PRACTICAL EXPERIENCES AND GENERAL PRINCIPLES FOR HYDRO ACTIVE TRAFFIC AREAS IN GERMANY

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SUMMARY

Permeable pavements have been used in Germany since the 1970's. Since that time, extensive measurements were collected from these pavements at numerous construction sites, which resulted in a so-called "technically regulated construction method" in Germany.

The SF-Kooperation, the leading association of international concrete material manufacturers, has been engaged with this subject matter from the very beginning. It plays a decisive role in collecting and implementing scientific knowledge into practice by supporting relevant research projects and through development of appropriate products for the concrete pavement industry.

The purpose of this paper is to reflect the scientific-technical and practical experiences primarily from the German point of view. It will describe the theoretical fundamentals and the proven practical implementation of the standards for permeable pavements made of concrete paving stones. Discussions will continue to be stimulated within the international community.

1. INTRODUCTION

The development of permeable paving stone systems is connected to the increased population density since the 60's in Germany. Within three decades, land development almost doubled in size. The sealing of urban areas, the direct flow of rainwater into channels and the artificial straightening of rivers resulted in flooding and damages to the environment. This problem was recognized already in the 70's and rainwater management had to be reevaluated. The solution was to locally infiltrate rainwater to drain to ground water– the decentralized infiltration.

The development of standards for permeable pavements in Germany is based on regional soil and climate conditions as well as on technical requirements and experiences for road construction using paving stone systems.

Limitations for the system are given by several factors, such as the permeability of the soil, distance to ground water, traffic loads and ground water protection and the regional morphology.

2. EXPERIENCES WITH DESIGN RAIN AMOUNTS AND STATISTICAL EVALUATION IN GERMANY

The question of design rain amounts for permeable pavements is the consideration between economic efficiency of the investment and the toleration to allow flooding. For the dimensioning of infiltration

without storage possibilities, short-term storm peaks are of interest since statistically the rain intensity lessens with the length of a rain event.

2.1 Design rain amounts

Based on this consideration, the design rain amount in Germany has been set for a rain intensity of a 10-minute rain event every 5 years for a regular infiltration without storage capability.

For the construction of permeable pavements an instruction guide was published [3] in 1998 which standardized rain amounts for all of Germany. These were based on rain statistics from the year 1940. To simplify the calculation, an average value for all of Germany was set at 120 l (sec x ha). The value was based on the higher rain amounts experienced in Southern Germany. This average value was than projected with a time factor to 5-year rain events. This procedure was the basis for the design value of 270 1(sec x ha) for permeable pavements.

In 1997 a very extensive and unique rain evaluation was introduced - the KOSTRA-Atlas. Precipitation events were statistically evaluated over a longer observation period and by using a larger number of rain recorders. This atlas provides rain data with a much higher accuracy compared to previous observations. The new rain documentations show that the assumption of 270 l (sec x ha) was chosen to be too high in many parts of Germany. In some regions the assumption was correct, and in very few cases the rain amounts were higher.

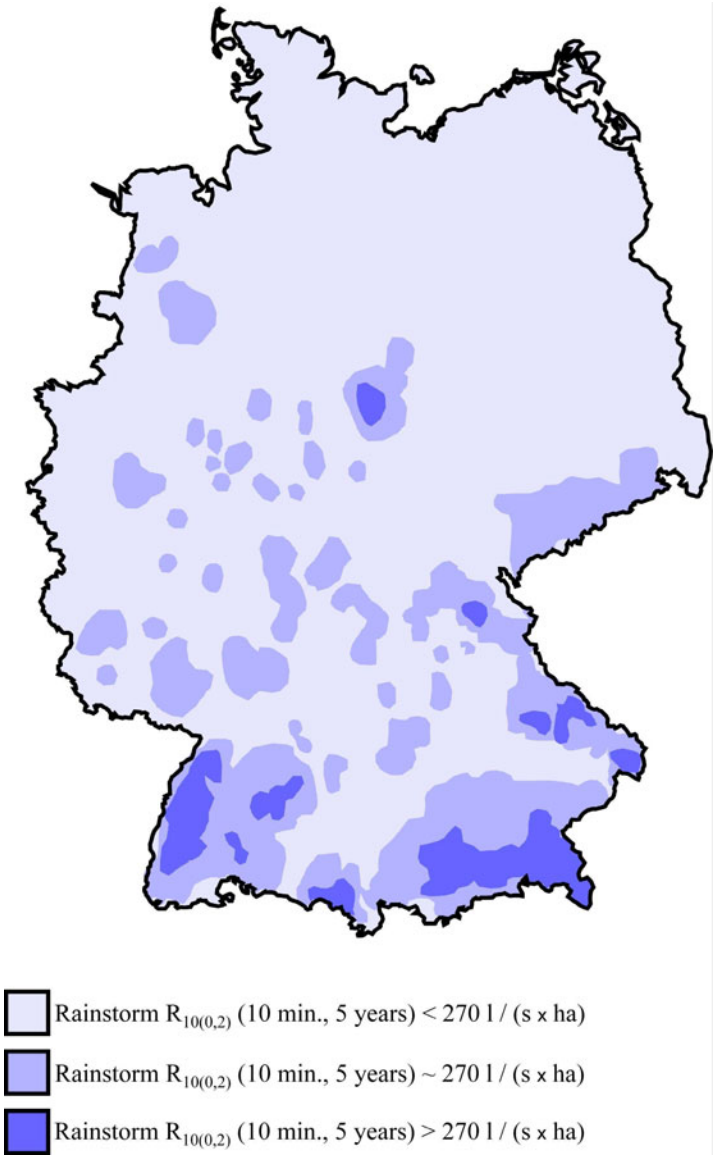

Figure 1. Map of rainstorm regions in Germany with threshold at 270 l/s x ha)

3. DECREASE OF INFILTRATION CAPACITY OF PERMEABLE PAVEMENTS

An important understanding of long-term observation is that the infiltration capacity of permeable pavements decreases over time [BORGWARDT] [8]. Sediment deposits and post-compaction of the base layers can contribute to this effect.

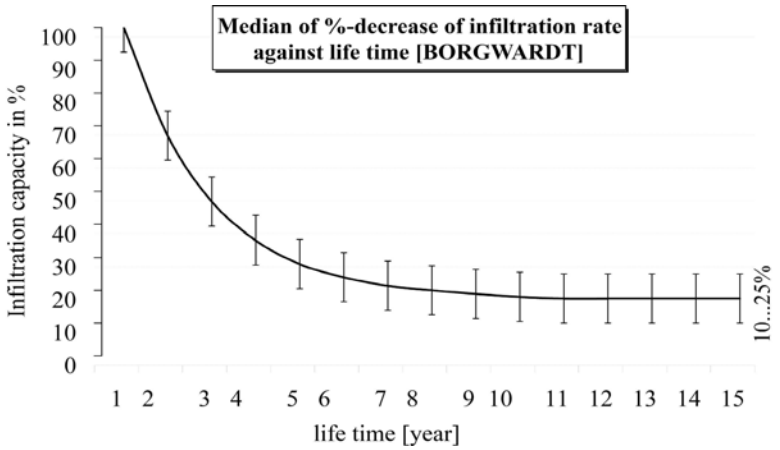

Figure 2. Median of 5-degree of infiltration against life time [BORGWARDT]

The extent that infiltration decreases depends on many single factors and cannot be calculated in advance. According to the German Guidebook [3] permeable pavements are considered to be a drainage facility and additional drainage features (trenches, ditches etc) must be provided. Due to the decrease in permeability, only 50 % infiltration must be taken into account, based on the design rain amount of 270 l/(s x ha).

For the other 50%, separate drainage measures with a storage capacity or runoff capacity of 135 l/s x ha must be provided. That is the reason why qualified permeable pavements are constructed with very high infiltration rates to begin with. However, the demand for separate drainage facilities is rarely implemented in practice.

On behalf of the Ministry of Environment and Nature Conservation of North Rhine-Westphalia, the technical college Bochum tested various publicly funded permeable pavements for drainage capacities [9] after periods between 4 and 7 years in the ground. From a total of 23 objects, 49 single readings (from yards, parking spaces, driveways) were taken using a drop infiltrometer. A special focus was directed to pavements made of porous concrete paving stones.

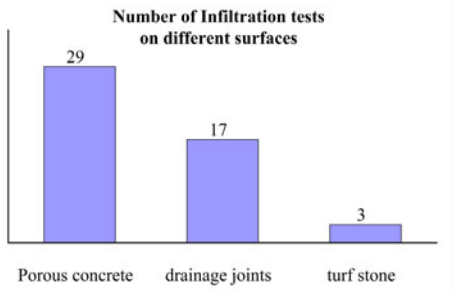

Figure 3. Number of infiltration tests on different surfaces

From the measurements taken, 21 of the 23 objects performed better than what was required.
At four single tests no sufficient drainage amounts were measured, because of:

- The use of a fine joint material (210 l/s x ha), installation error
- Moss-covered joints (90 l/s x ha)
- Lanes, tracks (100 l/s x ha)
- Deposits of dirt from neighboring gravel area (0...60 l/s x ha)

Neighboring areas with varying noticeable contaminations were compared to determine the influence of dirt. As expected, considerably lower infiltration rates were measured on the soiled surfaces. An explanation was given, that moss respectively vegetation grew in these shady locations. Also deposits of dirt particles from neighboring areas had a partly sealing effect.

A further item of this investigation was to determine the influence of water content in the pavement and in the base layers for measuring the permeability. At dry conditions, the permeability was between 1,030 and 1,200 l/s x ha, whereby at the weather-induced wet areas only a permeability of 210 respectively 260 l/s x ha was measured.

4. EFFICIENCY OF PERMEABLE PAVEMENTS WITH RESPECT TO INFILTRATION RATE

From the legal point of view, the sufficient infiltration capability is the criterion for the functioning. With insufficient infiltration rates, the advantages of permeable pavements are being challenged very quickly. However, even lower infiltration rates have advantages through ground water recharge, lesser need for sewage systems and the improvement of micro climate.

Since precise rain data is available in Germany [1], a certain region was chosen to determine the efficiency of a permeable pavement with up to 50% (135 l/s x ha) permeability based on the statistical heavy rain data and the yearly average rain amount.

From the intensity of the 5 to 45 min. heavy rain events the rain amount of 135 l/s x ha was split off and converted with the duration and frequency of the rain to a total sum in mm/a.

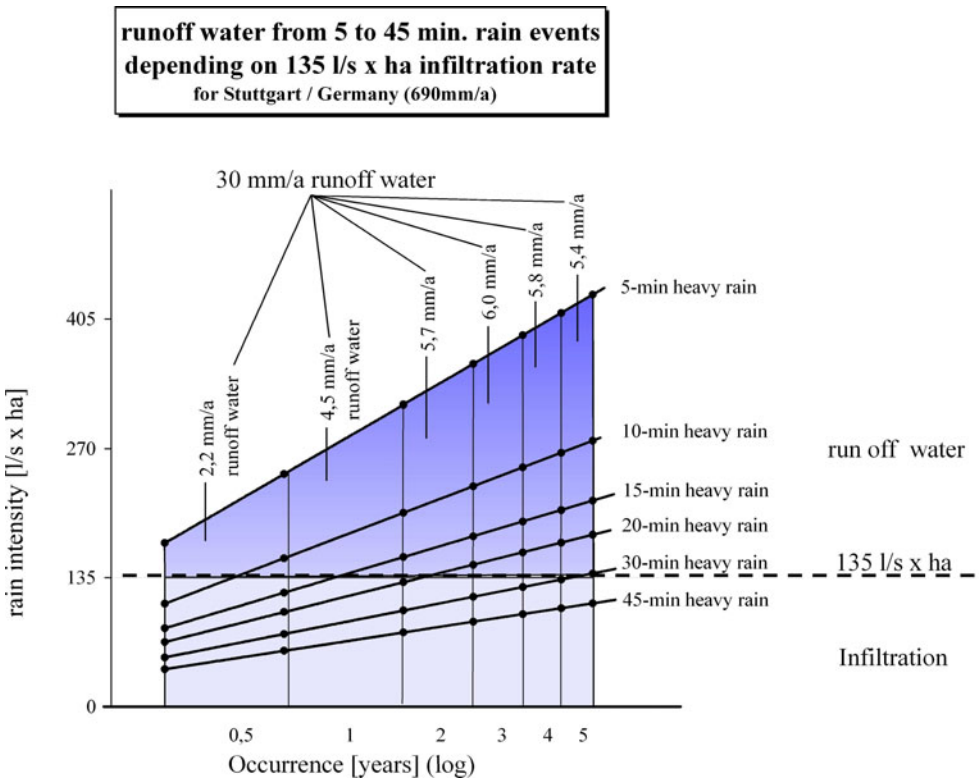

Figure 4. Conversion to mm/a of non-draining heavy rain amounts with a frequency up to 5 years based on an infiltration capability of 135 l/s x ha

The sum of >135 l/s x ha of falling rain and therefore run-off per year for this region is approx. 30mm/a. The average yearly precipitation in this region is 690 mm/a.

$$\text{Efficiency} = 100\% - \frac{30\text{mm/a}}{690\text{mm/a}} \cdot 100 = 95.7\ \% \quad \text{(Equation 1)}$$

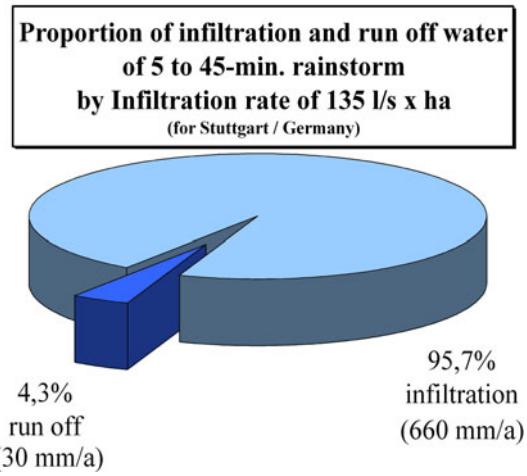

Figure 5. Proportion of infiltration and runoff water of 5 to 45-min. rainstorms by infiltration rate of 135 l/s x ha (for Stuttgart/Germany)

The efficiency of a just 135 l/s x ha permeable pavement is still 96%. Further consideration of the effectiveness with dependence of various infiltration capabilities, infiltration rates in the ranges of 25%, 50%, 75% and 100% were calculated based on the requested infiltration capabilities and the effectiveness based on the previous rain data example:

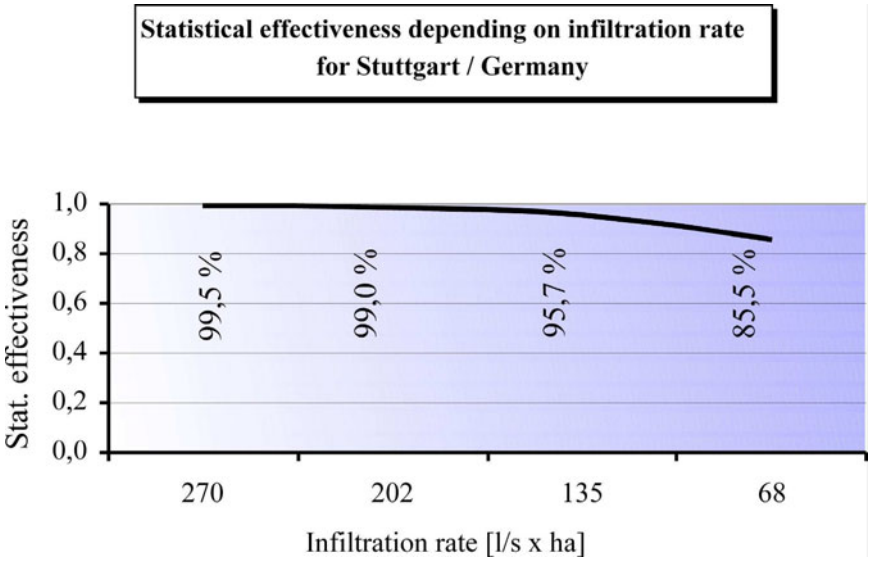

Figure 6. Course of effectiveness based on different infiltration rates)

A reduction of infiltration to 50% of the requested infiltration rate increases the danger of local flooding to 50%, but the environmental advantages remain.

5. VSCIENTIFIC DISCOVERIES AND APPROACH FOR INFILTRATION OF SOILS (MODEL ATTEMPT, CALCULATION PRINCIPLES, MITIGATION FACTORS)

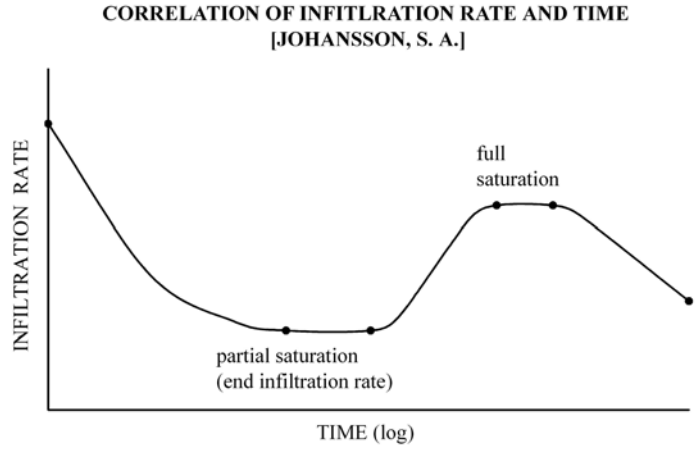

Figure 7. Course of infiltration rate through partial saturation and full saturation in dependence of time, according to JOHANSSON, S.A.

The basics for the calculation of permeability are determined by the ratio of flow velocity for a specific area in dependence of the hydraulic slope $k_{f\,in}$ m/s [DARCY].

DARCY's law however, describes a gross simplification of complex flow processes of fluids flowing through a porous medium. Flow velocity is unsteady through the porous medium. Factors such as saturation, infiltration amount, and the existence of air pockets (partial saturation, full saturation) play a variable role [4]. Further influential factors, such as surface tension, soil density and bacterial growth affect the flow velocity.

A severe reduction of infiltration results from influential factors, such as traffic related post compaction and the entering of sediments. The post compaction especially on permeable pavements is caused by the concurrence of optimal moisture content and traffic loads. [PROCTOR].

5.1 Theoretical permeability

For various soils and particle size contributions, the permeability can be estimated in advance. Many researches have dealt with the permeability of soils [CASAGRANDE, HAZEN, BEYER, CAMPBELL, JOHANNSON and others]. A common method to estimate the infiltration rate from sieve analyses was published by BEYER [5] for gravel and sand (non-cohesive soils):

$$kf = 0{,}0116 \cdot U^{-0{,}201} \cdot d^2_{10} \qquad \text{[Equation 1]}$$

U = Coefficient of uniformity in relation to particle size *d* during sieve test 60 respect. 10 % d_{60}/d_{10}
d_{10} = particle size at 10% sieve test

5.2 Reduction caused by entrapped air

These values relate only to saturated conditions. Entrapped air in the soil reduces the drainage capabilities. The effective drainage rate of partially saturated soils therefore needs to be adjusted by a correction factor of $k_f/2$ for sand and gravel. For crushed minerals a correction factor of $k_f/4$ should be used.

5.3 Reduction of permeability due to fines

As a result of higher shear forces, base layers consisting of crushed mineral aggregates are the preferred material used for road construction compared to sands and gravel. However, the content of finer particles (<0.063mm) increases when using crushed mineral aggregates during the compaction process. This concentration is even higher than when using sands with a rounder aggregate shape. Fine components are of great importance to increase shear forces and therefore for the load bearing performance. But they have a negative effect on the infiltration capacity and increase the tendency of sealing the surface.

For permeable pavements the fine components with less than 0.063 mm should therefore be limited to 3 weight% for crushed rock and to 5 weight% for gravel base layers.

6. PERCEPTION AND EXPERIENCES OF BASE COURSE COMPACTION

One of the influences for the water permeability of soils is the degree of compaction of base layers. It is known that higher compaction energy can almost eliminate permeability in layers of sands and gravel.

Compaction energy happens during the construction process. Also through the dynamical loads of traffic, a constant post-compaction takes place. Test results have shown that often base courses block the infiltration. Heavily trafficked pavements made of conventional paving stones even show strong compaction in the bedding [11].

The willingness for compaction of base courses depends on many factors (particle shape, surface of particle, aggregate size, water content etc.). Bringing together all influential factors to make a recommendation may be very complex and possibly not practical.

The compaction requirements for permeable pavements are of mediocre standards due to the limitation of traffic loads to protect groundwater. In Germany, the base courses require – depending on the utilization of the pavement – a proctor density of close to 100%. Experienced construction personnel are often responsible for the implication of the requirement. Aside from compaction rollers, there are also handheld compaction devices with an overall compaction control available, whereby the compaction control occurs during compaction.

In many instances, the construction crew is doing the load bearing control. The deformation modulus E_{v2} as well as a ratio value from two readings is herewith determined. Rarely is the proctor density established. In most cases, the achieved compaction is higher than requested, and the deviations are of acceptable terms. The required permeability of the base courses is very rarely tested.

The scientific perspective between compaction of base layers and permeability has not been researched sufficiently so far. In reality however, sufficient permeability is achieved when the trade rules are followed, when qualified material mixes and gradation are used and the limitation of fine particles is <3% and the base is not overly compacted.

To understand the dependence between compaction and permeability of base layers, a large-scale test is presently under way collecting data from four research institutes. After reaching a statically value, these test results will be evaluated.

7. CONSERVATION AND IMPROVED ENVIRONMENT IN GERMANY

In almost all German states, state laws demand local infiltration of rain water wherever locally feasible. Groundwater regeneration as well as the improvement of the micro climate are top priorities. Using the groundwater as an intermediate storage area, peak flows of naturally flowing waters are greatly reduced. Groundwater regeneration also has a positive effect on flora and fauna.

Protection of the groundwater as an ecological product and a “food item” is a top priority. Rain runoffs from trafficked pavements have relative high concentrations of substances, especially heavy metals and organic substances when compared with runoff from non-polluted surfaces.

The filtering effect of permeable pavements and the underlying bases have not been satisfactory tested yet. At the University GH in Essen, the retention of heavy metals was compared between a pavement with crushed coarse aggregate and turf pavements with a micro organic surface layer. It was discovered that the following heavy metals**:** Cadmium (Cd), lead (Pb), copper (Cu) and zinc (Zn) were retained within the pavements with drain joints by only about 1/4, compared to turf pavements with 3/4. One can reasonably assume that harmful substances enter groundwater through permeable pavements that lack intermediate storage.

To limit the entering of harmful substances into the groundwater, the use of permeable pavements in Germany is limited to low trafficked areas. These are: roads and parking spaces of residential streets with mainly automobile traffic and little truck traffic, parking lots, industrial areas and subordinated pavements such as agricultural roads, drive ways, walk and bicycle paths and plazas. In water protection and extraction areas the use of permeable pavements is only permitted at the external protection zone of the area and only for walk and bicycle paths.

8. CONVERSION OF THEORETICAL KNOWLEDGE INTO PRACTICE

The more scientific knowledge, experiences and perspectives on construction methods gained, the more complicated it becomes to summarize all conditions under one easy and general rule. Germany did very well so far in formulating regulations and recommendations for road construction by using various construction systems. However, they became very complex and immense to be used for all different applications.

To transform these requirements, architects, engineers, concrete manufacturers, contractors and installers, have to fulfill their duties. On the part of the industry, different associations published recommendations and instruction manuals, which helped planners and contractors to understand the complex regulations. Also the readily availability of relevant products (concrete stones, base, bedding and joint material) is guaranteed in sufficient quantities.

The transformation of requirements by the planner and contractor for construction projects are only successful if one of them understands the thematic and can recognize mistakes immediately. There are no control functions for planning and execution by authorities Germany.

The largest hurdle for a qualitative implementation however is the kind of order placing for public orders and the present competition pressure in Germany.

8.1 You get what you pay for

There are always companies who can offer products and services to better conditions as professionals with competent experiences. Because of “empty pockets,” many customers are forced to accept the cheapest offer.

It is also common to provide certificates of the material used, however there is hardly any control exercised by the builder. Exemptions are larger construction projects where professional engineers are hired as planners.

To counteract this trend, an association was founded in 2003 to certify construction work. With this measure, the industry hopes to improve quality in planning and execution of concrete pavements, also for permeable paving stone systems.

9. CONCLUSIONS

The construction method for permeable pavements has grown in Germany as the result of experiences and knowledge and is presently technically controlled. The development of the most important experiences and also the current reversal experiences are described within this paper.

Almost all concrete product manufacturers in Germany have permeable paving stone systems in their delivering program as standard products. All material necessary for the construction method are available everywhere and are economically reasonable. Many of the completed projects are functioning very well. The number of construction defects and mistakes are within reasonable borders. The quality of constructing pavements however is spoiled by faulty care in planning and execution, especially through high competition pressure. The demand for control and its execution as well as lasting continuing education of planners and constructors would result in a higher quality of the construction.

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