CONCRETE PAVING BLOCKS - CORRECTLY APPLIED
DESIGN HINTS AND PRACTICAL TIPS FOR THE SUPPLY, ACCEPTANCE AND LAYING OF CONCRETE PAVING BLOCKS

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1. INTRODUCTION

In the Federal Rupublic of Germany over 70 million, possibly even 80 million, square metres of concrete block paving is laid each year. The statistical figures indicate only about half as much because the official production statistics do not include manufacturing plants with fewer than 20 employees on the payroll. It is known, however, that more than half the manufacturers of paving blocks have fewer than 20 employees.
These figures mean that for each inhabitant of the Federal Republic between about 1 and 1.5 square metres of new block paving is installed year after year.
The principal applications are on residential roads, pedestrian precincts and frontage roads; also industrial and private car parking areas, railway platforms, yards, terraces, garage driveways, etc.

In the Federal Republic an increasingly clear-cut distinction is made between two classes of paving block.
On the one hand, there is so-called industrial paving consisting generally of interlocking blocks, rectangular or hexagonal, but without any special surface finish or pattern, i .e. not coloured nor with a textured surface on one face.
On the other hand, there is higher-grade paving with special surface finish or pattern and generally coloured. This class of block now constitutes something like 20 to 30 per cent of the total output and is primarily used by private consumers, but also by public authorities for all manner of improvement to the outdoor residential environment.

Although the use of concrete paving blocks has been successfully established for many years now, there unfortunately still often occur misunderstandings between client and contractor and between designer and block manufacturer. In many cases such misunderstandings are due to lack of understanding of each other's position and to lack of detailed knowledge.

This article aims to improve the situation.

The Bundesverband Deutsche Beton- und Fertigtei1 Industrie (Federal Association of the German Precast Concrete Industry) has, for some years now, issued Technical Redommendations for the supply and for the laying of concrete roadmaking products. Along with Standards and other sets of regulations these recommendations have received general recognition and embody a large proportion of the suggestions contained in the present article.

2. Product range and general design suggestions

According to their shapes, concrete paving blocks can be classified fairly simply as follows:
square, rectangular and hexagonal blocks, furthermore interlocking blocks in the following shapes: S, T, Uni, V, WM, WV, X (cross), Y and Z.
In addition, there are a number of "paving block systems" in which a paved area has to be formed with various shapes of block which are specially adapted to one another, for example:

- rectangular/square block paving systems
- octagonal/square block paving systems
- round block paving systems
- curved block paving systems

All sets of blocks for curved road alignments are likewise to be ranked as block paving systems.
With regard to the surface of the paving, a distinction is to be made not only between coloured and uncoloured blocks, but also and more particularly with regard to surface finish, e.g.: normal or fine-textured aggregate exposure by washing, sandblasting, flame treatment, roll ered or textured finish.
The shape, colour and surface finish therefore determine the appearance of the paving block. The borderline between "paving block" and "paving slab" is not sharply defined.
The designer must, however, be aware of the general principle: the stouter and more compact the shape of a paving block element the greater is its load-carrying capacity.
Thus, in the case of heavily loaded industrial block-paved areas the length-to-thickness ratio of the blocks must not be more than 2:1. For pedestrian precincts which may carry occasional motor traffic the German guideline recommend keeping this ratio below 4:1.
Concrete slabs, as distinct from blocks should be used only for pavings which will not have to carry any other than pedestrian traffic. (For slabs the length-to-thickness ratio is commonly between 6:1 and 8:1).

What matters more than choosing the right thickness of the paving element is choosing the right shape, more particularly the appropriate length-to-thickness ratio.
On industrial paved areas, for example, the wheel loads may be more than twice as large as those due to normal road traffic. This severe loading is caused by solid rubber tyres under

loading is caused by solid rubber tyres under which the contact pressures may be as high as 20 bar, whereas the contact pressure exerted by pneumatic-tyred road vehicles is limited to 10 bar under the relevant statutory regulations.

The higher the vehicular loading to which it will be subjected, the more sensitive is the paving to defects in the sub-base and to the consequences of laying the blocks with too narrow joints.

In the great majority of cases, when the precast concrete elements suffer damage, even when they are of^perfectly good quality, this is due to technical defects of the sub-base or the laying course (bedding) or to incorrect 1aying.

When there is insufficient oil in the gearbox of a machine, damage will inevitably occur. There is a similarity with this situation when the joints in a block-paved area are too narrow. An expert will, in the former example, detect lack of lubrication as the cause of damage; in the latter he will begin by checking the strength of the blocks themselves.

A few words must be devoted to the fall, or gradient, to which concrete block paving should be laid. This is something which, like many other technical details, will have to be contractually agreed with the firm that carries out the work. In general, a minimum fall of 2.5 per cent is sufficient.

This figure, however, relates to the resultant of the longitudinal and the transverse fall. This means that, for example, where large areas have to be provided with adequate water run-off and there is a straight cross-fall in two directions from a peak in conjunction with a longitudinal gradient, a correspondingly reduced percentage of slope can permissibly be adopted for the longitudinal and transverse fall components.

3. Layout of paved areas

In urban road construction, but also in the paving of privately utilized areas, increasing importance is attached to layout and design arrangements for improving the appearance of the roads and pavings concerned.

It is important that the materials used for constructing the paving be judiciously suited to the adjacent buildings and to the intended purpose for which the paving is to be used, to the cost of constructing it and to the interests of those who are responsible for its maintenance.

From the pedestrian's point of view a paved area may be either too smooth (slippery) or too uneven. With regard to goods traffic it may be too liable to suffer damage; from the road cleaning point of view the paving may be awkward, and it may present problems when trenches for underground services have to be dug and subsequently filled in. And from the town planner's point of view it may be aesthetically unsatisfactory in relation to adjacent buildings.

Hence there are many design consideration to be faced, in connection with which the laying of the paving must take account of the material itself, the surface texture, the pattern formed by the joints, the colour and the contrasting effects of colour and texture.

On the other hand, it is necessary to caution against overrating the importance of any design features, for the following reasons:

- In general, the paved area is viewed by road user only under a very low angle so that, for example, large patterns are mostly not noticed.
- Only on wet surfaces do colours really show up to advantage at low viewing areas.
- In dry weather it is not so much the differences in colour as the contrasts between light and dark features or contrasts the roughness or texture that are observed.

Contrast effects should, so far as possible be manifested under all weather conditions i.e., both dry and wet; therefore it is advantageous to vary rough concrete surfaces with normal ones, also - and more particularly if they are coloured. In this way more effective solutions are obtained than by relying on colour contrasts alone.

The pattern formed by the joints, or the joint spacing rhythm due to the use of different shapes and sizes of blocks or slabs, can likewise be utilized for achieving lasting contrast effects.

If coloured blocks or slabs are used, “warm” shades are preferable, i.e. “earth” colours such as brown, red, reddish or yellowish-brown .

Purely colour-based contrast effects are, however, obtainable with black and white blocks possibly also with black and red ones, when on an even concrete surface no lasting contrast effects are obtained with, say, black and grey or red and grey materials.

In making decisions relating to the design of pavings it is often not sufficiently considered that, regardless of how appealing the pattern on a coloured plan may appear, it will not show to advantage when viewed from the pedestrian's eye level.

Finally, it should be considered already before designing the paving whether it will be laid by hand or by mechanized methods. (An analogy: even a ready-made garment may turn out quite satisfactory; but if requirements are pitched higher, it will be necessary to have it made to measure.)

Particularly with mechanized laying of any paving elements it is preferable to use blocks provided with 1.5 - 2.0 mm thick spacers.

Here are a few more design tips:

paved areas should be provided with linear drainage, if possible. If point-type drainage is employed, the paving blocks in the vicinity of the inlet gully should be laid in dry

premixed mortar.
Paved areas must not be designed with too pronounced recessed portions, otherwise there will be a risk of spalling at the edges thereof.
Sets of blocks intended for laying to curved alignments of the paving are available in many types of interlocking block, and their use is appropriate and effective in many instances, including more particularly the construction of paved areas for motor vehicular traffic.

It should be remembered, however, that from the viewpoint of paving structure such assemblies of special blocks always constitute a "foreign body" in the surrounding block paving because these blocks have been cast in special moulds, usually at a different time from the other blocks (with all the concrete-technological consequences of this).
Besides, such blocks are difficult to replace correctly in position if they have to be taken up for access to services below. Accordingly, for the paving of footpaths and cycle tracks in the present preference is to employ rectangular or interlocking blocks in narrow strips without "specials" for forming curves, the width of the strips being suited to the radius of curvature, while the transverse interlock of the blocks between adjacent strips is omitted (Odenwalder bond).

4. Quantities of blocks required

The quantity of paving blocks or slabs needed for a particular job will of course depend on the area to be paved, taking account of the joints, the number of joints being dependent on what system of block or slab paving is used.
It is therefore appropriate to calculate the cost per square metre of block or slab paving taking account of the joints for purpose of contractual arrangements between precast concrete manufacturing plant and construction materials dealer. For the supply of paving blocks this procedure is now standard commercial practice and has proved satisfactory. It offers the advantage that the number of units required is constant for any particular block system and takes account of all dimensional deviations allowed in the individual block subject to compliance with the relevant Standard.
Table *2* gives the quantities per square metre of paved (as-laid) area for a few commonly used types and systems. These figures are based on information supplied by the manufacturers and may vary even within the individual system, depending on the laying grid. The rectangular block with nominal dimensions of 10 cm x 20 cm (actual 96 mm x 196 mm) and a grid of 1.00 m, for example, requires 50 blocks/m^2. However, if the grid is 1.01 m, the corresponding quantity will be 48 blocks/m^2.
The so-called TT interlocking block type requires 36 blocks/m^2 for the 1.00 m and 35 blocks/m^2 for the 1.01. m grid.

5. Construction and acceptance of pavings

Unfortunately for all parties involved, any objections to the appearance and material properties of concrete paving blocks are generally raised only after the blocks have been installed. Yet at that late stage it is in fact only the block-laying workmanship itself that can properly be judged, since the quality of the products supplied should have been checked immediately on delivery to the site. The criteria applicable to such checking are primarily that the consignment delivered indeed conforms to what has been ordered and that the blocks look satisfactory on expert visual inspection. If there is doubt whether the blocks supplied conform to those ordered or whether they are of the desired quality, laying the blocks must not begin until the position has been clarified.
For example, if major differences in colour or other defects causing doubts as to what can be tolerated or justifiably expected are detected already on arrival of the blocks or, at the very latest, on laying them, then the job supervisor will, either on his own responsibility or after immediate consultation with the client, have to decide whether or not to accept the blocks. In the latter case the supplier of the blocks will promptly have to be informed of the rejection.
With regard to colour variations in concrete paving blocks see also the guidance note (Merkblatt) "Coloured concrete products in road construction" issued by the Road Research Association (Forschungsgesel1schaft fur Strassen- und Verkehrswesen), 1985 edition /7/, /5/.
Paving blocks which, having been delivered to the site, are rejected on account of, for example, unacceptably strong variations in colour or other noticeable defects must of course on no account be laid.

6. Assessment of coloured blocks

In connection with the acceptance of coloured concrete road construction products there often occur differences of opinion arising from the appearance of the as-laid paving. Unfortunately, defects detected at this stage are often bound up with criteria of individual taste and therefore very difficult to assess objectively. Whereas a worm-eaten antique wood surface, for example, is usually rated as "attractive", and variations in the colour of natural stone are regarded as pleasingly enlivening the appearance, similar phenomena on a concrete surface often give cause for complaint.
Coloured concrete products for road construction, however, are mass products made from natural materials which, even with all due care and monitoring of the factors liable to affect colour, may be subject to colour vari ations.
There are numerous factors that can cause such variations, namely, the natural colour of the cement, the grading of the aggregates, the

natural colour of the aggregates, the water-cement ratio, the pigments, the curing conditions and the age of concrete.

Many of these factors can be modified, but only within certain limits so far as some of them - such as the colours of the natural starting materials - are concerned. They cause variations which are liable to be different from one production batch to another. Also, within any one given shade of colour they may differ in intensity according as the causal factors act together to strengthen or to cancel one another.
Such colour variations cannot be accurately measured by simple means. Hence the only way to judge them is by visual inspection. This being so, agreements relating to the desired colour of the product can apply only within the context of such variations inherent in the manufacturing process, and any samples are always only to be regarded as examples.

In the case of paved areas which have lain already for a relatively long time it must moreover be borne in mind that the accumulation of dirt and the action of de-icing salts may alter the surface both of coloured and non-coloured paving blocks. In consequence of natural weathering and more particularly mechanical actions to which the trafficked area is subjected, the aggregate particles may in course of time become distinctly visible on the surface of the concrete and affect the overall visual impression by their natural colours.
Different weathering conditions and differences in mechanical action will with all concretes lead to changes in the original colour. This applies also to artificially coloured concrete. Such changes are more quickly noticeable on very light or very dark coloured surfaces, both as regards the brightness and the purity of the colour, especially if the differently affected surfaces are in close proximity to one another.

7. Efflorescence

Efflorescence constitutes a special problem. It often gives cause for complaint, more particularly from private customers who attach particular importance to attractiveness and purity of colour on their pavings.
As a rule, efflorescence shows up only on dry concrete surfaces and then it occurs in varying intensity. In such cases the concrete exhibits lighter-coloured areas and a blotchy appearance. In extreme cases it may be covered by a white coating.
Efflorescence is due to chemical reactions involving the cement, the mix water and the air in young concrete. In terms of concrete technology these reactions are a perfectly "natural" feature of the hardening process. Hence efflorescence in no way adversely affects the physical properties of concrete. On the other hand, there is as yet no infallible means of obviating it in practice.

Chemically it is due to deposits of dissolved calcium hydroxide $Ca(OH)_2$ which, after evaporation of the water and reaction with the atmospheric carbon dioxide CO_2, is precipitated as calcium carbonate $CaCO_3$ on the surface of the concrete. Alternatively, consisting of calcium sulphate $CaSO_4$ or magnesium sulphate $MgSO_4$ occasionally occurs.

As a result of natural weathering and under normal conditions of service the efflorescence tendency diminishes, and the actual deposits are dissolved by rainwater. Generaly speaking, in the case of road construction products any efflorescence will disappear in the first year or two of use.
Calcium carbonate efflorescence can also be removed by scrubbing with dilute acid, e.g. hydrochloric acid (1 : 10), or with cleaning agents commercially available for the purpose. If acid is used, the concrete surfaces should be thoroughly wetted beforehand and be thoroughly washed down with water after another treatment. It should be borne in mind however, that changes in texture and thus of colour may occur in consequence of the dissolving action of the acid on constituents of the fine mortar layer at the concrete surface. When dealing with coloured concretes such treatment must therefore be carried out with particular care in order to avoid lack of uniformity in the appearance of the surface.

8. Suggestions for installation

It is undoubtedly a major advantage of concrete block paving that it does not require any specially skilled operatives for laying it - unlike natural stone paving - but that most work can instead be adequately carried out with semi-skilled labour. All the same, there are a number of rules to be observed, especially those contained in the "Guidance note on block and slab pavings" (1983 edition) issued by the Road Research Association (Forschungsgesellschaft für Strassen- und Verkehrswesen.

With regard to the common mistake of laying the elements with too narrow joints the publication states:
"The blocks should ... be laid with adequate joint width (3 to 5 mm), determined by the grid dimension adopted, on the prepared laying course. With interlocking blocks and other special sizes the laying instructions that may be supplied by their manufacturers should be complied with" /6/.
What is more important than the 3 - 5 mm width mentioned in the above passage is that indication that the blocks should be laid in accordance with the grid dimension. The reason for this is as follows:
Concrete paving blocks in the present state of the art (cf. DIN 18501) may deviate by ± 3 mm from the specified length or width dimension. Even with optimum manufacturing technology there may still be a difference of 2.5 mm in length between the shortest and the longest block produced in a day's output, which is

simply something to be accepted as an unavoidable fact. Only when laying is based on a grid dimension which takes account of the above-mentioned deviations will "adequate joint width", as envisaged in the guidance note, be duly obtained. On a paved area constructed on this principle it will subsequently quite easily be possible to take up the blocks and re-lay them /3/.

Blocks incorporating "integral" spacers are available. The spacers are 1.5 - 2.0 mm thick projections moulded on the blocks. They do indeed prevent laying the blocks cheek-to-cheek, as it were, i.e., with zero-thickness joints, but must not be regarded as a substitute for proper joint width control. In other words, the spacers can serve only as an aid to ensuring the required minimum widths. It remains necessary to work with a laying grid and provide joints of adquate width.

Typical damage attributable to laying the blocks too close together consists of shell-shaped spalling at the upper edges. The systematic use of chamfered blocks can help to reduce the severity of such damage (and this applies also to blocks with spacers), but such blocks must as a rule also be laid with adequate joints.

In the present state of the art the technical requirements for good laying can be certainly complied with when the blocks are laid by hand. When laying machines or tools are •employed, some special requirements must be satisfied.

Therefore it should be decided already at the design stage whether paving is to be laid mechanically or by hand, because in the former case it may be necessary to satisfy additional design requirements. For example, the paved areas will have to be provided with suitable boundaries or be so subdivided that any mistakes in laying the blocks can be systematic-corrected or that cumulative build-up of errors are avoided.

Besides, in comparing manual with mechanical laying, not just the savings in time and cost must be taken into account, but also any difference in the execution of the job. For example, with machine-laid paving the more limited possibility of laying the blocks in conformity with the grid and the reduced compacatabi1ity of a prcompacted sand laying course must be considered. Furthermore, only with laying by hand is it possible to take blocks from different packages simultaneously, which is advisable even when constructing only cement-grey or single-coloured pavings if the paved area is required to look particularly good.

Irrespective of whether manual or mechanical laying is employed, the following sequence of activities constitutes the correct procedure:

(1) Acceptance of the sub-base of the paving with regard to proper construction and correct position and level.
(2) Taking delivery of the blocks supplied and checking their conformity to the order.
(3) Placing and levelling the laying course (bedding).
(4) Laying the first rows of blocks, taking account of the grid dimension, and installing strings in the direction of paving construction and, if required, also transversely to it.
(5) Laying the paving, with due regard to the block manufacturer's instructions.
(6) "Blinding" the paved area with sand scattered over it (to close the joints) and brushing away the surplus sand; these operations proceed continuously with the progress of laying the paving.
(7) Vibrating the paving to bed the blocks, starting from the edges and working towards the middle.
(8) Again "blinding" the paving with sand, leaving surplus sand on the surface for some time, if possible.

Should the joints become empty in course of time, more sand should subsequently be scattered. The premature use of sweeping machines to remove surplus sand may be harmful. Only when the paving has, after being in service for a time, become fully consolidated and the blocks securely gripped at the joints can mechanized removal of surplus sand be harmlessly carried out.

Before blocks are laid, the sand laying course should be correctly placed and finished to be desired surface profile by screeding between screed!ng rails. Sands containing cohesive silty fine particles (with at least 3-5 per cent by weight, or more, of settleable components) are unsuitable for the bedding of concrete paving blocks, as also are, for example, sands which are too fine, ungraded sands, and too coarse mixtures of crushed stone sand and chippings.

Already at the time of laying the first row of blocks it is in any case essential that in the direction transverse to the direction of paving construction the grid dimension associated with the block size and shape is duly complied with.

To ensure properly straight alignments, strings in the longitudinal direction should be provided at distances of 3 m apart, taking particular care that the tranverse joints are correctly at right angles to these guide strings. For large paved areas it will be necessary to have strings in both directions. Proper "squareness", i.e., with the rows accurately at right angles, must be ensured from the very outset, using an optical square, for example. Later, as construction proceeds, squareness should be checked every 1 - 3 m. If hold-ups occur during the job or waviness at the edges or other deviations are detected, the alignment should be corrected, e.g., with the aid of timber battens or steel templates.

If blocks have to be divided to adapt them to the edges of the paving it is preferable to cut rather than split the blocks, especially

if the edges in question are in prominently visible parts of the paving.

9. Vibrating the paving

That the paving must terminate with proper joints at kerbs and at any other edges and built-in features need hardly be emphasized. However, a few comments on the final vibratory compaction of the block paving would seem important:

The vibrators employed should, in accordance with their manufacturers' information, be suitable for the job. They should be fitted with appropriate plate attachments, if necessary.

Some manufacturers recommend using plastic plates on their vibrators when applied to textured blocks. It should be borne in mind that a proportion of the valuable vibration energy will then be lost, however.

Vibrating rollers should not be used for the purpose. Unsuitable vibrators that are too heavy are liable to cause light-coloured borders to appear on the blocks. If that occurs, vibrating should be stopped at once.

Before vibration, the paved surface and the vibrating plate should be cleaned. If possible, vibrating should - especially with coloured and textured blocks - not be applied when the surface is wet, for the movements of air between the vibrating plate and the surface of the paving are liable to cause stains due to accumulations of dirt and dust. These are "ironed onto the surface" under the plate and, like chewing gum, are very difficult to remove.

As an unavoidable consequence of manufacturing technology, and tolerated by DIN 18501, differences in height of + 5 mm may occur between individual blocks. These differences are compensated when the blocks are laid on an uncompacted laying course. With mechanized laying on a precompacted laying course, complete surface regularity is achieved only when the paving is subsequently vibrated.

In principle, vibration should be applied only until the blocks are firmly bedded into the laying course. Any additional vibration, in order to get rid of surface irregularities by sheer force, will cause damage.

On surfaces with different falls (gradients), vibrating should not be continued over their boundaries of intersection. This applies more particularly to the boundaries between concrete blocks laid on a sand bedding and gutter units, etc. laid on in-situ concrete.

From this last-mentioned point it is evident that the vibration of the finished paving is something that should be considered in principle already at the design stage:

for example, pavings should be provided with linear drainage, if possible. Paved areas with point-type drainage may cause difficulties in connection with vibration.

Besides, washing-out of sand is liable to occur in consequence of seepage water outflow in the vicinity of gullies unless the blocks are laid there in premixed dry mortar. Too pronounced convex areas in paved surfaces are also liable to cause problems because of spalling of the edges of blocks under vibration. This is something to watch more particularly on block-paved footways at garage entrances or other places where the kerb has been locally lowered, for example.

10. Summary

Between 70 and 80 million square metres of concrete block paving are laid in the Federal Republic of Germany each year.

The principal applications are in residential roads, pedestrian precincts and frontage roads; also industrial yards, car parks, and paved areas in parks and gardens.

The commercially available range of concrete paving blocks should be scrutinized by the pavings designer with regard to suitability of the products for his particular purpose. Numerous aspects of design and layout have to be considered, but also the interests of the civil engineer, the road user and the road maintenance authorities.

Suggestions are made with regard to the ordering, supply and acceptance of paving blocks and to the assessment of coloured blocks and the occurrence of efflorescence. Finally, some tips relating to correct laying of the blocks, to avoiding mistakes and to the final vibratory compaction of the paving are given and explained.