Experience with asphalt pavement on the heavy loaded port area of the "Niedersachsenkai"

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ABSTRACT

From 2008 to 2012 the Brake port was expanded by the "Niedersachsenkai". Brake is located in northern Germany between Bremen and Bremerhaven, 26km upstream from the outlet of the river Weser to the North Sea. At the Niedersachsenkai mainly iron/steel, project and general cargo are handled.
Pavements of industrial ports such as the Niedersachsenkai have to be adapted to the very heavy loading resulting from storage as well as loading of the cargo on the one hand and to the corresponding traffic. In the context of the load itself, the storage area has to be very bearable, resistant to deformation and to ageing, and durable. Furthermore it has to possess particularly evenness and no bumps, offsets, or edges in order to allow high transportation speed, thus fast dropping and loading of the ships.
The design life of the pavement was set to 45 years. The structure was computationally dimensioned, which was done for port areas for the first time. It consists of: asphalt surface course out of AC 16 with polymer-modified bitumen and additives, asphalt base course out of AC 32 with standard bitumen and 30M.-% reclaimed asphalt, crushed aggregate base course, and a course out of dredged sand.
The existing cargo stored on the pavement induces vertical stresses up to 3.3N/mm² depending on storage and bearing, but should not exceed 2N/mm² for a longer time to avoid slight deformation.
Higher and appropriate requirements on both the mixture and the courses assured a high quality, homogenous, dense, and even asphalt pavement that offers high durability, bearing capacity, and resistance to deformation as proven in practice so far. Owing to these very good results, the pavement concept was adapted to further port construction projects already.
The paper presents the background of pavement design, the realization of the requirements and specifications to construct a durable pavement, and findings from the six years usage.

Keywords: Bearing capacity, Design of pavement, Industrial application, Mixture design

1. INTRODUCTION

The port of Brake is located about 26km upstream of the outlet of the river Weser to the North Sea. The port area extends today for 2.5km length along the Weser and was enlarged from 2008 to 2012 by the so called "Niedersachsenkai" (Fig. 1) in the northern part.

The quay of the Niedersachsenkai possesses an overall length of 450m with a sole depth of SL (sea level) −17.00m so that two handymax ships with 12.80m draft can dock and be served. The average high tide is SL +2.06m and the average low tide NN −1.82m. The top edge of the quay is at SL +5.50m, and the storage area lies at about SL +6.00m. One rail that runs directly at the quay and two more tracks that are parallel to the quay in the storage area are connected via the station Brake to the national rail network. The storage area was extended in 2012 of about 180.000m² and a warehouse having 8,000m² was built in 2013. The whole project was prepared in 2006 already by dredging of sand and preloading the ground.

The paving system of both the quay area and the storage area was planned and designed by means of computational dimensioning according to RDO Asphalt 09 [1], which was particularly developed for the construction of highly trafficked roads. However, the use and load of the port area clearly differs from that one on roads. Therefore, the use, the load, and the basic conditions were analysed in detail first in order to create an adequate concept as well as to transfer the well-known method, which bases on long-term experience in road construction, appropriately to the application for the port pavement.

Figure 1: Overview on the Niedersachsenkai at the port of Brake

2. CONCEPT OF THE PAVEMENT

2.1 Use and load

At the port of Brake 6.3 million tons of goods were handled in 2014 [2], whereof the main part belongs to corn and feeding stuff shipped in the southern part of the port. The Niedersachsenkai was particularly planned for the transhipment of both iron and steel goods that came to 0.8 million tons in 2014. Furthermore, parts for onshore wind mills as well as other project cargo were handled at the Niedersachsenkai. For the handling of the goods, two gantry cranes possessing 60t lifting capacity were installed and two mobile cranes with a lifting capacity of 140t and 144t respectively are available. The subsequent transport is made by heavy-duty forklifts, reach-stackers, roll-trailers with towing vehicles, and van-carriers intra-port, or to the destinations by platform-trailers with towing vehicles.

The dimensioning of roads bases on the number of equivalent 10t axle loads during the specified design life [3]. In order to calculate the loading of the storage area at the port, a so-called substitutional axle load of each cargo handling device was determined. This substitutional axle load was estimated based on the device weight, the cargo weight, the arrangement and numbers of axle and wheels, the tyre contact area, the resulting vertical stress in the tyre contact area, and an theoretical axle pressure. Table 1 shows the weights and the substitutional axle loads of each cargo handling device.

Table 1: Assumptions regarding the load of the present cargo handling devices

cargo handling device	cargo weight (t)	total weight (t)	substitutional axle load (t)
mobile crane	140	452	11.3
heavy-duty forklift	25	78	front: 13.0 rear: 15.5
reach-stacker	35	114	14.4
roll-trailer	50	70	12.6
platform-trailer I	20	35	8.4
platform-trailer II	80	103	14.4
van-carrier	110	176	17.6

In case of the Niedersachsenkai, the heavy-duty forklift was used as reference device, to which the stress of the other cargo handling devices or their substitutional axle loads was related. This was considered by a so-called "passage-factor", which allows a simple determination of the impact of any other or new cargo handling device. This method is suitable and appropriate in practice as the past 7 years usage proves.

The storage of the goods generates a high static load. Given an appropriate stacking and bearing, the bearing vertical stress was rated to about 1N/mm² as a rule and up to 2N/mm² for the storage of steel. These vertical stresses exceed in part the vertical stresses calculated for the cargo handling devices; hence, a high resistance to deformation of the pavement is essential to avoid creep and deformation as far as possible.

Due to its exposed spatial location, the area is heavily open to the weather impact and the dredged substructure to the water levels changing with the tide. The first mentioned aspect requires a dense, durable surface and the latter one has to be considered regarding the bearing capacity. Furthermore, the surface has to possess particularly evenness and no bumps, offsets or edges to allow a facile handling of the cargo and a high transportation speed, thus fast dropping and loading of the ships.

The drainage of the area is guaranteed by a gradient of 1.5% orthographical to the quay.

2.2 Structural design

The dimensionally relevant stress was calculated in the style of the German guideline RStO 12 [3] where the different common factors given in RStO 12 were adapted to the application to port areas and the situation in detail. The design life of the storage area was set to 45 years.

While on roads vehicles travel precisely in line usually, the cargo handling devices disperse on the port or storage area according to the usage conditions, logistics, and goods. Thus, the stress of the pavement varies likewise, and the approach concerning the substitutional axle load mentioned above proves itself as well.

Based on the handling capacity of 750,000 tons per year per berth, 180 movements of cargo handling devices per day were calculated, regardless of the type of both the cargo and the vehicle in detail. The substitutional axle loads of the devices (Table 1) were simplifying assumed to average 12t, 13t, 14t, and 15.5t and to be homogeneously distributed at the Niedersachsenkai. From this, the load spectra quotient comes to 3.6358.

The type of the pavement was chosen with regard to the experience in the past, the requirements to usage (especially concerning the evenness), and the planned loading of the storage area; hence, an asphalt pavement was deemed being suitable. Only the track installation and the quay area were paved with blocks to allow easy accessibility for maintenance.

The storage area was planned with a two-layered asphalt pavement, consisting of a durable surface course highly resistant to deformation and a very stable asphalt base course, built on a highly load bearing crushed aggregate base course and a course of frost-proof material. Comparable structures were realised successfully at the ports of Hamburg and Wilhelmshaven as well as at different inland-waterway ports already.

The course thickness was calculated by computational dimensioning according to the RDO Asphalt 09 [1]. At it, the bearing performance of each course is considered, and the material parameters are adapted and specified iteratively so that neither the subformation level nor the courses of the pavement themselves give reason to expect structural damage within the specified design life. The calculations of the computational dimensioning were conducted by using the software "PaDesTo" (Pavement Design Tool, [7]). This software correlates with the specification given in the RDO Asphalt 09 regarding both the dimensioning method and the analysis procedure.

The asphalt mixture for both the surface course and the asphalt base course was designed and tested in the laboratory first, and the stiffness and the fatigue performance were determined. Afterwards, numerous calculations by computational dimensioning were conducted using PaDesTo, varying both the course thickness and the course characteristics, where the laboratory data was considered, and assumptions regarding the E-modulus of the crushed aggregate base course, the expected load, and further input parameters according to RDO Asphalt 09 were made. Based on the results, it was decided to build the storage area as given in Figure 2, with 80cm frost-resistant pavement in total.

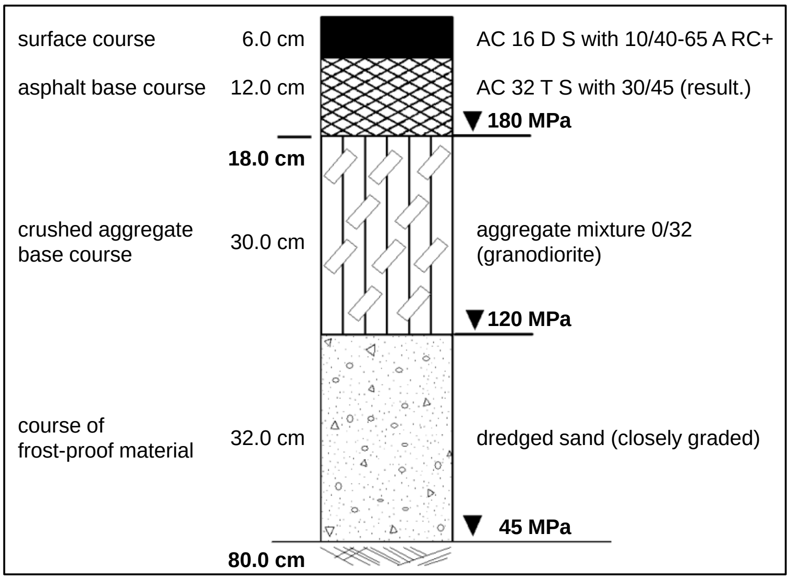

Figure 2: Structure of the storage area at Niedersachsenkai

The course of frost-proof material consists of the dredged sand that had to be treated and compacted, and which is closely graded due to its origin.

The crushed aggregate base course had to offer a deformation modulus of at least 180MPa. It provides a highly load-bearing base for the asphalt pavement and a suitable elasticity at the same time. Thus, a crushed aggregate base course is preferred to a stabilisation, although the latter one is applied (inappropriately) for port areas often. The disadvantage of a stabilisation, and which is why it was not applied here, is manifold: In case of producing a stabilisation from dredged sand, a part of the cement has to compensate the missing fines. Consequently, a greater amount of cement has to be added compared to wide graded material in order to achieve the same stability. But this is accompanied by the risk of an unwantedly too high stability, which may lead to cracks in the stabilisation and later on to reflective cracking of the asphalt pavement. Furthermore, blow-ups may arise in the asphalt pavement resulting from a different expansion of the stabilisation across the profile due to intensive insolation. In order to restrict damages, stabilisations beneath asphalt pavements always have to be built with a very high uniformity and an appropriate compressive strength, which is a formidable challenge for big areas as the storage area of the Niedersachsenkai. Another disadvantage of the stabilisation is its fatigue performance, its decreasing compressive strength in the course of the serviceable life, and, as a consequence, its decreasing bearing capacity. In contrast, a crushed aggregate base course undergoes no fatigue, which is due to the conception itself, especially if natural crushed aggregate is used only. Thus, and given an appropriate thickness as well as a compaction compliant with the requirements, the achievable and sufficient bearing capacity and appropriate elasticity of the crushed aggregate base course remains virtually constant.

The asphalt base course was planned and built 12cm thick in the area closer to the quay. In the rear storage area the thickness was reduced to 10cm due to the area being less used because of logistical reasons.

According to calculation statistics by computational dimensioning, the level of fatigue of the 12cm asphalt base course comes to 45% after 30 years and to 68% for the 45 years design life. So therefore, no fatigue cracking is expected during the specified design life, still taking into account that regular maintenance needs to be carried out. The maximum compressive strength of the crushed aggregate base course is exploited by 0% and 1% respectively.

Figure 3 depicts the course of the level of fatigue calculated using PaDesTo of the 10cm asphalt base course, which was placed in the rear storage area. It can be seen, that the level of fatigue is 75% at 30 years and 113% at 45 years respectively. After 40 years and beyond, when the level of fatigue exceeds 100%, one would have to expect cracking of the thinner asphalt pavement if the rear storage area was as heavily trafficked as the area closer to the quay. However, since the rear storage area has an expected lower traffic load it can be assumed that no cracking will occur during the design life. The maximum compressive strength of the crushed aggregate base course would be used by 14% and 21% respectively.

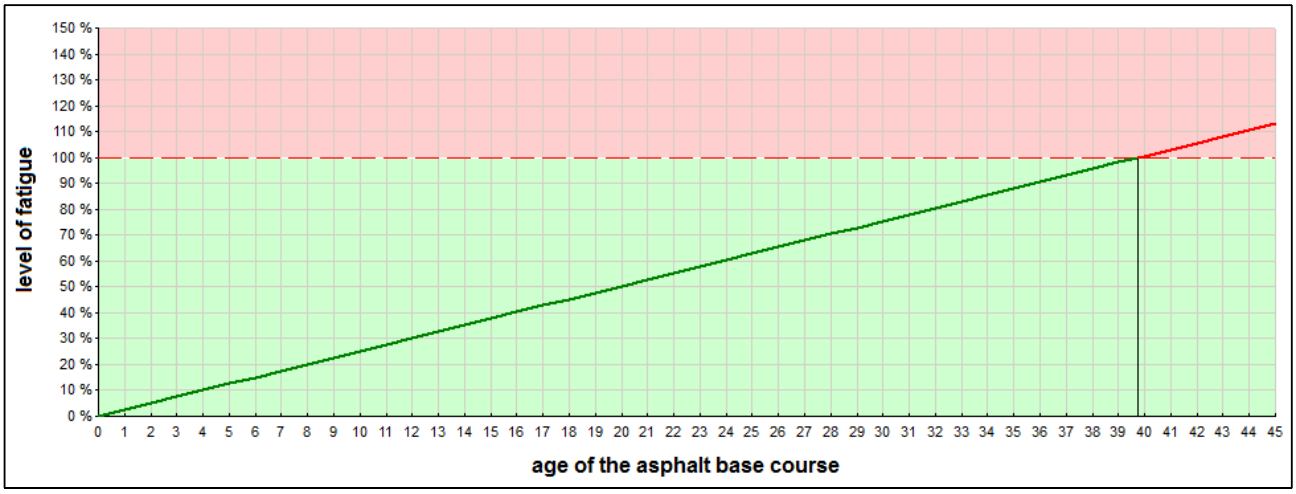

Figure 3: Course of the level of fatigue of the 10cm asphalt base course built onto 30cm crushed aggregate base course

3. PRODUCTION AND PLACEMENT

3.1 Requirements

Due to the ambitious demands regarding the usage and the loading of the storage area, special requirements were imposed to the realisation of the pavement to ensure a high quality of the courses.

The unevenness within a 4m measuring section must not exceed 10mm on the crushed aggregate base course, 6mm on the asphalt base course, and 4mm on the surface course. This ensured a very good evenness of the surface as well as a mostly homogeneous structure. In order to enhance or ensure the homogeneity of the courses (e. g. in terms of the placed mixture and the compaction of the courses) as well as the evenness requirements, a feeder had to be used when placing the asphalt courses and the crushed aggregate base course had to be laid in two layers. Furthermore, the connections on the surface had to be realised at the same height.

Besides, the asphalt had to be paved over the whole width as far as possible or with adjacent pavers slightly offset in order to avoid seams. The seams in the surface course that were unpreventable had to be formed as joints and filled with a joint sealant.

The rate of compaction of the asphalt base course must not come below 99% with 3.0Vol.-% to 8.0Vol.-% void content. In case of the surface course, the rate of compaction must be at least 98% with 2.0Vol.-% to 6.0Vol.-% void content. Beyond, the tolerances for the deviation regarding the production have been narrowed and a limit for the bond between the surface course and the asphalt base course has been set, which was higher than the limit given in the current standard ZTV Asphalt-StB 07/13 [4].

3.2 Composition and characteristics of the courses

The crushed aggregate base course had to be made of a solely natural crushed aggregate mixture according to the TL SoB-StB 04 [5]. It was not allowed to use recycled aggregates or industrially produced aggregates. Thus, at the Niedersachsenkai granodiorite was applied for the crushed aggregate base course as well as for both asphalt mixtures.

The asphalt concrete AC 16 D S for the surface course had to be produced with polymer modified bitumen 10/40-65 A RC+ and 3% viscosity modifying additive. This organic additive is a so-called Fischer-Tropsch-wax (FT paraffin) having a melting point of about 60°C. The asphalt concrete for the asphalt base course AC 32 T S could contain reclaimed asphalt. The bitumen resulting from the mixture of the added fresh bitumen and the bitumen contained in the reclaimed asphalt had to possess bitumen characteristics comparable with bitumen grade 30/45. Both asphalts mixtures had to be composed following the TL Asphalt-StB 07 [6] already, even though it was not yet published at that time. Furthermore, the asphalt mixtures had to be tested additionally within the type testing in order to prove high resistance to deformation and sufficient bearing capacity. The data of the type testing and the average results of the check test on both the asphalt mixtures and the courses are given in Table 2.

Table 2: Composition and characteristics of the asphalt of the surface course (AC 16 D S) and the asphalt base course (AC 32 T S) according to type testing

	characteristic \ asphalt		AC 16 D S		AC 32 T S	
			type testing	check test	type testing	check test
1.	**aggregate**					
	type		granodiorite		granodiorite, reclaimed asphalt	
	percentage of reclaimed asphalt	M.-%	–		30	
2.	**bitumen**					
	bitumen type		10/40-65 A RC+ and 3% VMA 1)		30/45	
	binder content	M.-%	5.0	5.1	4.2	4.2
	softening point ring and ball	°C	89.0	86.6	54.6	58.7
3.	**asphalt and course**					
	void content (Marshall specimen)	Vol.-%	3.4	3.7	5.5	4.8
	void content (core)	Vol.-%		4.3		4.3
	rate of compaction 2)	%		99.3		100.9
4.	**additional tests**					
	wheel tracking depth 3)	mm	1.5		3.3	
	low temperature test 4)					
	- breaking temperature	°C	−17.0		−19.6	
	- breaking stress	N/mm²	3.56		4.10	
	fatigue resistance at 5°C 5)	–	139,599		88,743	
	data for computational dimensioning					
	- stiffness/E-Modulus 6) at −10°C	N/mm²	19,507		17,324	
	0°C	N/mm²	18,874		14,282	
	10°C	N/mm²	12,507		9,888	
	20°C	N/mm²	8,365		8,519	
	- fatigue 6) $x = \varepsilon$	–	$2.0282 \cdot x^{-4.3898}$		$139.29 \cdot x^{-3.3077}$	
	coefficient of determination R^2	–	0.93		0.91	

1) VMA: viscosity modifying additive (Fischer-Tropsch-wax)
2) calculated as the ratio of the bulk density of the core sample to the bulk density of the sample compacted by impact compactor
3) testing according to TP A-StB [8] at 50°C in water-bath and with a steel wheel
4) testing according to test specification [9]
5) number of cycles; testing with the cyclic tension test at 5°C according to DIN EN 12697-24 [10]
6) testing according to the draft of AL Sp-Asphalt [11]

The results of the additional testing done within the type testing show that the asphalt concrete for both the surface course and the asphalt base course offers a high resistance to deformation and a good fatigue as well as low-temperature performance suitable for the application.

The low void content proved in the check test and the high rate of compaction of the surface course and the asphalt base course attest the placement of an asphalt pavement that is durable and resistant to deformation.

After the completion of the first stage of expansion of the port, the bearing capacity of the pavement was examined with the falling-weight-deflectometer. The tests were conducted at sunny weather with 28°C surface temperature with a load of 50kN that represents the load of heavy load wheel running at 50km/h, and which was applied by a load plate having 300mm in diameter. Based on the deflection of the pavement measured in 0mm, 200mm, 300mm, 450mm, 600mm, 900mm and 1.500mm distance to the centre of the load plate the E-modulus was calculated whereat the structure was modelled as a three-layer system (asphalt pavement, crushed aggregate base course, and unbound layers) and the standard-temperature was set to 20°C. The measurements showed a very good homogeneity of both the courses without binders and the asphalt courses. The E-modulus of the course of frost-proof material (compacted dredged sand) ranges between 146MPa and 167MPa and the E-modulus of the crushed aggregate base course between 265MPa and 299MPa.

Thus, the courses without binders fulfil the bearing capacity requirements. The E-modulus of the asphalt pavement was calculated to 7,900MPa and lies on a satisfying high level.

4. USAGE

Since its completion the storage area was loaded with diverse steel goods and parts of wind mills; Table 3 gives some examples for the load resulting from the goods. When storing, the goods were placed on planks, squared timbers or the like due to logistical reasons as well as to achieve a good load distribution on the pavement. Thus, the bearing vertical stresses mainly came to 0.3N/mm² to 1.8N/mm² in terms of the steel plates and steel components (Fig. 4) and to 0.4N/mm² to 1.1N/mm² in case of storing the parts of wind mills (Fig. 5). Even after 4 to 6 weeks duration of storage no indentation was to be noticed, neither due to the stored goods nor the cargo transport traffic (Fig. 6). Minor indentations from 2mm to 3mm were noticed only after 3 months duration of storage.

Sole exception posed a storage of coils (Fig. 7) weighing 25t to 29t each, and which are two-ply stacked usually. At that time, the coils were placed on two or three planks (with 3cm thickness and 15cm to 20cm width) that lay across the coils in a distance of 30cm to 40cm. Despite the 20cm long contact area per plank the resulting bearing vertical stress was about 4.5N/mm². This is 2.5 times the maximum bearing vertical stress resulting from other load, which is equal to almost the 40-fold damage of the pavement according to the 4^{th} power rule. Hence, up to 12mm indentation existed after 6 weeks duration of storage. As a consequence of this, the bedding of the coils was adjusted; now, the planks are put adjacent to one another and over the whole width of the coils so that the bearing vertical stress is reduced to about 2.3N/mm². Thus, and as given for the other goods no or only minor indentations arose afterwards.

Table 3: Examples for the load on the storage area resulting from the storage of diverse goods

good	weight	stack (layers)	distributed load [t/m²]
crushed aggregate base courses material	2.2t/m³	up to 15m height	30
coils	25 to 29t/piece	2	24.6
steel plate	8t/piece	70 to 100	13 to 19
slab	10.5 to 25t/piece	7 to8	9 to14
wood blocks	0.5t/m³	8	4
pipes, Ø 770 mm	4.5t/piece	5 to 7	3.1
pipes, Ø 1200 mm	12 t/piece	2 to 3	3
parts of wind mills	13 to 82t/piece	1	0.5 to 5

Figure 4: Storage of beams at the Niedersachsenkai

Figure 5: Transport and storage of parts of wind mills at the Niedersachsenkai

Figure 6: Handling of steel plates at the Niedersachsenkai

Figure 7: Transport and storage of coils at the Niedersachsenkai

The loading of the pavement is always accompanied by both a temporary settlement depression because of the elasticity of the pavement and by transverse forces with associated tensile strains due to the gradient of 1.5%. Usually this is not an issue. However, it led to an obvious crack in the joints in the adverse concurrence of very high loads resulting from the storage of coils and a severe winter, which exhibited longer-term temperatures of up to −20°C, and thus a reduced elasticity of both the asphalt pavement and the joint sealant. Therefore and given such weather conditions, not only the bearing of the goods must be considered but also the number of layers of the stack must be reduced in order to decrease the resulting tensile strains at weak points. For the same reason the gradient was reduced to 1.0% for the storage areas planned and realised subsequently.

5. CONCLUSION

The Niedersachsenkai at the port of Brake was finished in 2011 and offers a berth for two handymax bulker with 12.80m draft. It was designed especially for the transhipment of steel goods and parts for wind mills. The cargo can be handled by two gantry cranes with 60t lifting capacity each, two mobile cranes with 140t and 144t lifting capacity respectively, and numerous mobile cargo handling devices. Tracks, which run along and parallel to the quay, are connected to the national rail network and, hence, provide an alternative to the carriage of goods on the road network, which is within easy reach, too.

The usage of the area is characterised by high loads due to the type of the goods and requires a very good evenness with no bumps, offsets or edges to allow a facile and rapid handling of the cargo. Thus and considering the existing experience, an asphalt structure was deemed being suitable for the area and preferred to a block pavement, which was common for the storage areas at the port of Brake previously. Only the quay area and the track installation were paved with blocks to allow easy accessibility for maintenance.

The asphalt pavement was designed by means of computational dimensioning, which was applied to a port area for the first time. The specified design life is 45 years. The two-layered asphalt pavement consists of a 6cm surface course, which is notably resistant to deformation and made of asphalt concrete AC 16 D S with polymer modified bitumen 10/40-65 A RC+ and 3% viscosity modifying additive, and an asphalt base course made of asphalt concrete AC 32 T S with 30M.-% reclaimed asphalt and a binder comparable to paving grade bitumen 30/45. The asphalt base course thickness is 12cm in the storage area closer to the quay and 10cm in the rear storage area where less traffic exists because of logistical reasons. The asphalt pavement was placed onto 30cm crushed aggregate base course and a course of frost-proof material that is dredged and compacted sand. The crushed aggregate base course is made of natural aggregate (granodiorite) and was laid in two layers for reasons of homogeneity and quality. Compared to a stabilisation, the crushed aggregate base course provides the advantage that it offers a durable highly load-bearing as well as suitably elastic base for the asphalt pavement. For the production of the asphalt and the characteristics of the pavement additional or higher requirements were imposed in order to ensure the placement of a high quality, homogenous, dense, and even pavement.

The high bearing capacity as well as the good resistance to deformation proved itself already during its usage and the storage of diverse steel goods and parts for wind mills. However, the resulting bearing vertical stresses should not exceed 2N/mm² in the long term. The positive trend of the usage as well as the transhipment volume handled at the Niedersachsenkai (Fig. 8) attest its spatial as well as structural practice-oriented design, which moreover keeps enough space for an adequate expansion in future and a third berth.

Figure 8: Overview from the upstream face on the Niedersachsenkai with two handysize bulker at the berth

This article exemplifies the approach of the development of a pavement concept for traffic areas as well as storage areas at ports. The pavement of several container ports (both seaports and inland ports), ports for heavy project cargo, and ports for the offshore wind energy industry have been successfully and suitably designed based on that approach over the past years. However, the concept cannot be transferred offhandedly from one port to another port since every port possesses different environmental, legal and usage conditions; thus, the concept has to be adapted or developed for each port individually.

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