DESIGN OF CONCRETE BLOCK PAVEMENTS IN FRG

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SUMMARY

In the Federal Republic of Germany (FRG) concrete block pavements (CBP) are in use for decades. An increasing application is to be observed since the early seventies, when pedestrian precincts and traffic-free zones were required not only by the inhabitants of big cities but also of small towns. Nowadays the application on urban streets and industrial areas is of increasing importance.

Since 1986 the structural design of concrete block pavements in the FRG is specified in a thickness catalogue, the standardization "RStO 86". All roads and urban zones are within the scope of this catalogue, whose main specifications are shown.

However, for heavy duty CBP a special thickness design is necessary. An example for the pavement of a container terminal, where the containers are piled up threefold is given as well as for an area which is travelled by very heavy stacker trucks with axle loads of up to 800 kN. These CBP need a thick bound base of even more than 30 cm.

Special caution should be given to the water permeability of this base course in order to prevent frost deterioration in the bedding layer; this could be achieved by a respective base course of No-Fines-Concrete. A recommendation for the structure of this pavement type will be outlined.

1. THICKNESS CATALOGUE

In 1986 the revised thickness catalogue "Richtlinien für die Standardisierung des Oberbaues von Verkehrsflächen - RStO 86" has been introduced in the FRG. Contrary to former standardizations this catalogue is not only applicable for roads but also for urban streets and urban zones. It therefore was an absolutely necessary demand that in this catalogue not only asphalt and concrete pavements should be included but also CBP.

Advantage of a standardization against other design methods is that only those structures are comprised, for which sufficient long-term experiences are available. Further advantage is the ability to select among several suggestions that structure which considers the actual local conditions most promising (Fig. 1).

1.1 Traffic Class

Six traffic classes are considered in the standardization RStO 86, depending on the number of heavy vehicles per day (VB), defined as:

$$VB = DTV^{(SV)} \cdot f_1 \cdot f_2 \cdot f_3 \cdot f_4$$

where : $DTV^{(SV)}$ = average number of trucks with a maximum total weight of ≥ 2,8 t per day (all lanes of the road), when opened for traffic

f_i = factors, considering expected future traffic, number of lanes, width of lanes and slope, respectively.

In the lightest traffic class VI the traffic volume VB results to < 10 and in the heaviest traffic class I (highways) to VB > 1800. The use of CBP is restricted to traffic classes III to VI (medium to very light).

If the traffic intensity cannot be determined for special types of urban streets or paved areas these zones are related to the traffic class by its function (Tab. 2). It is evident that e.g. a pedestrian precinct with heavy loading traffic corresponds to traffic class III.

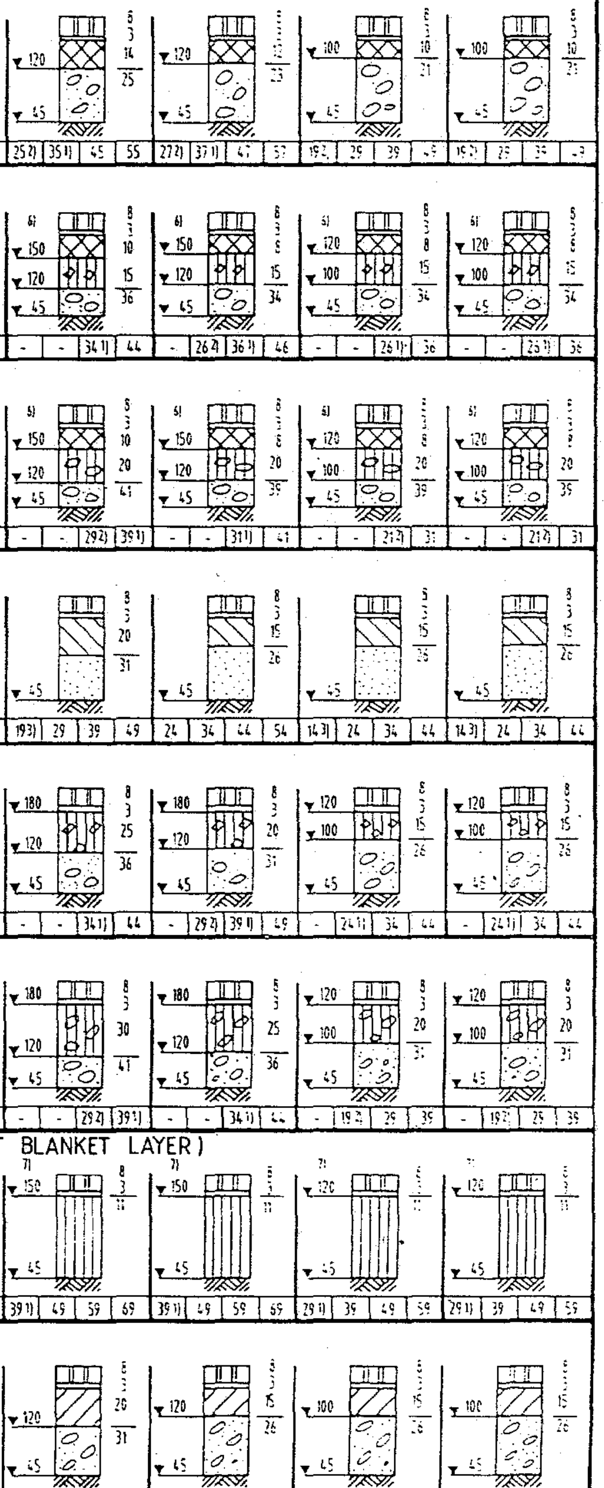
Table 2 : Recommended minimum total construction depth of pavements

Frostsusceptibility Class of Subgrade Soil	Min. Construction Depth Traffic Class	
	I to IV	V and VI
F 2	50 cm	40 cm
F 3	60 cm	50 cm

FIG. 1: STANDARDIZED CONCRETE BLOCK PAVEMENTS

(thickness in cm, ▼ modulus of reaction E_{v2} in MN/m²)

	CLASS	I				II				III				IV				V				VI			
	traffic volume (VB)	> 1800				900 - 1800				300 - 900				60 - 300				10 - 60				< 10			
	construction depth	50	60	70	80	50	60	70	80	50	60	70	80	50	60	70	80	40	50	60	70	40	50	60	70
1	**ASPHALT BASE** (concrete block paving / asphalt base / blanket layer) — depth of blanket layer									25[2]	35[1]	45	55	27[2]	37[1]	47	57	19[2]	29	39	49	19[2]	29	39	49
2	**ASPHALT- AND CRUSHED STONE-BASE** (concrete block paving / asphalt base / crushed stone base / blanket layer) — depth of blanket layer									-	-	34[1]	44	-	26[2]	36[1]	46	-	-	26[1]	36	-	-	26[1]	36
3	**ASPHALT- AND GRAVEL-BASE** (concrete block paving / asphalt base / gravel base / blanket layer) — depth of blanket layer									-	-	29[2]	39[1]	-	-	31[1]	41	-	-	21[2]	31	-	-	21[2]	31
4	**STABILISATION OF SOILS** (concrete block paving / stabilisation of soils / blanket layer) — depth of blanket layer									19[3]	29	39	49	24	34	44	54	14[3]	24	34	44	14[3]	24	34	44
5	**CRUSHED STONE BASE** (concrete block paving / crushed stone base / blanket layer) — depth of blanket layer									-	-	34[1]	44	-	29[2]	39[1]	49	-	24[1]	34	44	-	24[1]	34	44
6	**GRAVEL BASE** (concrete block paving / gravel base / blanket layer) — depth of blanket layer									-	-	29[2]	39[1]	-	-	34[1]	44	-	19[2]	29	39	-	19[2]	29	39
7	**GRAVEL OR CRUSHED STONE BASE (WITHOUT BLANKET LAYER)** (concrete block paving / gravel or crushed stone base) — depth of base course									39[1]	49	59	69	39[1]	49	59	69	29[1]	39	49	59	29[1]	39	49	59
8	**CEMENT TREATED BASE** (concrete block paving / cement treated base / blanket layer) — depth of blanket layer									-	29[2]	39[1]	49	-	34[1]	44	54	-	24[1]	34	44	-	24[1]	34	44



1) round aggregate only when proved satisfactory under local conditions

2) only broken aggregates and when proved satisfactory under local conditions

3) only "mixed in place"

6) for temporary traffic use of asphalt base or if a membrane is required

7) if temporary traffic use of base or a membrane is required an 8cm asphalt base (10cm in class III) should be installed

1.2 Construction Depth

The necessary total construction depth of the CBP depends first of all on the bearing capacity of the base and subbase courses. For this purpose a bearing capacity of $E_{V2} \geq 45$ N/mm² (determined by a plate bearing test) always is required on the formation level. If this value is not to be expected due to poor subgrade conditions a cement stabilization or similar measures to increase subgrade strength should be planned. Besides a certain thickness of the base and subbase courses should be remained, otherwise compaction and bearing capacity on top of base will not be satisfactory. The required thicknesses are shown in Fig. 1, depending on the kind of base. For example, an asphalt base should have a minimum thickness of 8 cm; a frost blanket layer of round aggregates (sand or gravel) in a minimum thickness of 24 cm and of broken aggregates in a minimum thickness of 19 cm may be installed only in areas, where local experiences are available, that the required load bearing value of $E_{V2} \geq$ 100 N/mm² on top will be reached.

Secondly the total construction depth depends on the frost conditions. To determine the necessary frost resistant depth of the pavement the frostsusceptibility-classes of the subgrade F1 (non), F2 (severe) and F3 (very severe) have to be taken into account. Tab. 1 shows the recommended minimum construction depths. The local conditions are to be considered by increasing or decreasing the minimum depth by the following term:

constr.depth [cm] = min.depth [cm] +A+B+C+D+E

where:

A = climatic conditions (3 climatic zones): 0 to + 15 cm

B = vertical alignment (cut, embankment) +5 to -5 cm

C = horizontal alignment; if situated on a north incline: +5 cm

D = water conditions; if ground water level less than 2 m under formation level: +5 cm

E = edge zones paved, drainage conditions: 0 to -10 cm

The total construction depth should be rounded in full decimeters. Under very unfavourable local conditions the increase of the minimum construction depth results to +30 cm, i.e. the total construction depth sums up to 90 cm!

Table 1: Types of road and traffic zones related to traffic class

TYPE	TRAFFIC CLASS
Mayor Road Industrial Street Pedestrian Precinct with Heavy Loading Traffic Bus Lanes in Bus Stations Entries to Truck Parking on Highways	III
Local Distributor Road, Trunk Road Pedestrian Precinct with Loading Traffic Lay By in Bus Stations Parking Places for Trucks and Buses (constantly used) Traffic Zones for Cars and Trucks on Highways	IV
Frontage Road Pedestrian Precinct Parking Places for Cars and some Trucks (constantly used) Parking Places for Trucks and Buses (seldom in use)	V
Frontage Road Parking Places for Cars (constantly used) Parking Places for Cars and some Buses (seldom in use)	VI

1.3 Concrete Block Pavements

The CBP listed in Fig. 1 in dependency of the construction depth are all shown with 8 cm thick blocks and a 3 cm thick bedding course. This is the standard structure; however, rectangular blocks or those of different shapes in a thickness range between 6 cm and 14 cm and a bedding course of more than 3 cm, depending on the kind and size of blocks, are allowed. The respective thickness difference is to be equalized in the frost blanket layer.

The requirements for concrete blocks are listed in DIN 18501 (the maximum block length should not exceed 28 cm, the concrete compressive strength should exceed an average value of 60 N/mm²).

The bedding layer (maximum thickness 5 cm when compacted) should consist of sand 0/2 mm or 0/4 mm or of graded chippings 0/5 mm. A maximum size of 8 mm never should be exceeded. With heavily trafficked CBP the admix of cement or lime to the bedding material (volume content 1 : 8) could be appropriate. However, under severe frost conditions and application of de-icing salt often deteriorations of this treated bedding layers are observed. Decisive for a good long term behaviour of the bedding layer is a functional pavement drainage. Surface water, penetrating in the block joints must be drained off rapidly by a sufficient cross fall (≥ 2,5 %) and a sufficient water permeability of the base courses; this is especially important in the case of cement treated bases.

The listed CBP-structures comprise different types of base courses (bound and unbound). As outlined before the thicknesses are prescribed especially for constructive reasons. Therefore the bearing capacity of these CBP-structures is not always equivalent. However, the planing engineer can select that pavement structure which fulfills the local conditions best: e.g. future service requirements, like capability of rapid repair (unbound base), or temporary bus traffic on the base course during construction-phases (asphalt base), can be taken into consideration.

2. DESIGN OF HEAVY DUTY CBP

The application of CBP on industrial zones, which are travelled by special heavy-duty trucks (high wheel-loads, multi-tyred axles, high inflation pressures), is not within the scope of the standardization RStO 86. A structural design has to be performed in that case.

2.1 Design Method

Most common for this design is the use of multilayer theory. Each layer of the pavement structure is represented by its thickness h, modulus of elasticity E and Poisson's ratio μ. The traffic load Q is acting on the pavement surface, assumed to be uniformly distributed over a circula area with the radius a and respective contact pressure p. To simplify the design procedure the load distributing effect of the concrete blocks with the thickness h_1 can be taken into consideration by an increased circular area of radius $a^* = a + h_1 + d$ with respectively reduced contact pressure p* on the top of the second layer, which should be of bound kind (cement treated) to withstand the high traffic loads. If the bedding layer consists of cement treated sand or mortar its thickness d may be integrated into the CTB; thus only a two-layer-system has to be evaluated (Fig. 3).

The calculation of bending stresses on the underside of the cement treated base due to multi-tyred traffic load can simply (if computer programs are not available) be performed either by means of WESTERGAARD's equations in connection with his influence-curves for radial and tangent moments to consider neighbouring wheels outside of load axis, or by the influence charts of Pickett and Ray [1].

The actual stresses are to be compared with the allowable ones under repeated load; if they are lower, then the pavement under design is satisfactory.

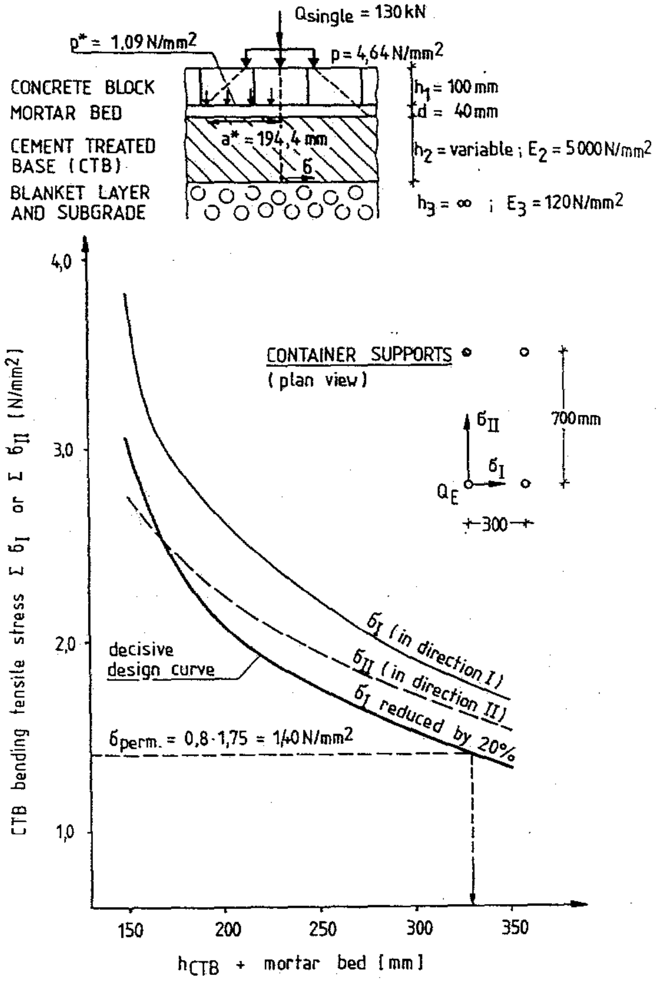


Fig. 3: Concrete block pavement for container terminals: bending tensile stresses at bottom of the cement treated base under container loading

Therefore, an essential precondition is a knowledge of the E-modulus of the cement-treated base as well as of the subbase, subgrade (load plate bearing tests) and of the permissible stresses. Respective laboratory tests, performed at the Munich Technical University have shown, that cement treated bases with a compressive strength of more than 5 N/mm² at the age of 28 days (Proctor cylinder) will have a fatigue bending strength of about 40 to 65 % of the static bending strength even if the aggregates are not in accordance with the German specifications or consist of recycled concrete or asphalt [2,3]. The static bending strength was determined - mainly depending on the cement content (minimum value ≥ 3 % by weight) - between 0,8 and 3,0 N/mm², the modulus of flexural elasticity in the range of 8000 to 20000 N/mm².

Experiences have shown that considering fine structur cracks, which normally are available in cement treated bases, a in-situ-modulus of elasticity of E = 5000 N/mm² and a static bending strength of $ß_{BZ}$ = 1,75 N/mm² are representative values for the design of cement treated bases, which are in accordance with the German specifications ZTVT-StB 86. If no severe channelisation of traffic occurs (like on working areas) the permissible fatigue strength under repeated load is presumed to 0,6 . $ß_{BZ}$; under constant loading the allowable working stress is presumed to 0,8 . $ß_{BZ}$ (e.g. on container terminals).

2.2 Design of Container Terminals

The paved surface of container terminals is exposed to much higher loads and contact pressures than conventional road surface. Containers usually are piled up threefold and own only small supports (Fig. 2). Measurements of the German Railways DB and a theoretical investigation by means of mathematical statistic have shown that with a statistical confidence of 95 % a maximum load of 3 x 173 kN will not be exceeded if 40 foot containers are stacked. This results in a design load under one support of 130 kN and a respective contact pressure of 4,64 N/mm² (Fig. 2).

In Fig. 3 the calculated bending tensile stresses at the bottom side of the cement treated base (CTB), activated under the 4 design loads in direction I and II (nearly identical with the principal stresses) are plotted for a different thickness of the CTB plus the bedding layer (cement treated sand). It is evident that the CTB is exposed to marked flexural stresses. However, it should be pointed out that by means of the simplified design method, outlined in chapter 2.1, the load distribution capability of the CBP is considered only partly: the interlocked blocks, in whose joints fine sand (eventually cement treated) is brushed and vibrated is able to withstand compressive stresses due to an activated bending moment. To quantify this bending moment exactly is difficult; in a rough estimation a reduction of the activated bending tensile stresses by 20 % seems to be adequate, considering the safety redundance inherent in the pavement structure.

It may be inferred from Fig. 3 that with an allowable working stress of 0,8 times the static bending tensile

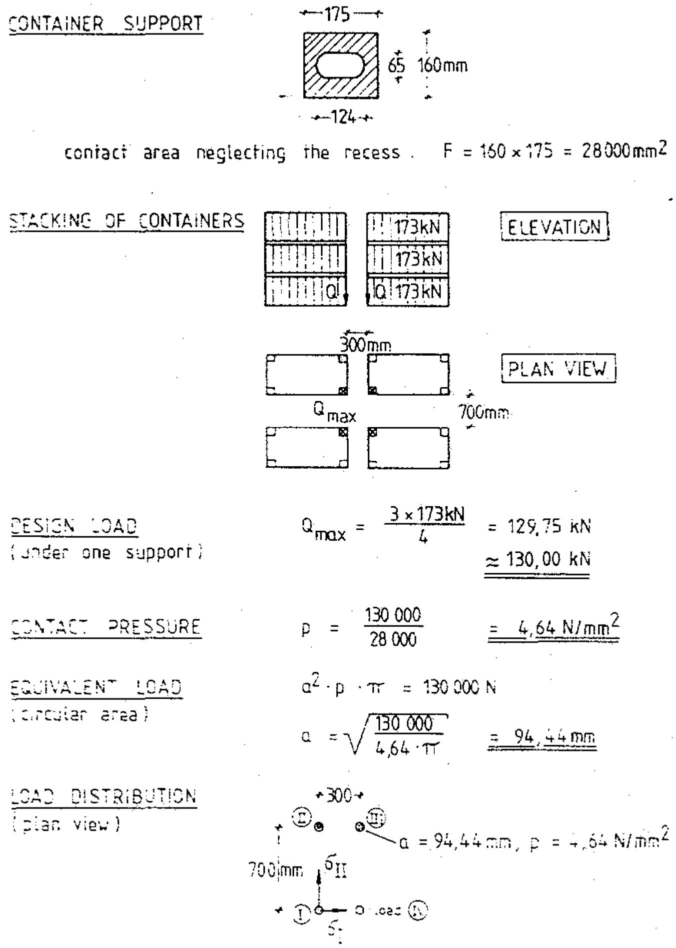


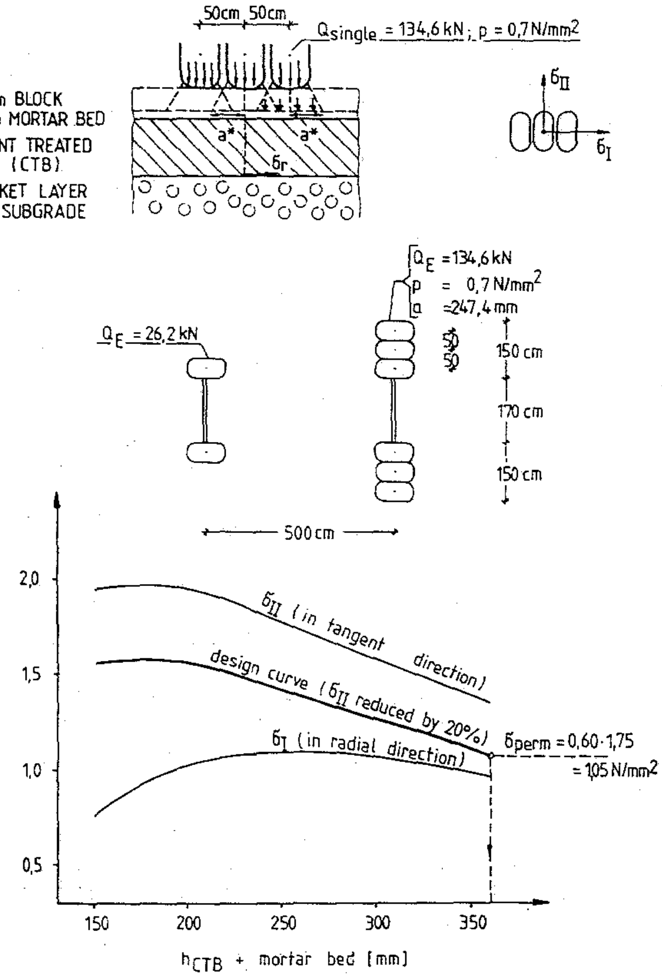
Fig. 2: Container terminals:
load and contact pressures

stress (constant loading) the required thickness of the CTB plus bedding layer results to 33 cm, i.e. the CTB should have a minimum thickness of 29 cm, installed on a frost blanket layer with a bearing capacity of $E_{V2} \geq 120$ N/mm² (plate bearing test).

A further calculation was performed to evaluate the influence of concrete block thickness on the necessary thickness of the CTB. This analysis showed, that an increase or decrease of the concrete block thickness by 4 cm (14 cm and 6 cm blocks) would results under the same design criteria in an about 2 cm thinner and 2 cm thicker CTB, respectively. Hence, by a simple cost-comparison the optimum thickness of the concrete blocks for installation in a most economic structure can be derived. It should be noticed, that the required thickness of concrete blocks is not necessarily a function of the loading: even 60 mm thick concrete blocks are mainly exposed to compressive stresses and are therefore able to withstand heaviest loadings!

3 Working Areas for Heavy Mobile
Equipment

large container terminals normally rking areas are installed which can- t be served by the loading bridge. ese areas are trafficked by very avy stacker trucks with a maximum ading capacity of 35 t. A typical le and tire configuration of such a avy vehicle is shown in Fig. 4; the ont axle is multi-tired (6 wheels th a single wheel-load of 134,6 kN), sulting in a maximum axle load of 7,6 kN.



ʒ. 4: Concrete block pavement: bending tensile stresses at bottom of the cement treated base under very heavy stacker trucks

ε bending tensile stresses at the lerside of the CTB due to this ıffic loading were calculated using ε design charts of Pickett & Ray [1], ιre the contact areas of the wheels ε assumed to be oval with a width of times the length. In Fig. 4 the ıuring stresses in tangent and radial ection are plotted in dependency of thickness of the boundary layer B + mortar bed). Decisive for design the tangent stress, however this stress again may be reduced by 20 % to consider the ability of the C.B.P. to withstand bending compressive stresses.

The allowable working stress of the CTB was presumed to 0,6 times the static bending tensile strength, i.e. $\sigma_{perm} = 0{,}60 \cdot \beta_{BZ} = 1{,}05\ N/mm^2$. From Fig. 4 can be concluded, that a 32 cm thick CTB will meet this design criteria.

2.4 Drainage problems with CBP

An essential precondition for a good performance of CBP-structures, especially under severe frost conditions, is a functional drainage system. On container terminals in general a maximum surface cross-fall of only 0,5 % is possible, as problems with stacking and loading facilities would arise by greater surface slopes (Only if a roof profile surface is chosen and the containers would be stacked in accordance with the centerlines of the combs, a cross fall of 2 % could be accepted). A sufficient number of slotted sewers, designed for repeated loading with heavy vehicles and with a greater inside slope than on the surface, enables to drain off the surface water. Special care should be given to the joint sealing between CBP and abutting sewer. Besides in this area the thickness of the CTB should be increased on a width of $\geq$ 1 m to counteract the occuring load case "free slab edge", as there exists no load transfer device between CBP and sewer.

However, one special drainage problem arises with heavy duty CBP: the required thick bound base in general has a low water permeability. Surface water, penetrating through the joints of the pavement, especially if only a small cross fall like on container terminals is installed, cannot be drained off rapidly. Hence in areas with severe frost conditions heaving and deteriorations of the block bedding layer are caused, mainly if the bedding layer is cement treated and if de-icing salts are in use. This problem could be totally solved by installing a course of porous concrete, the so - called "No - Fines - Concrete" instead of the CTB. This special layer should own a minimum void content of $\geq$ 20 % and a flexural strength of $\geq$ 2,5 N/mm² at 28 days. Experiences in France, where porous concrete is in use in highway and airfield construction for about ten years [4] show that these properties are to achieve by omitting fines, a low content of sand and $\geq$ 80 % of aggregates 5/22 mm. The required cement content is about 200 kg/m³; additives to ensure an uniform cover of the aggregates with cement-mortar are of special advantage. Respective

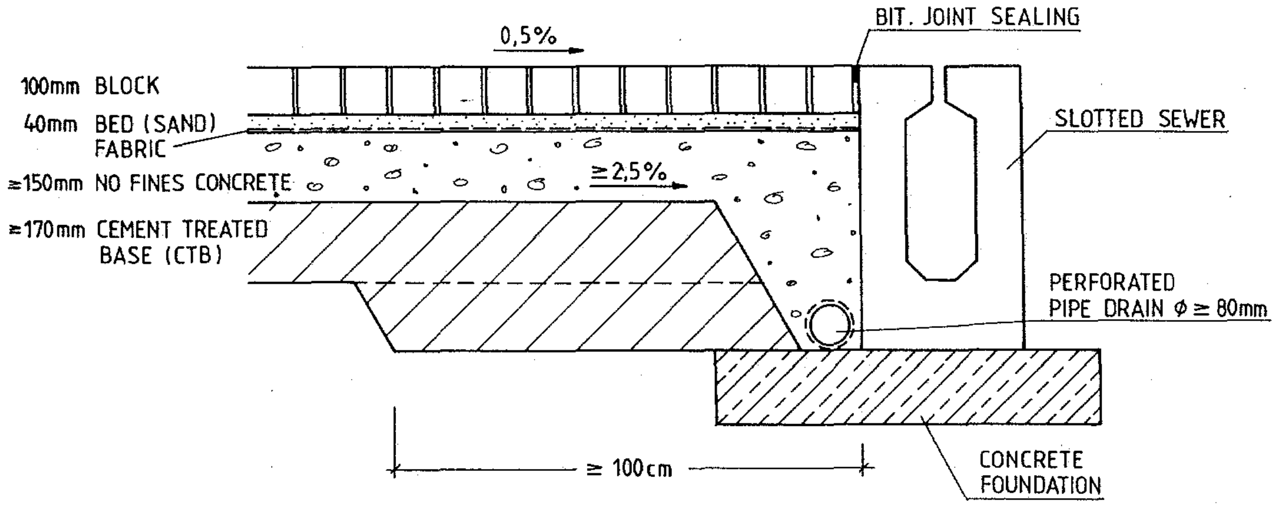


Fig. 5: Heavy trafficked concrete block pavement structure with a base course of No-Fines-Concrete

No-Fines-Concrete can be layed by conventional rail guided pavers as well as by slip-form pavers, however with strongly reduced vibration. As the flexural strength of this No-Fines-concrete is even better than that of a CTB, the designed CTB-thickness may be used for heavy trafficked CBP, i.e. 29 cm on container terminals and 32 cm on respective working areas. A more economical solution would be a structure, consisting of 15 cm No-Fines-Concrete, supported by a CTB in respective reduced thickness but with a crossfall of ≥ 2,5 % (Fig. 5). To prevent erosion of the block bedding layer (sand or cement treated sand) a fabric should be installed in the respective interface. Besides a functional connection between the porous concrete layer and drain pipes is necessary. A good long term behaviour without permanent surface deformations (rutting) is to be expected with this structure.

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