FULL-SCALE TEST TRACK FOR THE EVALUATION OF RC CONSTRUCTION MATERIALS WITH A HIGH PERCENTAGE OF BRICKS FOR USE IN UNBOUND LAYERS

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ABSTRACT

The importance of recycling (RC) construction materials in road construction has increased. Primarily they will be used in the unbound subbase of pavements. The technical requirements of these RC-materials are the same as for unused mineral aggregates. The current German standards for unbound mixtures allow RC-materials with a maximum brick content of 30 wt %. This limit has been evaluated primarily by using laboratory frost-heaving tests. There is a lack of systematically derived in situ measurements and tests. Therefore a full-scale test track has been constructed as part of the federal highway network. It consists of sections with six different subbase materials. Besides a reference section with unused mineral aggregates, there are sections with 10, 20, 30 and 40 wt % brick content, while the rest is crushed concrete,. Additionally there is a section with 30 wt % natural aggregates, 30 wt % crushed concrete and 40 wt % bricks. The test track has been fully fitted with temperature and moisture sensors, a traffic counting system, a meteorological station and has been monitored with periodic bearing capacity measurements and high precision levelling. Furthermore laboratory frost-heaving test have been undertaken. Three years of observation show that the suitability for RC-materials with high brick content is given.

1. INTRODUCTION

The importance of recycling (RC) construction materials in road construction increased in recent decades, partially due to the legal requirements. Construction materials, which already have to comply with the high requirements of civil engineering, will be reused with comparably high requirements in unbound layers. The technical requirements of these RC-materials are at the same (high) level as those for unused mineral aggregates. RC-materials from building demolition can contain a high percentage of concrete and bricks besides constituents of asphalt, insulation materials and impurities.

In Germany the suitability of recycling construction materials with a high percentage of bricks for use in unbound layers has been proved by laboratory tests. Referring to this, the current German standards allow 30 wt % of bricks for use in unbound layers, see table 1. This limit has been identified in a research project [1]. For this, several crushed brick types have been analysed concerning their general characteristics such as grain size distribution, grain shape, frost resistance and impact strength. Furthermore Proctor, CBR and frost-heaving tests have been carried out. The results of this research project have been verified in a follow-up project [2]. In this project the same samples have been analysed with a new frost-heaving test, see chapter 4, which is more suitable for unbound RC-materials.

Systematically collected practical experiences regarding the suitability of such recycling materials are not available. Therefore a test track has been installed to gather experiences.

Table 1 – Requirements for unbound mixtures with RC aggregates [3]

Constituent	max. allowable content [wt %]
Asphalt (fraction > 4 mm)	30
Bricks, tiles, vitrified clay (fraction > 4 mm)	30
Lime sand bricks, plaster, mortar (fraction > 4 mm)	5
Mineral insulation materials like porous concrete (fraction > 4 mm)	1
Impurities like wood, rubber, plastic, textiles	0,2

2. APPROACH

To analyze the suitability of recyclable building materials with a high brick content for unbound pavement layers, it was planned to install a test track with different sections. The sections should differ in the brick content of the unbound subbase layers. Furthermore a reference section with conventional natural aggregates was planned. The installation of the test track should be a part of a regular construction project. The test track should fulfil several needs, for example:

- high traffic volume,
- homogenous soil characteristics,
- homogenous field conditions (microclimate, shading, topography, vegetation),
- no longitudinal gradient, no distinctive bends.

All employed materials should be analyzed and fulfil the requirements of the relative standards. In addition, laboratory frost-heaving tests should be carried out on the unbound layer materials used.

To monitor the relevant behaviour of the different test track sections, several temperature and moisture sensors should be installed. In addition, repeated bearing capacity measurements and levelling were planned.

3. TEST TRACK SETUP

In 2007 the test track was constructed. The test track is a part of a federal highway in the eastern part of Germany, close to the German-Polish border, see figure 1. The track has a length of 1.200 m and is divided into 12 sections.

3.1. Subgrade

The subgrade at different parts of the test track consists of soils of high and medium workability (sand, silt, clay). During core-piling examinations, water was found at depths of 90 cm to 390 cm under the formation level. Therefore the effect of water on the pavement has to be classified as unfavourable according to the German standards for earthworks.

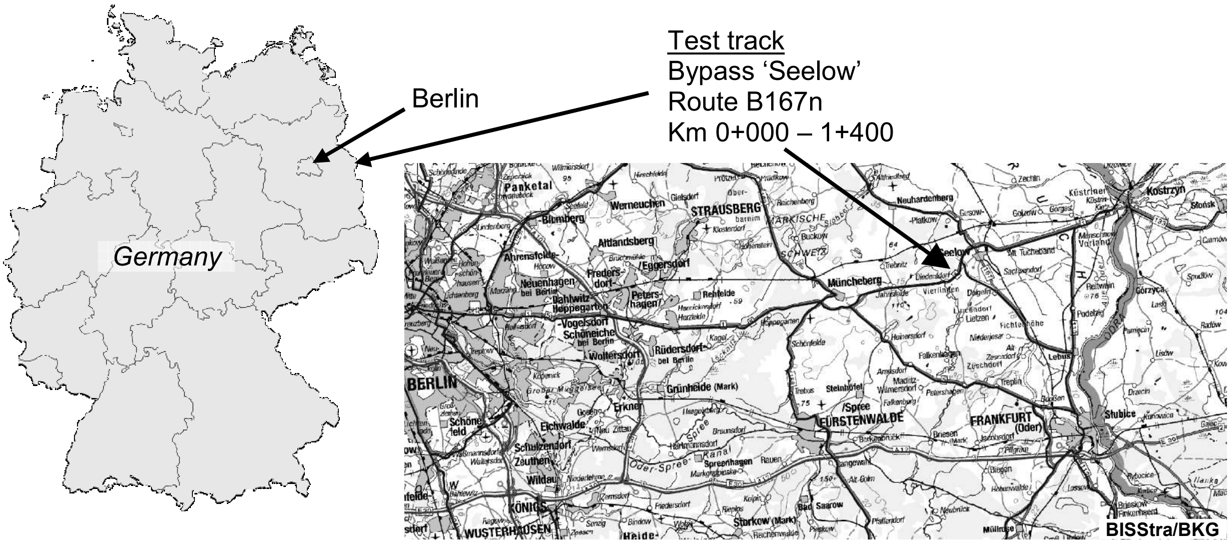


Figure 1 – Test track location

3.2. Sections and materials

The test track is divided into two halves. The southern half has an embankment profile and the northern part a cut profile. At each profile or half, six sections with different unbound layer mixtures are built. The alignment of the sections is mirrored in the middle of the test track. The compositions of the different unbound layer mixtures are shown in table 2. Within each section, the same composition for the gravel subbase (fraction 0 mm < d < 45 mm) and the frost blanket course (fraction 0 mm < d < 22 mm) was chosen. Figure 2 shows the alignment of the sections. Sections or layers which are part of the embankment profile are marked with ‘E’, the sections at the cut profile are marked with ‘C’.

The properties and composition of the unbound construction materials have been tested before and during construction (mix design and compliance testing). The required E_{V2} module (plate load test) on top of the frost blanket course (> 120 MN/m²) could be fulfilled at all testing positions. It varies from 121 to 245 MN/m². The required E_{V2} module on top of the gravel subbase (> 150 MN/m²) could be fulfilled at all testing positions. It varies from 160 to 213 MN/m². The compaction rate D_{Pr} meets the requirement (D_{Pr} > 103 %), except at four positions on the frost blanket course (95 % ≤ D_{Pr} ≤ 102 %) and at one position on the gravel subbase (D_{Pr} = 101 %).

Table 2 – Unbound layer mixture sections

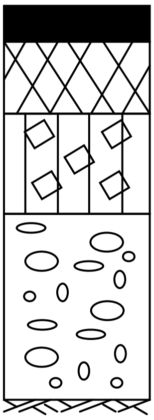
Section	Composition
0	100 wt % natural aggregates
1	RC-material with 10 wt % bricks and 90 wt % crushed concrete
2	RC-material with 20 wt % bricks and 80 wt % crushed concrete
3	RC-material with 30 wt % bricks and 70 wt % crushed concrete
4	RC-material with 40 wt % bricks and 60 wt % crushed concrete
5	30 wt % natural aggregates and RC-material with 40 wt % bricks and 30 wt % crushed concrete

South Embankment						Cut					North
5E	4E	3E	2E	1E	0E	0C	1C	2C	3C	4C	5C
30 wt % natural aggregates **40 wt % bricks** 30 wt % crushed concrete	**40 wt % bricks** 60 wt % crushed concrete	**30 wt % bricks** 70 wt % crushed concrete	**20 wt % bricks** 80 wt % crushed concrete	**10 wt % bricks** 90 wt % crushed concrete	100 wt % natural aggregates	100 wt % natural aggregates	**10 wt % bricks** 90 wt % crushed concrete	**20 wt % bricks** 80 wt % crushed concrete	**30 wt % bricks** 70 wt % crushed concrete	**40 wt % bricks** 60 wt % crushed concrete	30 wt % natural aggregates **40 wt % bricks** 30 wt % crushed concrete
0+240	0+300	0+400	0+500	0+600	0+700	0+800	0+900	1+000	1+100	1+200	1+300 1+400

Figure 2 – Alignment of test track sections

According to the German design guide for pavements, the chosen design of the asphalt course is thinner than it should be due to the expected traffic load. This reduction of thickness should simulate accelerated aging of the test track. The asphalt course consists of asphalt concrete with non-modified bituminous binder. The pavement structure is shown in figure 3.

Figure 4 shows a cross-section of the test track (with both profiles). Figure 5 gives an overview on the test track. It can be seen that the requirements of the test track concept have been fulfilled, meaning that there are homogenous field conditions and no relevant change in cross slope and longitudinal gradient. There is also no extensive vegetation, which can have a significant influence on the moisture and water conditions of the pavement.



4 cm Asphalt surface course AC 0/11S (50/70)

10 cm Asphalt base 0/22CS (50/70)

15 cm Gravel subbase 0/45

0	natural aggregates
1 - 4	RC-material with 10, 20, 30, 40 wt % bricks
5	30 wt % natural aggregates, 40 wt % bricks, 30 wt % concrete

51 cm Frost blanket course 0/22

0	natural aggregates
1 - 4	RC-material with 10, 20, 30, 40 wt % bricks
5	30 wt % natural aggregates, 40 wt % bricks, 30 wt % concrete

Figure 3 – Test track pavement structure

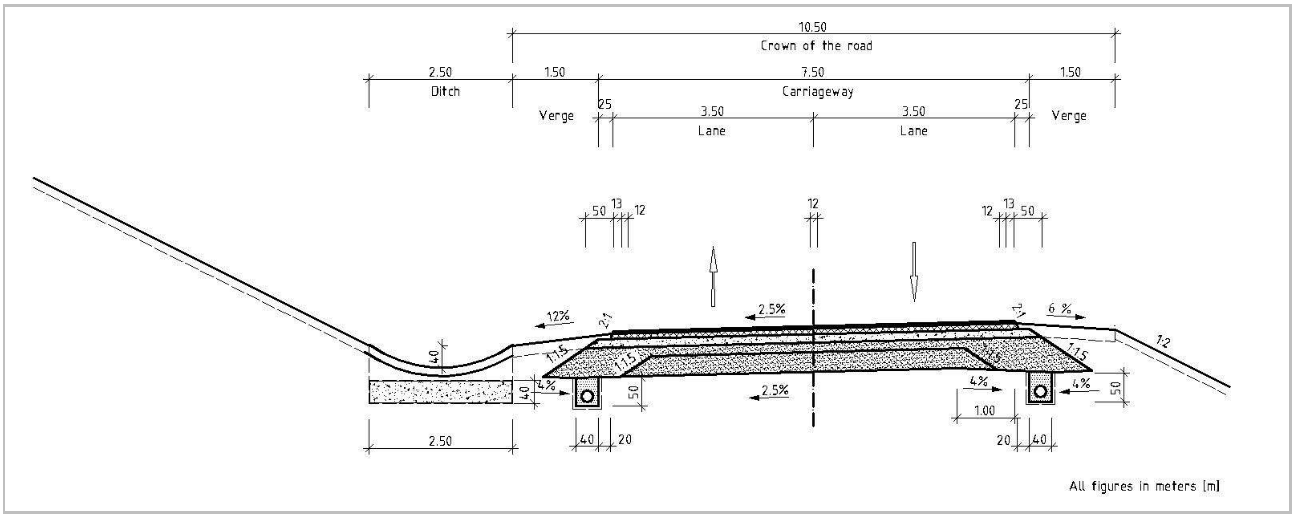


Figure 4 – Cross-section of test track

Figure 5 – View of embankment profile section (left) and cut profile section (right) in northerly direction

3.3. Instrumentation

Temperature sensors (thermocouples) have been installed at 24 positions of the test track. At each section two positions have been chosen to install five thermocouples at different depths, see table 3. At 12 positions, one per section, two moisture sensors (microwave sensor) have been installed into the frost blanket course and into the subgrade, see table 3. The data logging interval is one hour and takes place in weatherproof cabinets, which are installed beside the pavement, see figure 6. The thermocouples run on battery power, the moisture sensors are supplied by the traffic light power supply at the end of the test track.

In the middle of the test track, a meteorological station has been installed. This multi-function instrument can log wind speed and direction, relative humidity, air temperature, precipitation amount and intensity and global radiation. This station and the temperature and moisture sensors in the middle of the test track have been connected to a GPRS modem for remote data access.

Additionally an automatic traffic counting system has been installed at the south end of the test track.

Table 3 – Temperature and moisture sensor positions

Sensor	Position	
Temperature	- 2 positions per section (middle of right and left lane)	
	- depths:	
	4,0 cm	Asphalt course
	21,5 cm	Gravel subbase
	54,5 cm	Frost blanket course
	80,0 cm	Foundation
	130,0 cm	Subgrade
Moisture	- 1 positions per section (middle of lane)	
	- depths:	
	39,0 cm	Frost blanket course
	90,0 cm	Subgrade

Figure 6 – Weatherproof cabinets for data logging (left) and moisture sensor (microwave head / right)

3.4. Field measurements

After test track construction, the behaviour of the test track was monitored with periodic field measurements. Before (autumn) and after frost periods, the in situ frost-heaving has been measured with high-precision levelling. Therefore three profiles per section were marked with durable measuring points.

In autumn and spring, bearing capacity measurements were carried out with a Falling-Weight-Deflectometer (FWD) and Benkelman-Beam at the same stations and on the same day. Therefore 128 points with a longitudinal distance of 15 m have been marked.

4. FROST-HEAVING TESTS

Samples from the unbound layer materials with RC-material were taken from each section of the test track. Laboratory frost-heaving tests (FHT) and CBR tests before and after the FHT were carried out on each sample.

The applied FHT is based on the research work of Weingart et al. [4] and will be part of the German technical standards. ‘The new frost-heaving device can be used to perform double tests in separate test chambers. The test cylinders are made of Teflon rings that can separate from each other in order to minimise wall friction and allow frost-dependent heaving of the material. The samples are placed in a water bath in order to ensure the possibility of absorbing water during the entire test period. Cooling to simulate frost is applied by a cooling head placed on top the sample. A 24-hour temperature stabilisation period is followed by a 4-day cooling-down phase during which the cooling head temperature is controlled to ensure that the 0 °C-isotherm is approached at a constant speed in the middle of the sample. This condition is sustained during a 3-day frost exposure phase. During the subsequent 24-hour thawing phase, the sample is completely defrosted. The temperature at the surface and in the middle of the sample and the temperature of the water bath are measured. In addition, the heaving of the sample is determined. These data are automatically measured at 5-minute intervals during the entire test period.’ [5]

Figure 7 and 8 shows the FHT and a test cylinder. Figure 9 shows a typical diagram of the entire test period, which will be used for interpretation of the test results. The ‘heaving after freezing’ (maximum heaving), the ‘heaving after thawing’ (remaining heaving) and the ‘relevant frost-heaving speed’ (absolute difference between day 7 and 8 in mm/d) are relevant indicators for the frost-heaving sensitivity.

Figure 7 – FHT device and Teflon test cylinder with mounting devices

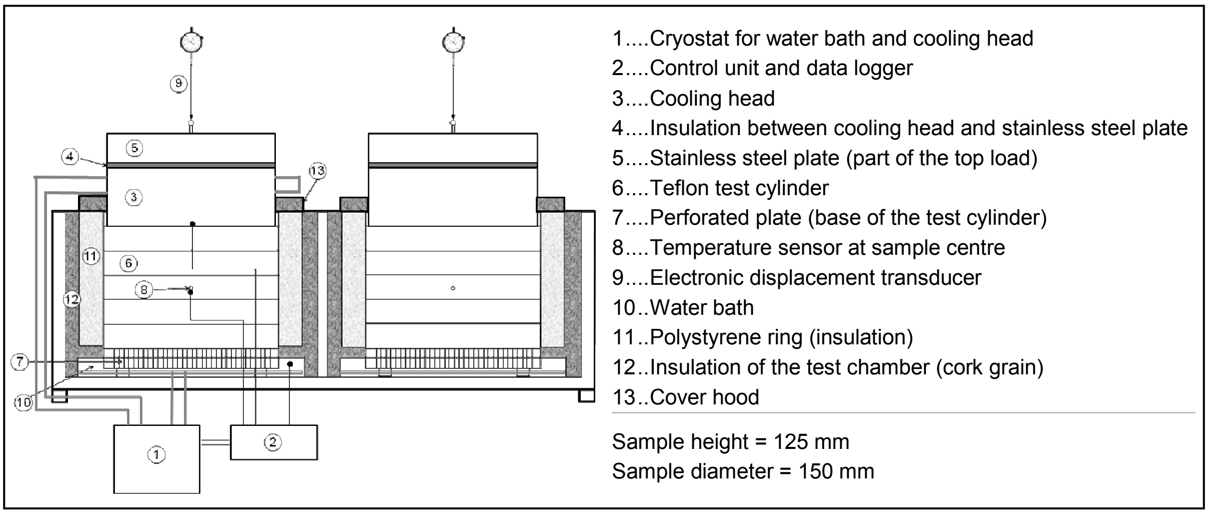


Figure 8 – FHT schematic [5]

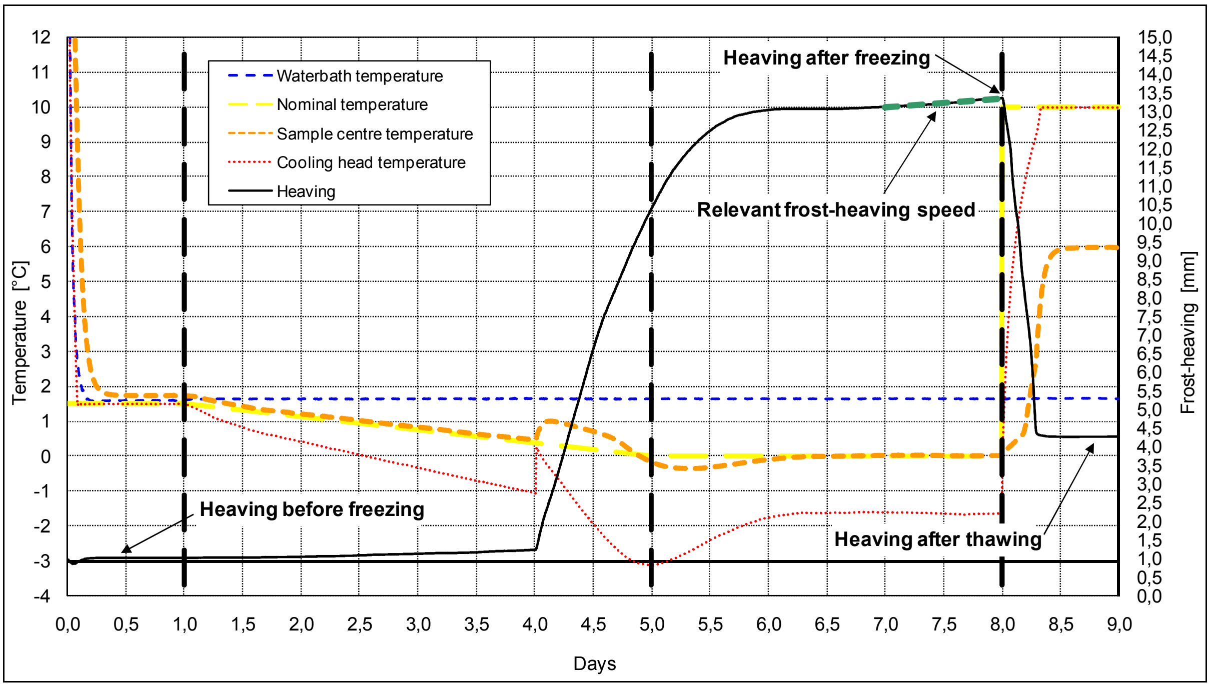


Figure 9 – FHT diagram

5. DISCUSSION OF RESULTS

For the evaluation of the suitability of RC construction materials, the following requirements should be fulfilled:

a. Compliance of the composition limits.
b. Compliance of mechanical and environmental requirements.
c. Suitability for structural engineering.
d. Frost-resistance (laboratory and in situ).
e. Resistance to frost-heaving, loss of bearing capacity and structural damage of the surface.

The compliance to ‘a’, ‘b’ and ‘c’ has been proved with the mix design, compliance testing and the experience gained during construction. To evaluate ‘d’ and ‘e’, first the climate and load impact on the test track will be analyzed. Then the effect of this impact on the bearing capacity, frost-heaving and surface distress will be evaluated. The construction of the test track has been finished in 2007 and the present evaluation covers the time from autumn 2007 to spring 2010 (observation period).

5.1. Climate impact

The climate impact on the pavement can be described with meteorological data and with the pavement data from the installed temperature and moisture sensors.

5.1.1 Meteorological data

Due to technical problems, the meteorological data from the installed station have been supplemented with data from a nearby station of Germany's National Meteorological Service (DWD). These data have been compared to the data of the WMO (World Meteorological Organization) normal period 1961-1990 of the abovementioned nearby DWD station. Referring to the mean monthly air temperatures, the observation period was often warmer than the normal period. But there were also superior freezing seasons, in particular the winter of 2009/2010, see figure 10 which shows the absolute difference between the average monthly temperature of the observation period and the normal period. The average precipitation during the observation period was close to the normal period.

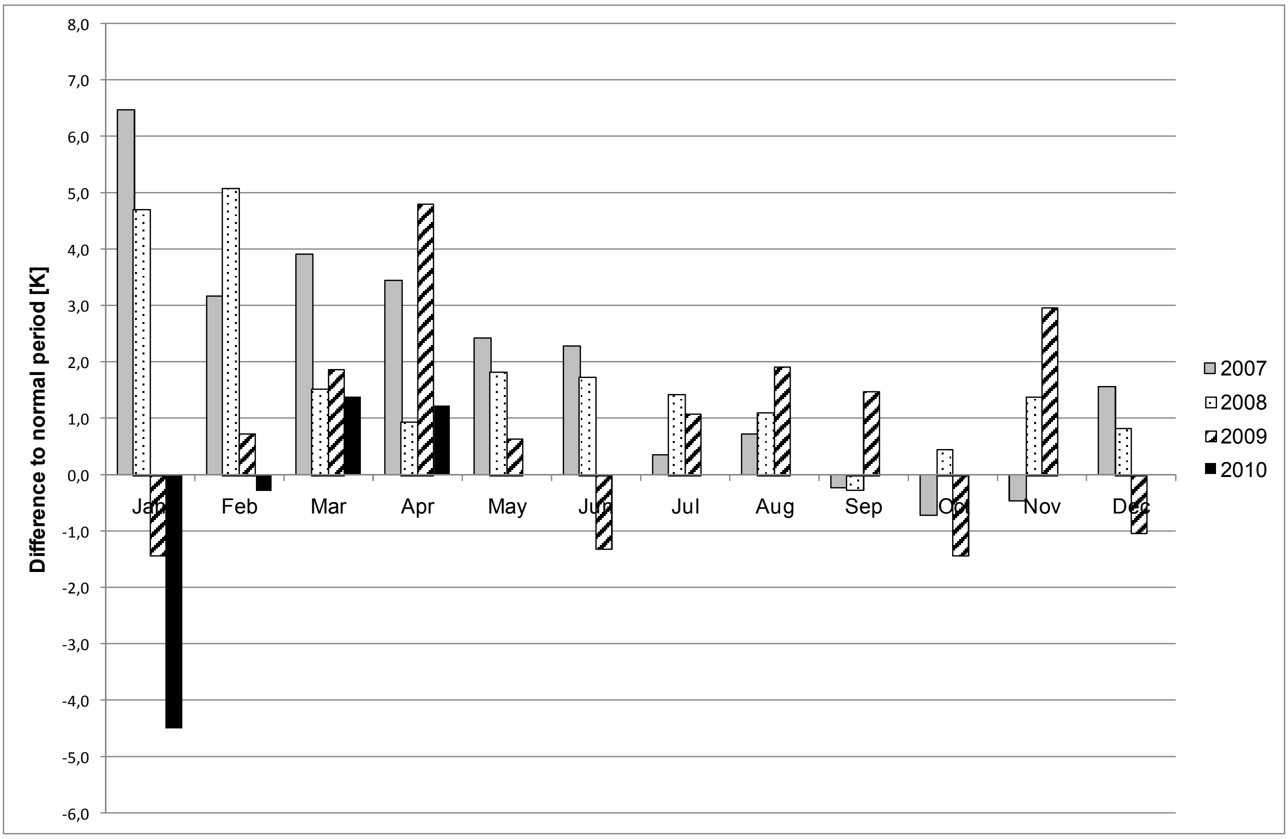


Figure 10 – Difference of average monthly air temperatures between normal period and observation period

To evaluate the strength of a freezing season the freezing index (FI) has been calculated. The freezing index is given by the summation of the degree-days for a freezing season. Degree-days are defined as days with a mean air temperature below 0 °C. Successive freezing seasons, which are interrupted for only a few days with positive mean air temperature, for example two days, can be seen as one freezing season. Table 4 shows the top four freezing seasons of the observation period and the estimated frost penetration depth z_F, which has been calculated with the following formula [6]:

$$z_F = 15{,}6\ (FI)^{0{,}3}$$

Table 4 – Freezing index and frost penetration depth (top four)

N°	Period	FI [°C·d]	Duration [d]	z_F [cm]
1.	2009/12/29 – 2010/02/17	-230,8	51	79,8
2.	2008/12/25 – 2009/01/17	-108,5	24	63,6
3.	2009/12/12 – 2009/12/22	-56,0	11	52,2
4.	2009/02/12 – 2009/02/21	-20,8	10	38,8

5.1.1 Pavement data

During the observation period from April 2007 to March 2010, 2,5 million temperature values were recorded with 120 temperature sensors. Significant differences between temperatures at the same depth of the cut or embankment profile or the different unbound layer materials could not be identified. The measured temperature range is -16,5 °C to 51,9 °C in the asphalt layer and -1,5 °C to 36,2 °C below the formation, see figure 11.

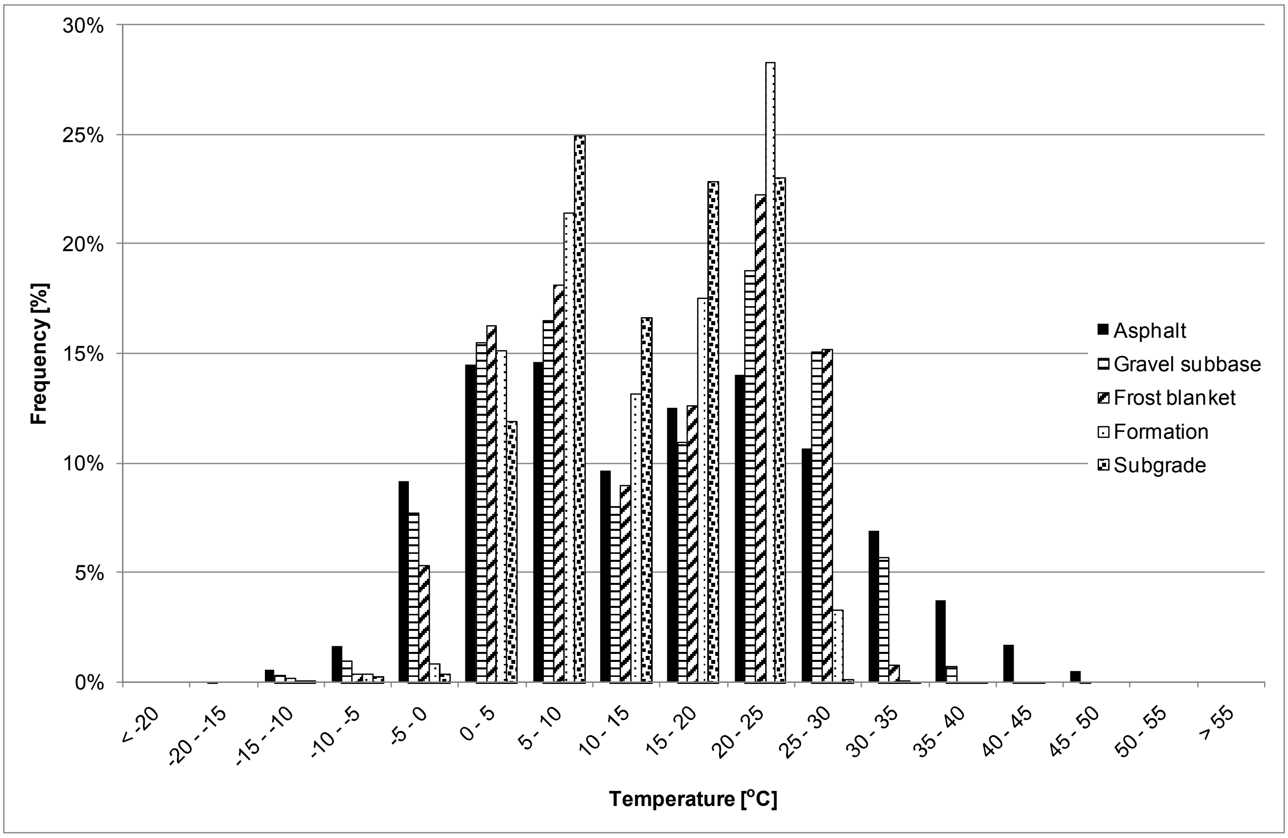


Figure 11 – Pavement temperature distribution (April 2007 to March 2010)

Table 5 – Maximum and minimum temperatures

Sensor position		Maximum temperature		Minimum temperature	
-4,0 cm	Asphalt	51,9 °C	16.07.2007, 16:00	-16,5 °C	27.01.2010, 08:00
-21,5 cm	Gravel subbase	45,5 °C	22.04.2008, 21:00	-12,4 °C	27.01.2010, 10:00
-54,5 cm	Frost blanket course	42,9 °C	28.05.2007, 10:00	-6,7 °C	27.01.2010, 11:00
-80,0 cm	Formation	40,3 °C	28.05.2007, 10:00	-2,9 °C	03.01.2010, 15:00
-130,0 cm	Subgrade	36,2 °C	28.05.2007, 10:00	-1,5 °C	25.02.2010, 14:00

The calculated frost penetration depths have been verified by the measured frost penetrations. The analysis shows that especially for long freezing seasons with FI < -20 °C·d, the calculated frost penetration depth is well suited to the measured frost penetration depth.

The measured moisture content has been converted to water content with the knowledge of the bulk densities of the materials. Significant differences between the test track sections could not be identified. Figure 12 shows the mean annual graph of the water content of the frost blanket course and the subgrade. The water content reaches its maximum in late spring and summer. There is a slight correlation with the mean precipitation of the normal period. The direct comparison to the measured precipitation data is very unsatisfying, because the influence of single precipitation events on the water content of deep layers is delayed and cushioned. The rapid change in the water content in the presence of frost, see figure 12, is due to the sensor technique. The moisture sensor measures the dielectric resistance of the sample, which significantly changes with the state of aggregation.

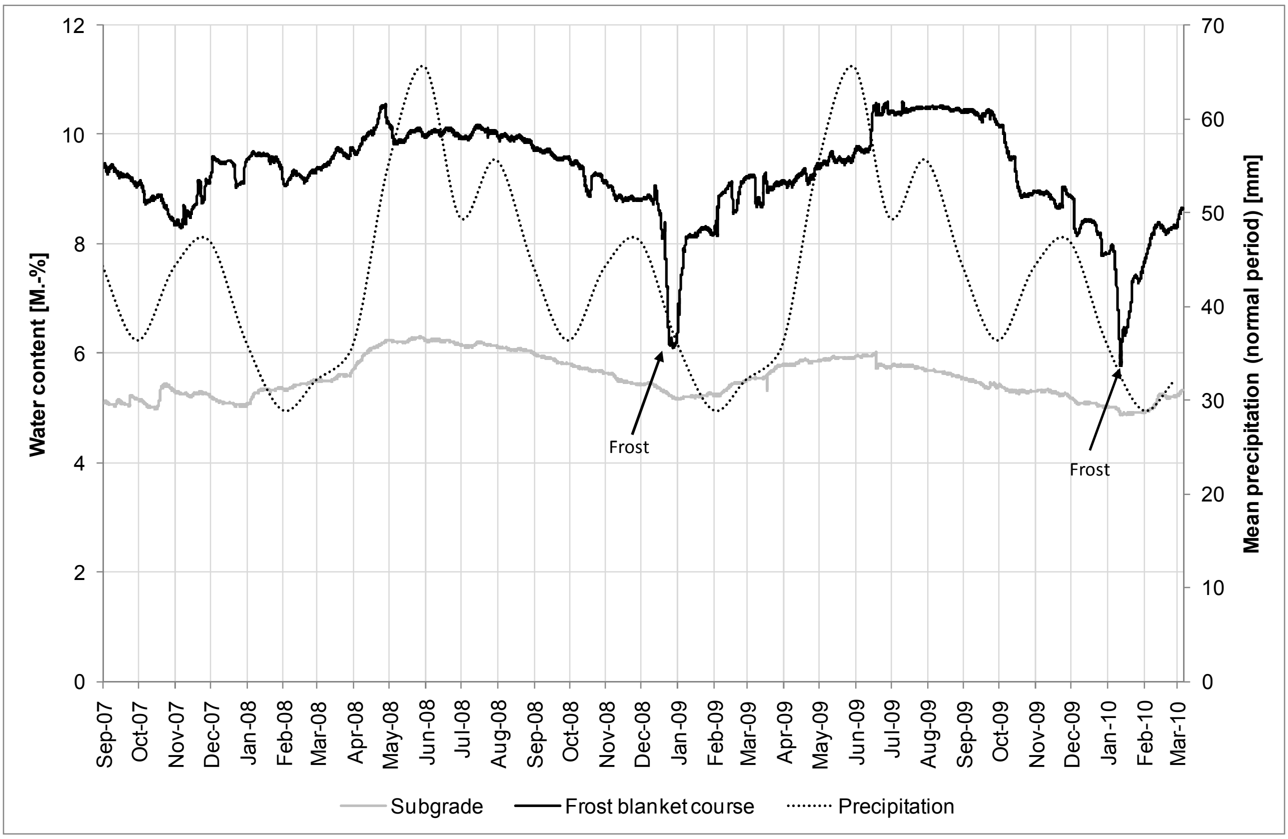


Figure 12 – Water content and mean precipitation (normal period)

5.2. Load impact

The results of the installed automatic traffic counting system are represented in figure 13. The average daily traffic (ADT) has a positive trend over the observation period in both traffic directions. The heavy vehicle (HV, gross vehicle weight over 3,5 tons) loading during the observation period does not reach the expected level of 262 vehicles per day but is slightly higher than the limit for the chosen construction thickness, according to the German design guide.

5.3. Frost-heaving

The frost-heaving in situ has been monitored by high-precision levelling before and after frost seasons. It will be compared to the results of the laboratory heaving-tests.

5.3.1 In situ frost-heaving

The average heaving of the test track at different positions during the observation period is about 2 mm. It is superposed by the consolidation of the test track. Systematic differences between the test track sections could not be identified. Frost-heaving and consolidation are at a harmless level and can be disregarded.

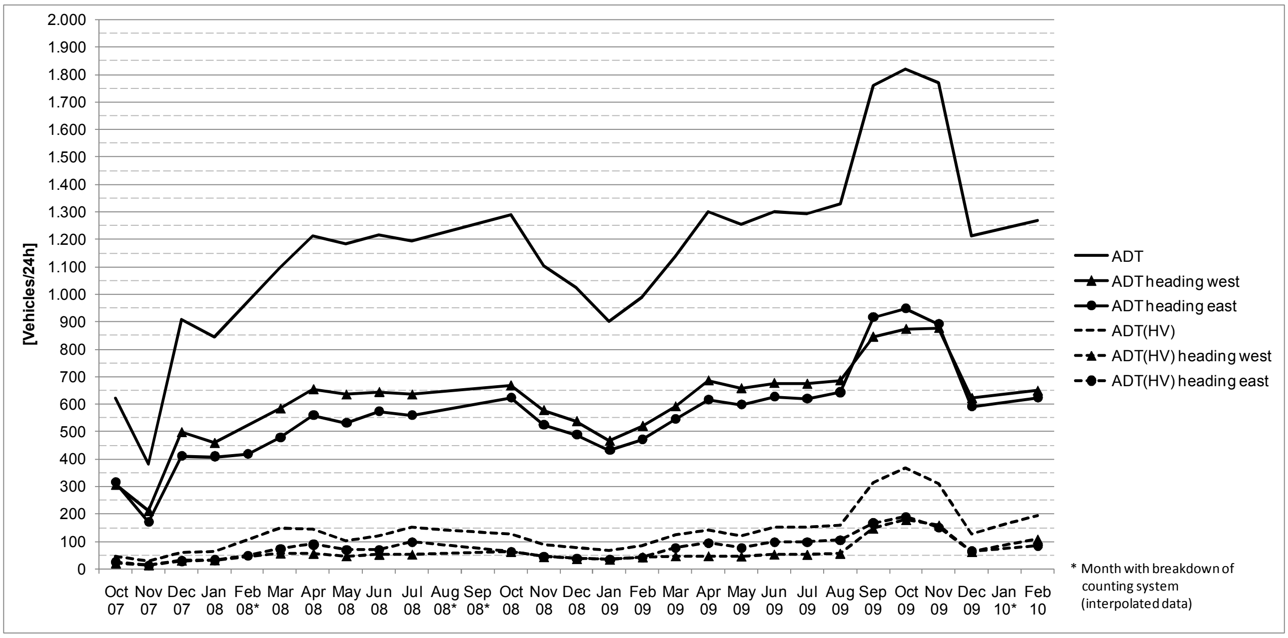


Figure 13 – Vehicles per 24h, mean per month (ADT = average daily traffic / HV = heavy vehicles > 3,5 tons)

5.3.2 Laboratory frost-heaving tests

The FHT data can be evaluated by the ‘relevant frost-heaving speed’, the ‘heaving after freezing’ (maximum heaving) and the ‘heaving after thawing’ (remaining heaving). Here these indicators are referenced to a sample height of 125 mm. The relevant frost-heaving speed is defined by the absolute difference in heaving between day 7 and 8 of the test. A minor relevant frost-heaving speed means lower risk of frost-heaving, because the feeding of water from the subgrade and the formation of ice lenses has been concluded. Limits for a rating of the frost sensitivity do not exist, thus the rating from the quite similar Austrian FHT will be used for orientation. To rate a sample as frost resistant, the relevant frost-heaving speed has to be less than 1 mm/d and the maximum heaving has to be less than 15 mm.

The relevant frost-heaving speeds are at low levels for all tested materials. They are 0,14 to 0,44 mm/d for the gravel subbase materials and 0,04 to 0,25 mm/d for the frost blanket course materials respectively. There is no relevant or systematic difference between the materials with or without RC-materials or natural aggregates respectively, see figure 14.

The absolute heaving after freezing and thawing for the frost blanket course materials is higher than for the gravel subbase materials. For RC-materials with 10, 20 and 30 wt % of bricks (Section 1, 2 and 3) the absolute heaving increases with the percentage of bricks. Lower frost heaving has been measured for the materials with 40 wt % of bricks (Section 4) and the materials with natural aggregates (Section 0 and 5), see figure 15.

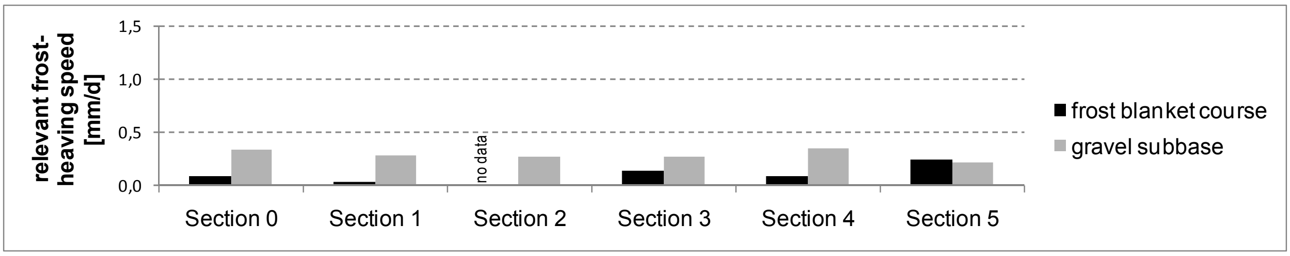


Figure 14 – Relevant frost-heaving speed

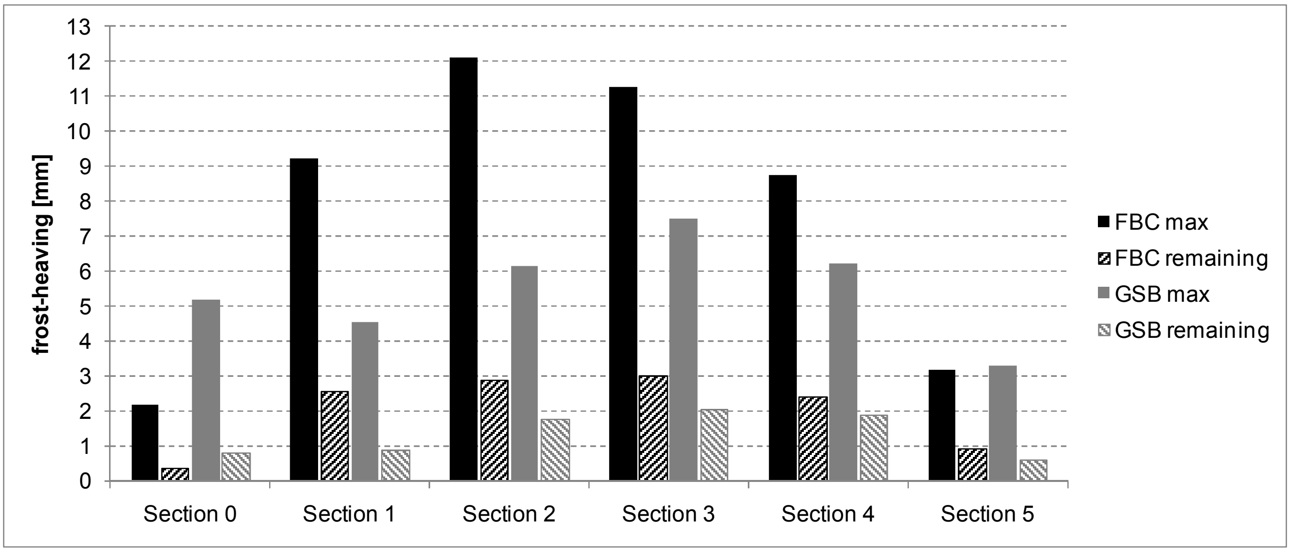


Figure 15 – Maximum and remaining frost-heaving
(FBC = frost blanket course material / GSB = gravel subbase material)

The California-Bearing-Ratio (CBR) before and after freezing has been measured on all RC-materials (Section 1 to 5). Figure 16 shows the changing of the CBR and the initial values (before freezing). Systematic trends cannot be identified and there is no correlation between the brick content and the change in CBR value.

Therefore the assumption that higher brick content has relevant influence on the frost-heaving sensitivity of unbound layer pavement materials cannot be confirmed.

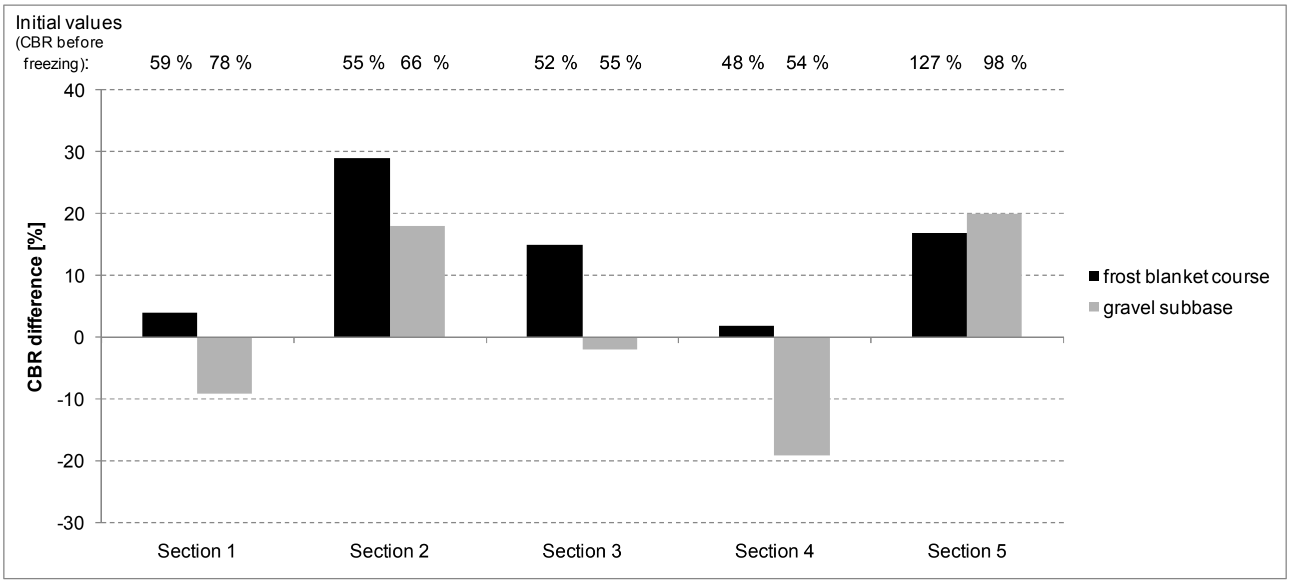


Figure 16 – CBR difference before and after frost-heaving test

5.4. Bearing capacity

The change in bearing capacity during the observation period has been monitored by FWD and Benkelman-Beam measurements. In the following, the FWD measurements will be discussed. The Benkelman-Beam values show the same trends.

Figure 17 shows the backcalculated elastic modulus E_{Sub} of the unbound subbase (gravel subbase and frost blanket course as one) for the measurements in autumn and spring.

The backcalculation has been done by using an iterative approximation algorithm for the measured deflection basin. The bearing capacity of section 1 to 4 is distinctly higher than the bearing capacity of the sections with a proportion of natural aggregates (section 0 and 5). The elastic modulus E_{Sub} of section 0 and 5 complies with known values for unbound layers [7]. In section 1 to 4, E_{Sub} decreases with increasing brick content. Because E_{Sub} of section 5 is lower than E_{Sub} of section 4, both have 40 wt % brick content, it can be concluded that the amount of crushed concrete in the mixture is decisive for the level of subbase elastic modulus.

The seasonal changing of the subbase elastic modulus, as well as the absolute change are dependent on the brick content and the crushed concrete content respectively. With a decreasing crushed concrete content (section 1 to 4), the range of E_{Sub} decreases.

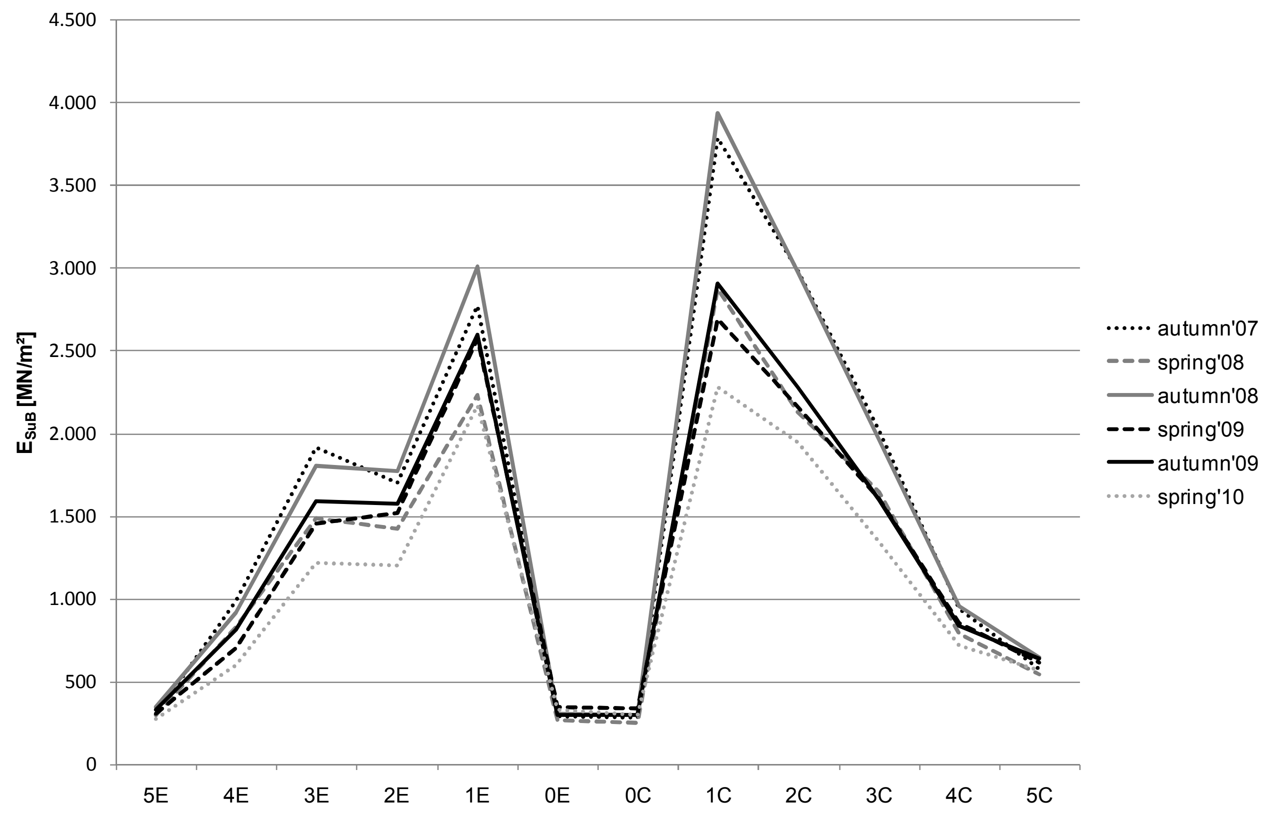


Figure 17 – Development of the elastic modulus of unbound subbase E_{Sub}, backcalculated from FWD deflection basins

5.5. Surface distress

Some distinctly and visible transverse cracks occured after the superior winter period of 2009/2010. Drill core evaluation in summer 2010 showed that these cracks only occur in the asphalt layer and are not continued in the unbound layer. The softening point ring and ball and the needle penetration have been tested at the extracted bitumen. Both indicators show a superior aging of the bitumen. Therefore cryogen stresses in the asphalt layer can be assumed as being the cause of the transverse cracks.

Furthermore, alligator cracking has been found in section 5E. The FWD measurements showed a massive loss of bearing capacity at this station. Drill core evaluation showed that the reason for the cracking was an undercut of more than 2 cm in the planed asphalt layer thickness.

All detected surface distresses are not induced by the use of RC-materials with a high brick content in the unbound subbase layers.

6. CONCLUSION

The measured climate and traffic data show that the conditions for a representative evaluation of the suitability of unbound pavement layers with RC-construction materials with a high percentage of bricks are given.

After three years of observation under climate and traffic impact, there were no surface distresses due to the use of RC-materials. The bearing capacity measurements with two testing systems show that the sections built exclusively with RC-materials have a significantly higher bearing capacity than the sections built with natural aggregates. The observed brick content plays a secondary part, while the content of crushed concrete is primarily relevant for the level and seasonal change in the bearing capacity.

The sections with natural aggregates and the sections with RC-materials do not show any relevant frost-heaving. The measured heaving is about 2 mm and therefore harmless for the pavement construction. The laboratory frost-heaving test results show that the frost sensitivity of all tested RC-materials is not superior. The maximum and remaining frost-heaving of the frost blanket course materials is higher than the values measured for the gravel subbase. The frost-heaving of the mixtures with exclusive RC-material is higher than for the mixtures with natural aggregates.

All evaluated data show that RC-materials with a high brick content are suitable for use in unbound pavement layers. The limit of 30 wt % brick content derived only by laboratory tests has been approved.

ACKNOWLEDGEMENTS

The author would like to thank the *Brandenburg State Office for Roads* for planning and building the test track and *Brandenburg University of Technology, Chair for Soil Mechanics and Foundation Engineering* for the installation and maintenance of the in situ sensors and coordination of the measurements.

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