	2 pressure cells
	30	Frost protection	
	-	Subgrade	2 pressure cells
5	10	Interlocking block 20/20 cm (8/8”)	
	3	Bedding	
	20	Unbound base course	2 pressure cells
	30	Frost protection	
	-	Subgrade	2 pressure cells
6	10	Interlocking block Double T	
	3	Bedding	
	20	Unbound base course	
	30	Frost protection	
	-	Subgrade	
7	10	Interlocking block 20/20 cm (8/8”)	
	3	Bedding	
	20	Porous concrete	4 strain gauges
	15	Frost protection	
	-	Subgrade	2 pressure cells

The test sections 2, 4, 5 and 7 were instrumented in the main loading line of the MLS10 with following devices to determine the response under loading condition (Fig. 2 and Fig. 3):

- On the bottom of the slabs strain gauges (type DMS LY 41-50/120) were applied at the center and at the edge of the slab to determine the extension.
- On the surface of the subgrade and the unbound base course soil pressure cells (type EBKE 20/30 K10 A) were built-in to measure the vertical pressure.
- On the bottom edge of the porous concrete special strain gauges (type EKD 1002) were built-in to measure the extension.

- Air, surface and bedding sand temperatures were also collected.

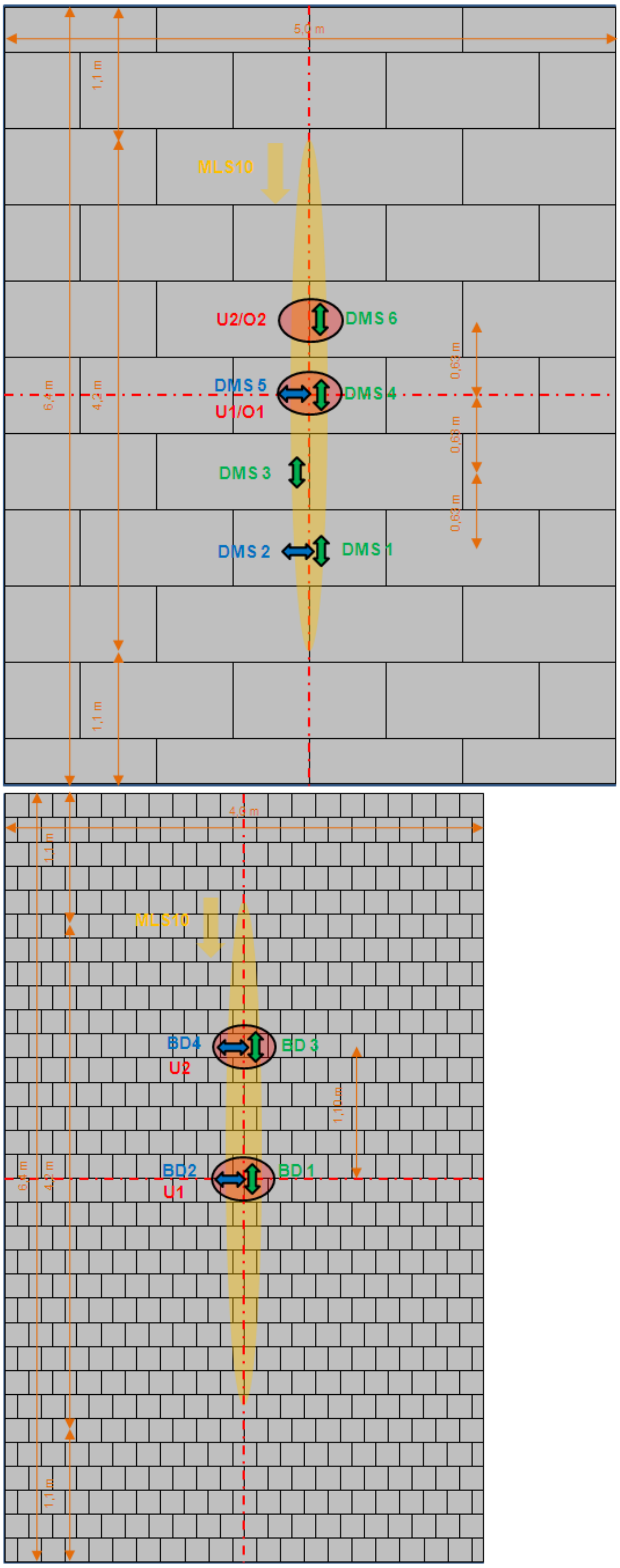

Figure 2. Layout of instrumentation on slab and block pavements.

The exact position and designation of the instrumentation is show in Figure 2 with following abbreviations:

- U Soil pressure cell on subgrade
- O Soil pressure cell on base course
- DMS Strain gauge on bottom edge of slab
- BD Special strain gauge on bottom edge of porous concrete

Figure 3. Strain and stress measuring devices.

2.2 *Test program*

2.2.1 *Visual inspection*

The visual inspection was done before and after the APT and included the following checks on each test section:

- Laying pattern and width of joints
- Filling of joints
- Damage of blocks or slabs
- Surface evenness and rut depth (also during maintenance stops of the MLS10)

2.2.2 *Measurements with Falling Weight Deflectometer*

Falling Weight Deflection (FWD) measurements were conducted on the surface of each pavement before and after the accelerated loading to assess the development of the bearing capacity of the test pavements. The measurements followed a fixed scheme as given in Figure 4 with an applied load of 50 kN. The following distances between the geophones were chosen: 0 – 200 – 300 – 450 – 600 – 900 – 1200 – 1500 – 1800 mm and no geophone was situated above a joint.

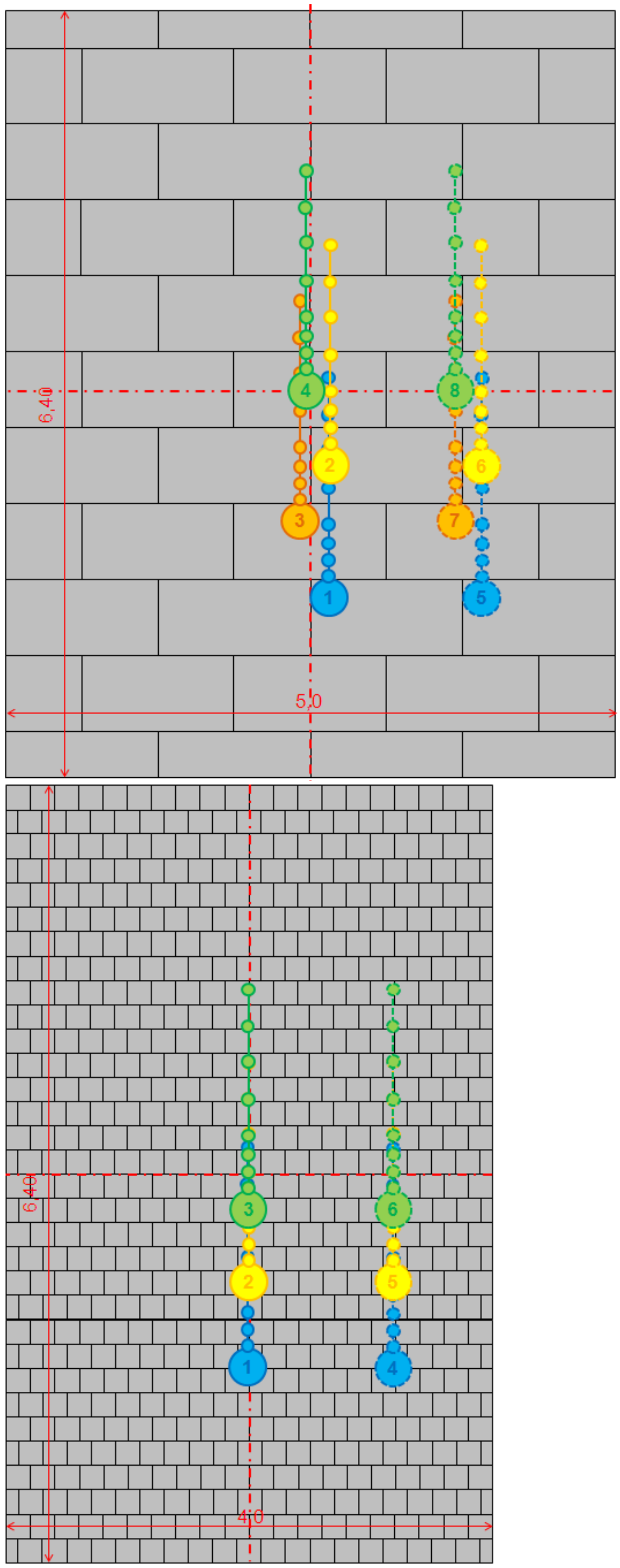

Figure 4. Scheme of FWD measurement points.

2.2.3 *Response measurements*

Four test fields were instrumented with different strain and stress measurement devices to determine the primary response under wheel load in order to verify the results of the developed FEM. The scan rate for all sensors was a frequency of 100 Hz. At the post processing the maximum, minimum, average and standard deviation per minute were calculated for each sensor for later analysis.

2.3 *Traffic simulation with New Mobile Load Simulator*

For the APT the New Mobile Load Simulator MLS10 from Switzerland (Partl 2008) was used (Fig. 5). Due to the given time restriction of two months for the tests it was necessary to increase the wheel load in order to reach the same amount of deterioration as for a standard axle load in Austria. As the available time and budget for the traffic simulation was limited a maximum of about 1.200.000 load applications could be applied in total on all test sections.

Figure 5. New Mobile Load Simulator MLS10 with super single tires.

The MLS10 was equipped with Goodyear super single tires 455/40 R22.5 with a tire pressure of 1.06 N/mm² (10.6 bar) and a wheel load of 65 kN. For that reason, changes in the geometry of the machine were done previous to the transport from Switzerland to Austria.

2.3.1 *Calibration of the MLS10*

At the start of the APT the wheel load was adjusted with a calibrated static scale and controlled with a mobile Weight in Motion device (WIM) to achieve a wheel load of exact 65 kN (Fig. 6). It took about three hours to adjust the wheel load for only one tire, so for the other three tires the same settings were used. It was planned to check the wheel load after finishing each test section, but no static scale and to less time was available. So the operating staff adjusted the MLS10 manually during maintenance stops.

Figure 6. Static scale and weight in motion.

2.3.2 *Preloading and continuous operation*

At the start of the traffic simulation a pre loading phase with reduced wheel load and a speed of 7.2 km/h (4.5 mph) took place on each test section for about 15 minutes (1.000 passes). During this time the MLS10 was not fully lowered to the pavement. After that the MLS10 was lowered to the pavement and the speed was increased to 22 km/h (13.7 mph). During the tests no lateral wandering or application of water was executed.

The MLS10 stayed 55 days in Austria and was operated 31 days with a total of 1.189.353 load applications distributed on seven different pavements. That’s about 38.400 load cycles per day (Tab. 2).

Table 2. APT schedule.

Day	Test section	Load passes	Notes
1-2	1, 2, 3, 4, 5, 6, 7		First visual inspection and FWD
3	2	14.146	Section aborted due loss of jointing sand and swinging of slabs
4	6	20.052	Section aborted due strong rutting
5	5	5.042	Rut depth at 1.000 and 5.000
6	5	49.018	Rut depth at 35.000
7	5	44.280	Rut depth at 80.000
8	5	47.919	
9	5	50.241	Rut depth at 150.000
10	5	19.452	Rut depth at 200.000
11	5, 7	51.641	Section 5 aborted due strong rutting at 250.000, section 7 rut depth at 17.000
12	7	47.914	Rut depth at 43.000
13	7	49.430	Rut depth at 115.000
14	7	27.490	
15	7	56.680	Rut depth at 165.000
16	7	50.000	Rut depth at 200.000
17-18	1, 2, 3, 4, 5, 6		Second visual inspection and FWD
19	7	36.000	Finish at 285.000
20	6	50.026	Rut depth at 33.000
21	6	20.158	Rut depth at 70.000
22	6	48.376	
23	6	54.598	Rut depth at 130.000
24	6	50.015	Rut depth at 175.000
25	6	42.560	
26	6	19.422	Finish at 285.000
27	2	48.011	Rut depth at 5.000
28	2	49.121	Rut depth at 65.000
29	2, 4	37.891	Section 2 finished at 100.000, section 4 finished at 35.000
30	3	40.094	Rut depth at 26.000
31	3	46.694	Rut depth at 75.000
32	3	13.242	Finish at 100.000
33	1	42.271	Rut depth at 35.000
34	1	37.921	
35	1	19.830	Section 1 finished at 100.000
36-37	1, 2, 3, 4, 6, 7		Third visual inspection and FWD
Total	7	1.189.535	MLS10 operating time 31 days, average 38.400 passes per day

Of primary concern was fact that there was not known previous experience, at least for the authors of the paper, of APT´s on block and slab pavements. The MLS10 had to be used for the first time to test block and slab pavements instead of asphalt or concrete pavements. The main concern was the possibility of exposing the machine, specially the loading system, to damage. If no lateral wandering is used, rutting on block pavements can depend on how the tire of the APT device is located in relation to the laying pattern of the blocks. Some blocks can then get the full load of the tires whereas others next to them are not loaded. This can induce to an uneven compaction of the bedding under the blocks resulting in an uneven surface with sharp borders that could be dangerous for the machine (Fig. 7). Most critical case could occur in the case of braking of slabs/blocks and suddenly getting loose due to the action of the moving load. To avoid this problem and to have a more representative situation of how loading distributes in real block pavements, the MLS10 was carefully positioned in order to set the tire path touching as many blocks as possible. On the other hand, permanent visual inspections of the surface were carried out to control that the surface does not have unevenness of more than 20 mm. This is also the threshold value for the rut depth in Austria.

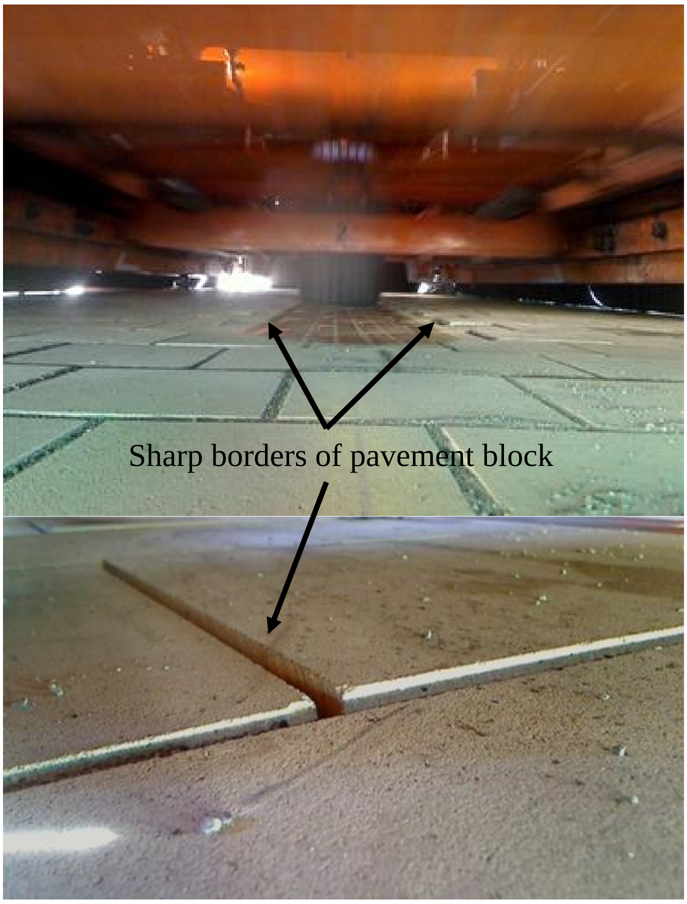

Figure 7. Uneven compaction.

3 FINITE ELEMENT MODEL

3.1 *Description of the FEM*

In this section a brief overview of the developed Finite-Element Model is given, to illustrate the use of the MLS10 test data for the validation of numerical simulation tools of the whole pavement structure.

The geometry and the boundary conditions of the FEM are illustrated in Figure 8. The thicknesses of the pavement layers are given in Table 1. The concrete slabs as well as the concrete blocks are modeled as linear elastic material. To the vertical joints, an anisotropic friction criterion in tangential direction and a nonlinear elastic material behavior in normal direction are assigned. To all unbounded layers (2)–(4) a Drucker-Prager type yield function with a cap-hardening rule is assigned. Moreover, all layers are laterally elastic continuous supported.

The material parameters for the unbounded layers were back-calculated from the FWD-measurements on the pavement surface and static plate load tests during the construction of the layers. The linear elastic parameters of the concrete were gained from ultrasonic measurements. Moreover, different joint-tests were developed and conducted for the determination of the anisotropic friction behavior of the joints between the concrete slabs/blocks.

The whole model is discretized with about 30.000 3D-Finite-Elements and 50.000 contact elements, both having quadratic interpolation functions.

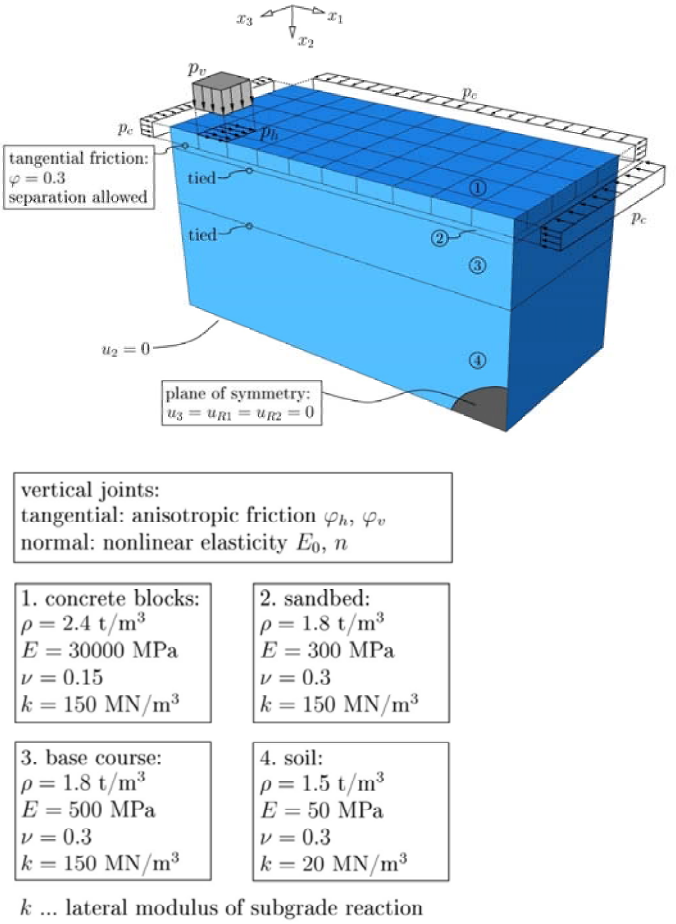

Figure 8. FEM for block pavement structures.

3.2 *Validation of FEM with sensor data*

For the validation of the FEM, static calculations for different positions of the super single tire (65 kN wheel load) were conducted. In Figure 9 the vertical deformation fields of a concrete slab pavement structure, for two different loading positions, obtained from FE-calculations are exemplarily shown.

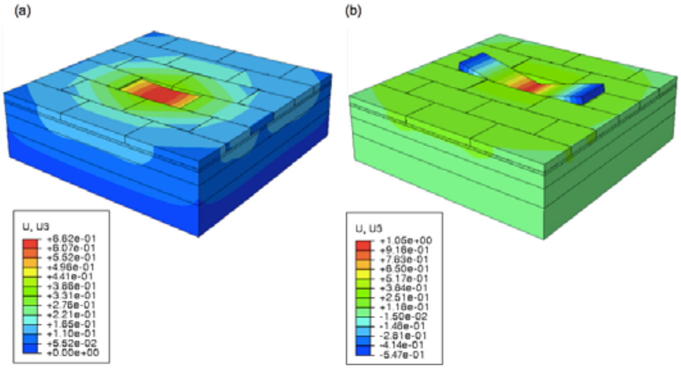

Figure 9. Vertical deformation of a concrete slab pavement structure loaded with a wheel load of 65 kN (a) in the middle of the slab and (b) at the edge of the slab.

The results were compared to the sensor data gained from the MLS10 tests. Both, the strains measured with the strain gauges applied at the concrete slabs and the pressure measured in the unbounded layers agreed well with results obtained from the Finite-Element simulations (Tab. 3). A comprehensive comparison of the Finite-Element results with the experimental test data will be presented in a follow-up paper.

Table 3. Sensor data and FEM results for slabs.

Sensor	Unit	Section 2		Section 4	
		Sensor	FEM	Sensor	FEM
DMS 1, 4	µm/m	20	21	40	50
DMS 2, 5	µm/m	65	52	80	95
DMS 3, 6	µm/m	35	30	55	66
O1	bar	0.80	0.43	0.6	0.64
O2	bar	1.70	2.00	0.40	2.40
U1	bar	0.4	0.35	0.4	0.39
U2	bar	0.55	0.54	0.50	0.57

With this simulation tool at hand, validated by means of pavement tests with the New Mobile Load Simulator MLS10, a mechanical-sound design and optimization of the whole pavement structures becomes possible. Moreover, realistic pressure and deformation states within all layers are available.

4 EXPERIENCES AND CONCLUSIONS

4.1 *Execution of APT*

The main problem of the APT was the quick loss of jointing sand, as the joints of the new surfaces had no time to consolidate. Therefore it was necessary to add jointing sand during the maintenance stops of the MLS10. But the inspection and refilling of joints are normal maintenance actions for block and slab pavements during their life time. For further tests it is recommended that new test sections should be exposed to environmental conditions (rain, dirt) for a few weeks before the start of the APT until the jointing material consolidates.

Although a few slabs and blocks were damaged, and some surfaces got deformed during the APT, it had no influences on the safety of the MLS10. To avoid that moving parts of the MLS10 get dirty by a mixture of jointing sand and water the APT was executed without any application of water on the pavement surface. The authors are aware of the unrealistic conditions for the test pavements, but the risk of damaging the MLS10 during the APT should be minimized.

In summary it may be said that the execution of the APT and the planned load applications were done successfully and a lot of time could be saved compared to test sections on public roads with high traffic volume.

4.2 *Performance of test sections*

The performance of test section 1 was as expected as it was a standardized superstructure in Austria. No slabs got damaged and the vertical deformations were within the allowed tolerances. After the appliance of more load passes the deformations increased slightly and some slabs were tipping. Also the lager slabs of test section 2 performed well, no slabs got damaged and the vertical deformations were lesser than on section 1 (Fig. 10), although this format is not standardized in Austria.

The thinner slabs on test sections 3 and 4 broke in the center of the slab along the loading line of the MLS10. This was expected as that formats were outside the regulations of the Austrian standards. But now the number of achieved load passes could be determined until the brake. Also the vertical deformations were higher than at section 1 and 2, because of empty joints and tipping of slabs which were loaded at the edge.

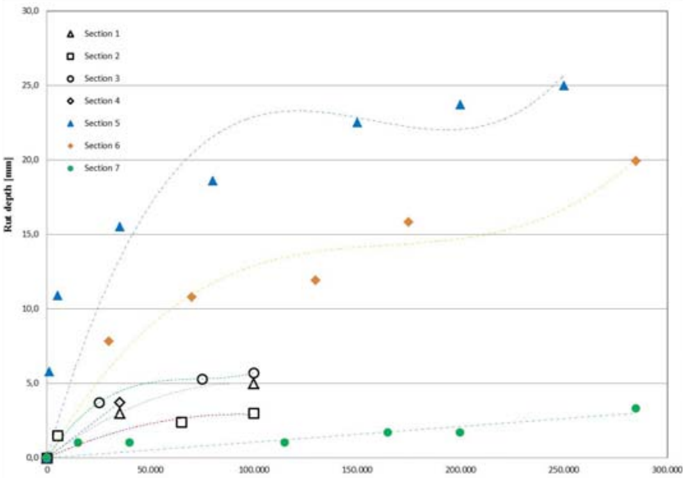

Figure 10. Rut depth of slab and block pavements.

On test section 5 the APT was stopped before reaching the planned load passes because of a rut depth more than 20 mm, which is the threshold value in Austria and also the maximum tolerance for the MLS10. The largest deformations were situated directly above the soil pressure cells in the unbound base course. So the compaction of the base course around the instrumentation was not perfect. Although high vertical deformations no blocks were broken only spalling on two stones occurred. The width of joints in the middle of the load line was below the allowable tolerances.

On test section 6 the rut depth was 20 mm at the planned end of the APT and no damage was visible on the blocks. Only in the touchdown area of the super single tires a horizontal deformation and a little tipping of two stones was observed. The width of joints in the middle of the load line was mainly below 1 mm.

The superstructure with porous concrete on test section 7 is a new construction method in Austria for which less know-how exists. The performance of this pavement was superb as no deformations were measurable and no damage was visible.

In total it could be assumed that the performances of the test sections showed realistic behavior during the APT compared to real traffic loads. The only disadvantage of the MLS10 is that no horizontal forces can be applied on the pavement surface. For further tests an additional breaking system for the MLS10 is recommended to evaluate the behavior of different block/slab pavements under brake load.

5 ACKNOWLEDGMENT

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