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Segmental Paving for Job Creation and Township Development Upgrading

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Segmental paving with concrete block paving (CBP) is a very efficient improvement for township development upgrading. The paving of residential roads, parking and pedestrian areas provides a low-cost and long-live hard surface with little or no maintenance. Because of minimum skill and equipment needed it is moreover creating employment opportunities within community housing projects.

Especially for township development the use of permeable paving is an important contribution to a sustainable and environmental useful management of drainage systems. Moreover the handling of stormwater runoff from sealed traffic areas is less complicated and more affordable when it is decreased considerably by the application of infiltratable pavements. There is a wide range of benefits to meet negative ecological effects, such as floods, overstressed drains, pollution of waters, and dropping ground water level. And there is a remarkable reduction of costs for the overall drainage of pavements with new building projects.

Since it is a design criterion for both construction and drainage, the accurate application and the knowledge of the infiltration performance of permeable CBP is of important significance during the service life of a road construction. This leads also to adequate proposals for monitoring and maintenance to achieve a long lasting infiltration performance on a high level.

1 Concrete Block Paving

1.1 Introduction and Importance

Segmental paving with blocks is the oldest design method for hard surfaces in road construction. It proved itself everywhere, where one has to consider at the same time load-bearing capacities, aesthetics, ecological aspects and cost-efficiency. With concrete paving blocks the field of application is very multifaceted because of different shapes, colours and surfaces of the blocks and therefore an efficient instrument in low-costing and long-living housing developments. The market for concrete block paving is worldwide strongly growing. For example in Germany as the biggest market, the development leads to approximately 240 m^2 paving blocks each year with a market share of 75 % with hard surfacing in urban areas. In addition, German research shows that the construction costs of low-cost projects like cycle tracks or similar with concrete block paving is up to 20 % less than with premix asphalt paving [1]. With yearly maintenance costs concrete block paving is even up to 50 % less expensive. And that besides that CBP can be aesthetically more pleasing and structurally superior.

1.2 Products and Areas of Application

Available paving block systems can generally be divided into blocks for industrial or high traffic usage, for design and aesthetical valuable needs in residential areas and into ecological effective paving blocks.

Paving blocks with a high load-bearing capacity are used in industrial areas or high-traffic roads. They are regularly 100, 120 or more millimetres thick are have shapes with interlocking effect for high structural performance particularly regarding the load transmission. Design paving blocks are regularly quadratic or rectangular with special emphasis on colour and surface retexturing and a thickness of regularly 80 millimetres. Finally ecological paving blocks are designed particularly with regard to rainwater infiltration and can be applied in all before mentioned fields with high traffic as interlocking shapes or in residential areas as rectangular blocks.

Concrete block pavements are very versatile and can be applied in almost all streetscape areas up to roads with a speed limit of maximal 60 km/h [20] and with a traffic load with a maximal of approximately 100.000 equivalent 10-tons-axles per year. This includes among others main and residential roads, car parks, industrial sites and domestic paving.

The construction with concrete block paving is more labour-intensive than capital-intensive than with alternative methods of surfacing [12]. It creates employment within community housing projects with minimum skill and equipment needed and is therefore for example attractive to township development upgrading.

1.3 Requirements and Design Aspects

The requirements for concrete paving blocks in South Africa are given in SANS 1058 and for the good practice in construction in SANS 1200 MJ [14]. The structural design regarding for example the subgrade found on site, the materials and thickness of the load-bearing base layers, the laying pattern of the paving blocks and the drainage of the surface is crucial for the successful long-term performance of concrete block paving.

Each pavement has to be designed to suit the particular need and sometimes up to the highest stresses out of heavy traffic. By that means the subgrade as well as base layers and surface has to

be compacted. The specific compactive effort depends on the soil found on site, especially on the permeability which can in some local areas as well mean on the frost susceptibility.
The base layers are regularly unbound but compactable granular layers with a traffic-related thickness, usually between 150 and 300 millimetres. The aggregate mixes for the base courses should have a particle size from 0 to 32, 45 or 56 millimetres. The structural design of the layer's thickness can be determined by different concepts. Catalogue design methods with standard classes of traffic volume, traffic type and climatic conditions can be sufficient with basic paving jobs. For more challenging projects research-based or computer-based design methods like the LOCKPAVE programme [13] should be used.
The paving blocks are laid in a bedding sand layer. This is a 20 to 30 mm layer usually of sand or gravel with a particle size of 0 to 4 or 5 millimetres. After laying, the blocks are compacted into the bedding layer and the joints between the blocks have to be completely and permanently filled with a fitting material like sand or gravel 0 to 2 or 3 millimetres. Ideally the jointing sand is fine plaster sand containing a little clay or silt [13].
The laying pattern allows a certain aesthetic appearance but is also determined by the structural requirements. The best resistance to both horizontal and vertical deformation is the herringbone pattern. Laying patterns with crossing joints or longitudinal joints in traffic direction are not possible on pavements with vehicle traffic.
The segmented paving is always integrated between edge restraints with in situ cast. These are holding the paving blocks in position and prevent horizontal creep and the subsequent loss of integrity of the pavement.
One of the most important design elements of the concrete block paving is the surface drainage. Usually the precipitation is led from the preferably even surface by 2 to 3 % cross fall into the next gutter. Together with the necessary stormwater structures like channels, pipes and other drainage facilities the drainage is the most expensive part of the pavement. Here, a more cost-efficient alternative is the use of Permeable Concrete Block Paving.

2 Permeable Concrete Block Paving

2.1 Permeable CBP as a Part of Road Drainage Systems

One significant effort of infiltration management is to relieve overstressed urban sewer systems from surface runoff of roads and other impermeable paved areas. Because Sustainable Urban Drainage Systems have high demands on land use, the application of permeable pavements is an important contribution to proper and cost-effective road drainage.
The design of drainage systems needs constant factors for dimensioning, i.e. the possible output or infiltration rate because of a present permeability. With permeable pavements the infiltration performance is decreasing over its service life due to the entrainment of mineral and organic fines into the hydraulic system which normally provides the constant data for the permeability. In other words and as it is stated in chapter 1.3: the clogging of the pores of porous concrete blocks or aggregates used in joints is leading to an irreversible reduction of water permeability and infiltration performance. Consequently the application of permeable CBP is more a method of reducing surface runoff rather than a controlled drainage system [8].
Nevertheless – although not managed drainage system – permeable CBP still have a considerable impact on the run-off process of the entire catchment area. Due to the fact that part of the rainfall is retained, this part is not added to the run-off total. This means reducing the total amount of

rainwater in the drainage facility and in addition dampening the run-off peaks because of its delaying effect [22], [6]. But for a appropriate application of permeable CBP and for the use as a supporting part of drainage the exact development of the infiltration process, the lasting infiltration performance and its dependence to the interacting factors have to be known.

2.2 Design Storm, Infiltration Rate, Permeability and Surface Water Runoff

For the hydraulic design of drainage systems the design storm as the input quantity for the dimensions of sewers as well as for the infiltration capacity of the permeable pavement itself has to be considered. The precipitation events are characterized by their four components of amount, intensity, duration and frequency. For the design procedure the value r describes the specified amount of water the pavement or a drainage facility has to be able to capture. In the following consideration the value r is measured as a rainfall with 10 minutes duration occurring once a 5 years ($r_{10\ (0,2)}$) in the dimension of millimetres per minute [mm/min] or litre per second and hectare [l/(s×ha)] [18]. A heavy storm for example with $r_{10\ (0,2)}$ has normally around 400 to 600 l/(s×ha) or 2.4 to 3.6 mm/min. In direct relationship stands the infiltration rate i as the amount of water – to result from a particular design storm – which can be retained or absorbed by a reservoir or a permeable surface.

The permeability k in meters per second [m/s] expresses the velocity of liquid in a porous medium in water-saturated conditions and accordingly is an attribute of soils or aggregates. A certain permeability k has to be made available e.g. by joint fillings or base courses to absorb a certain design storm. For design reasons the permeability k_u in unsaturated regions – like with aggregates for pavement structures – has a lower velocity and applies to the empiric relationship $k_u = k/2$ [12].

The specific peak runoff coefficient of a pavement as the quotient of the maximum surface runoff to maximum rainfall measure is important for the hydraulic design of the connected road drainage. A low runoff coefficient of a permeable pavement e.g. during intense storms indicates a good infiltration.

2.3 The Reduction of Permeability Due to Surface Clogging

Due to the entrainment of mineral and organic fines into the pores of porous concrete blocks or into the aggregates used in joints or openings, the irreversible reduction of water permeability can be assumed. Research results show that the infiltration performance decreases in the order of the power to ten after a few years [1], [4], [5]. The findings also are confirmed by additional authors [17], [19], [21]. These fines are based mainly on particulate emission, traffic-caused abraded particles and organic substances from surrounding areas.

These results are confirmed by in-situ field tests with a special infiltration-meter. This instrument measures the infiltration capacity in the laid condition with no disturbance and gives immediate results, taking into consideration local conditions such as age and traffic-load [8]. The infiltration curves are shown as regression curves of the averaged infiltration values. These tests can be continuously repeated to observe the long-term performance.

These tests show especially a significant relation between infiltration and age. The studies states moreover that the long-term in-situ infiltration performance and its observed decrease depends from the grain size of the aggregates used for joint filling. It is further more partly induced by the ratio of openings of permeable pavements respectively the pore size of porous concrete blocks [5].

The overall conclusion is that although permeable concrete block pavements cannot drain a traffic area entirely, they can still have a considerable impact on the run-off process of the entire catchment area. Due to the fact that part of the rainfall is retained, this part is not added to the runoff total and it can dampen the run-off peaks because of its delaying effect. In view of a overloaded sewer system this is of considerable ecological importance since the overload can be reduced by permeable concrete block pavements thus also avoiding discharge into the receiving water with the accompanying pollution. The respective relation between surface run-off and actual infiltration means for the hydraulic sizing of a drainage system that a more precise design method can be applied [9].

3 Types of Permeable CBP and Recommended Areas of Application

3.1 Permeable Paving Blocks

Available permeable concrete block pavers can be divided in (1) porous concrete blocks, (2) permeable concrete blocks with widened joints and (3) permeable concrete blocks with drainage openings [11].

Porous concrete blocks are permeable within themselves because of a increased volume of pores. The rainwater can be absorbed and passed on by the paver. Due to the point for point bonding of the relatively coarse and narrow particle gradation aggregate with the reduced cement paste the compressive strength is shortened with increasing permeability [16].

Permeable concrete blocks with widened joints are provided with separate and loosely-attached or with integrated and permanently affixed spacers that allow joints usually between 15 and 35 millimetres. Although for design reasons often found with grassed joints a high infiltration performance is only achieved when the joints are filled with coarse aggregates. The only benefit with grassed joints is a high degree of retention of precipitation [6].

Permeable concrete blocks with drainage openings are mainly developed from conventional formats with additional openings in the paver or at its side. These drainage openings can be in form of holes, hollow spaces, cavities or chambers. Usually a proportion of 10 % of opening ratio is achieved. Here again, the openings have to be filled with aggregate mixes permeable to water in order to achieve a permanent infiltration capacity.

3.2 Recommended Areas of Application

If a traffic area is to be paved the selection of a certain block paving type, surface structure or colour is mostly decided for aesthetic and design reasons. However, the choice of a permeable block paving system must be decided first and foremost on functional grounds and thus according to the traffic load to be expected, secondly because of the preconditions for a high-performance and long-term drainage and eventually for the aesthetics [10].

Taking this into consideration porous concrete blocks should – because of the reduced load bearing capacity as opposed to non-porous concrete block pavement – only be applied with lower traffic in terms of traffic quantity and traffic load, like private residential areas or on less loaded road construction.

With slightly higher traffic loads permeable concrete blocks with widened joints can be used – but only with integrated spacers. Due to the large joint width that weakens the horizontal load transmission, these systems can bear average loads, but can be used for parking areas with less traffic frequency.

Permeable concrete blocks with drainage openings can be utilized with heavy load traffic especially with interlocking formats. That means that they can be used for higher traffic loads up to residents-only streets.
Apart from the infiltration performance the kind of pavement system to be applied depends considerably on the traffic load to be expected. Permeable block pavement systems are suitable for a wide variety of residential, commercial and industrial applications but primarily for the use in areas of stationary traffic. When the interlocking effect is achieved pavement systems with drainage openings can also be used for the moving traffic in residential and residents-only areas. In particular due to the often simpler drainage possibilities (neighbouring areas of vegetation) and due to the more level surface structure, concrete pavers of porous structure can mainly be used in the less trafficked areas, on bicycle lanes and sidewalks and in the private-home environment.

4 Application and Design Considerations

The proper drainage of traffic areas for not only the surface but also the pavement structure and formation has to be considered as a major element already in the planning stage. When using permeable block pavement systems, an increased appearance of water in the construction has to be taken into account. The drainage of road surface water requires a road construction open to infiltration, with the layers being constructed according to standards, as well as a sub-base and subgrade open to infiltration. In addition, it has to be observed that even in the case of heavy rainfall a proper drainage of runoff from the road surface and into the drainage installations provided is granted. For traffic areas, it is therefore necessary to keep to a minimum cross inclination even in the case of permeable block pavements, but in order to reduce runoff; this should be at 1 % [18].
In order to be able to take in the required design storm $r_{10\,(0,2)}$ of for example 200 to 300 l/(s×ha) damage-free and without any additional measures and in order to be able to pass it on quickly, the subgrade and the sub-base need to show a permeability of at least 5×10^{-5} m/s for the performance required according to the bearing capacity with the corresponding required compaction. The permeable soil layer has to have a thickness of at least 1000 millimetres [18].
The thickness measurement of the construction is determined on the one hand by the traffic load and on the other hand – if needed – by the required thickness of the frost-proof base. The determination of these two required values is done independent of the construction method and is thus also applicable to construction methods with permeable block pavement surfaces [10]. If the subgrade exhibits a sufficient permeability of 5×10^{-5} m/s, the base can be dimensioned in dependence on the traffic load according to standard design.
If the subgrade does not offer sufficient permeability, the base course can be increased up to a permeability coefficient of 5×10^{-6} m/s by making allowance for additional thickness due to unfavourable drainage conditions and frost impact. If the subgrade is even less permeable, it either has to be improved or the water infiltrating through the block pavement surface needs to be deviated within the road structure to the sides of the layers, directing it to drainage installations (drainage pipes, gravel-filled drain trenches) in order to let it drain in areas with a higher degree of permeability. Thus, the use of permeable block pavement systems is extremely costly with a given permeability of the subgrade of less than 5×10^{-6} m/s or 5×10^{-4} cm/s and can only be recommended in exceptional cases. The determination of permeability can be done at the location by means of infiltration tests according to the Open-End Test [23], [8].

The requirements for the natural aggregate mixes to be used for the base course and frost protection layers as regards water permeability are once again derived from the intake of the required design storm of 200 to 300 l/(s×ha). Taking into account the required compaction which has to be kept for reasons of load bearing performance in dependence of the traffic load, the natural aggregate mixes to be used have to exhibit a permeability of at least 5×10^{-5} m/s after construction.

Usually, both requirements can be fulfilled if the course of the grading curve is in a lower range which means to limit the fines at a maximum of 5 mass-% [10]. In case of fewer requirements as regards load bearing performance and compaction capability, neighbouring particle sizes can be combined, leaving out the zero grades. Particular attention has to be directed towards keeping the filter stability. The determination of permeability is fixed locally by means of infiltration tests with the above mentioned infiltration meter.

The necessary permeability of the joints depends on the amount of drainage openings and on the natural aggregate mixes being used. This can be calculated on the basis of an approximate determination of the water permeability of a mineral substance according to the gradation [3] with a given amount of joints. In order to achieve maximum stability, the bedding should consist of the same natural aggregate mix as the joints, or at least determined according to a qualified filter rule.

The infiltration capacity of the surfacing is the factor that limits the water intake. The infiltration can only occur through the joints and drainage openings filled with natural aggregates or through the pores. For the selection of the adequate block pavement system and in order to achieve a permanently optimal infiltration of the required rainfall measure of 200 to 300 l/(s×ha), the permeability of the pores or the natural aggregate mix of the joints or drainage openings needs to be increased accordingly, thus, the entire block pavement area needs to exhibit a permeability of at least 5×10^{-4} m/s in dependence on the share that has to be absorbed. Generally, this value can only be achieved by using gravels with particle sizes of 1/3 or 2/5 mm [11]. Other particle like sands and crushed sand/crushed gravel mixes up to 0/5 mm can only be used for infiltratable pavement if they are suitable. These natural aggregate mixes are generally suitable if the amount of particles to be washed out is reduced. This, however, requires control checks of the complete compliance with the demands after construction.

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