CONCRETE BLOCK PAVING AS A SURFACING MATERIAL FOR CONTAINER STORAGE AREAS

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SUMMARY

It is now common for containers to be stored five or more high on paved areas in ports. The stresses applied to the pavement through their corner castings are very high and usually lead to damage to all categories of surfacing material. This Paper describes and compares the performance of container handling yards surfaced with pavers with a Heavy Duty Macadam (HDM) (asphalt concrete) roadbase and with a lean concrete roadbase.

This paper describes a container storage yard case study where deformation of the HDM roadbase and impact by containers led to damage to those pavers directly beneath the corner castings at a site in the UK. It shows that the damage is significantly greater than that sustained by a similarly loaded pavement which included a lean concrete roadbase instead of the HDM roadbase. This Paper describes the level of damage sustained and proposes an HDM roadbase as a cost effective solution in the case of pavement overlay even taking account of the deformation at the locations of container corner castings and the ensuing maintenance cost.

The Paper describes the result of an investigation into the reasons for the deformation of the HDM (asphalt concrete) and suggests that the design of those parts of a heavy duty pavement loaded by containers should be based on the underframe load of the container, not the stress applied through the corner castings.

1. INTRODUCTION

The storage of laden containers five high is now common in ports worldwide. The introduction of Reach Stackers which can access five high containers makes this a financially attractive proposition. So much so that the logistics industry often takes advantage of the relatively low port storage costs to deliberately retain imported goods in their containers at or near the port to avoid the costs of constructing additional inland distribution warehouses to deal with peaks in import volume. In many regions, an industry of secondary container handling at ports has developed in which imported containers are taken from the quayside container yard to a storage area adjacent to the port where they remain, often for months, until the importer requires the goods at the inland warehouse.

This Paper presents a case study in which an existing bituminous heavy duty pavement at such a secondary container yard adjacent to a port was strengthened by the construction of an overlay comprising Heavy Duty Macadam (HDM) and concrete block paving. The pavement strengthening comprised 80mm thickness rectangular concrete pavers installed in 30mm thickness of laying course sand over a 120mm thickness overlay of HDM. The overlay was installed in 2000/2001 over an

existing 1995 pavement comprising HDM over lean concrete over crushed rock which had been designed to accommodate the handling of empty containers. The reason for the overlay was to strengthen the 1995 pavement, which had been designer to handle empty containers, so that the operator could store five high laden containers.

From 2000, laden 40ft and 20ft containers were stored five high on the strengthened overlain pavement and were handled by Reach Stackers and Front Lift Trucks. The overlain pavement soon developed deformation at every container corner casting location as shown in Figure 1 and these deformations eventually attained a depth equal to the downstand of the container corner castings, about 15mm, after which the containers began to rest directly upon their underframes and no further deformation occurred.

The container handling company's difficulties arose when they elected to undertake "aisle rotation" in order to prolong the life of the running aisles between the container stacks. "Aisle rotation" means laterally displacing containers so that the parts of the pavement taking the weight of 100t front axles of container handling equipment are changed. However, it was discovered that when Reach Stackers/Front Lift Trucks traveled over zones previously deformed by container corner castings (but not repaired); previously benign corner casting induced depressions grew into significant zones of failure.

The dispute centred upon the suitability of HDM as a roadbase material in container storage areas. The yard operator considered that the development of depressions where container corner castings had stood was unacceptable. The designer pointed to the fact that in advance of the operational use of the yard, the operator had been told that pavers would break at container corner casting locations and that they would need to be repaired as soon as possible. The designer also pointed out that the upgrading of the 50,000m^2 yard in 2000/2001 had cost £1,600,000 whereas the cost of installing a concrete roadbase (which would not have deformed) would have exceeded £2,500,000.

This Paper sets out the properties of the HDM roadbase and shows that it can be used cost effectively as the roadbase in the case of overlaying a pavement but that the user must be made aware of the need for maintenance of depressions caused by corner castings if the depressed areas are to be trafficked by container handling equipment

2. COMPARISON OF THE PERFORMANCE OF LEAN CONCRETE AND HDM AS ROADBASE MATERIALS IN A CONTAINER YARD

Figures 1 to 4 show damage sustained by pavers installed over HDM at the container handling yard in Felixstowe. Figures 1 and 2 show the levels of damage caused by container corner castings. Figures 3 and 4 show enhanced levels of damage inflicted by Reach Stackers traveling over those areas which had been initially damaged by container corner castings. Figures 6, 7 and 8 show a similar cycle of usage but this time the pavers are installed over lean concrete at a container handling facility at Southampton. Although the initial deformation of the pavers at container corner castings is less, nonetheless damage is sustained by the pavers. However, when these damaged pavers are subsequently trafficked by Reach Stackers, the pavement remains serviceable. Both of these pavements were designed according to the British Ports Association heavy duty pavement design manual[1].



Figure 1. Damage sustained by concrete block paving at five high container corner castings with an HDM roadbase.



Figure 2. Containers have been removed from this area of pavers with an HDM roadbase. The pattern of broken and depressed pavers reflects the former position of container corner castings.



Figure 3. Trafficking of pavers installed over HDM and previously damaged by container corner castings roadbase leads to enhanced levels of damage. Here four small zones of damage are progressively coalescing into one.



Figure 4. Because these pavers were installed over an HDM roadbase, damage initiated by container corner castings has been enhanced by subsequent trafficking by Reach Stackers such that total paver failure has developed.



Figure 5. Reach Stackers have front axle loads exceeding 100t.

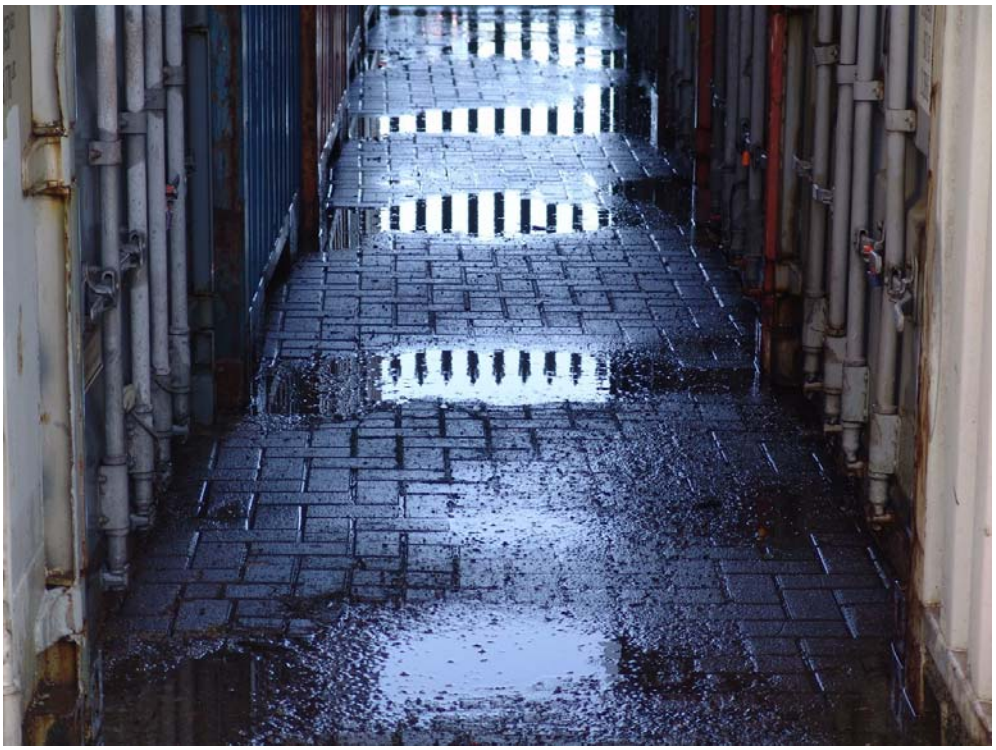


Figure 6. Containers stored on pavers with a lean concrete roadbase. Although there is some deformation, as highlighted by the standing water, it is much less than when HDM is used as a roadbase. Nonetheless, damage to pavers does occur at corner casting locations.



Figure 7. Pavers installed over lean concrete suffer some deformation and damage, although at a slower rate than those installed with an HDM roadbase.



Figure 7. Pavers over lean concrete damaged by container corner castings then trafficked by Reach Stackers suffer a little more damage but much less than they would had they been installed over HDM.

If it were the case that HDM and lean concrete were of similar initial cost then Figures 1 to 8 indicate that lean concrete would be the preferred roadbase material for container yards. In the case of new build, the difference between the cost of lean concrete and HDM is marginal and in the UK nearly all container handling facilities include a lean concrete roadbase. However, in the case of overlaying an existing pavement, HDM has several advantages. Firstly, it can be installed in thinner layers and is therefore more amenable to level adjustment. Secondly, HDM requires less curing time than lean concrete and allows a yard to be brought into service sooner. This is often a critical matter in overlay work, less so with new build. Thirdly, being a flexible material, HDM copes better with variable support which is often a feature of pavements being overlain. Fourthly, it is more amenable to being installed in tapered section which is a common requirement for pavement overlay projects. For these reasons, HDM is often a preferred roadbase material in the case of overlay work.

An investigation into the cause of the deformation of the pavement shown in Figures 1 to 4 confirmed that the surface of the HDM had deformed in line with the pavement surface. Tests showed that the HDM material included particularly cuboid/spherical particles in the range 2mm to zero which prevented the aggregate interlock from developing which is crucial to the inherent stability of HDM. Tests undertaken on HDM with more angular particles showed that it would have enhanced deformation resistance and stiffness, although it would be unlikely that these enhancements would be sufficient to entirely eliminate deformation at container corner castings. Although HDM derives much of its strength from aggregate interlock, it nonetheless derives some of its deformation resistance from the bitumen coating the particles. It is the flow of the bitumen which allowed the HDM to deform at Felixstowe.

This finding can be used positively as follows by port pavement designers. The British Ports Association port pavement design manual[1] provides guidance on the design of pavements to support stacked containers. Table 1, taken from the BPA manual, shows loads applied by containers of different stacking heights. It is often the case that container stacking zones govern the design of a port pavement because of the high loads applied and because of the intensity of pressure. By including within the pavement a layer that will deform at container corner castings until the depth of deformation is equal to the corner casting downstand, the pavement need only be designed to sustain the distributed load applied by the container underframe. This leads to a lighter pavement.

Table 1. Pavement loads from stacking containers

Stacking Height	Reduction in Gross Weight	Contact Stress (N/mm^2)	Load on Pavement (kN) for each stacking arrangement		
			Singly	Rows	Blocks
1	0	2.59	76.2	152.4	304.8
2	10%	4.67	137.2	274.3	548.6
3	20%	6.23	182.9	365.8	731.5
4	30%	7.27	213.4	426.7	853.4
5	40%	7.78	228.6	457.2	914.4

A way in which a designer can take advantage of this behaviour is as follows. The pavement can be designed to sustain only the loads applied by container handling equipment. The container corner castings will then cause the HDM to deform. The deformed HDM can be left in-situ until container

relocation is required. At that time, a local repair can be made at low cost (see Section 4) and the operation can continue unhindered.

Two important features of the deforming HDM allow the above design approach to be undertaken. The first is that when the HDM deforms at container corner castings, it does not fail in any way. The material retains its integrity, merely thinning by the amount of the downstand of the container corner castings. Secondly, experience with this case study showed that when the deformed zone is repaired, all that is needed is the resetting of the pavers on additional laying course material. Areas repaired in this way have successfully sustained trafficking by Reach Stackers applying 100t front axle loads. The only enhancement in the specification of the repair is that a Category 1 laying course material to BS7533: Part 3[6] should be used because the depression will attract water and the sand will need to retain its integrity in a saturated condition.

3. PROPERTIES REQUIRED FOR HDM AS A CONTAINER YARD ROADBASE

The following materials are used commonly in port pavements in the UK. Because other terminologies are used elsewhere, the Author includes the following definitions to inform the reader.

Concrete Block Paving – concrete blocks of modular plan dimensions 200mm x 100mm and of thickness 80mm installed into a 30mm thickness bed of compacted sand.

Heavy Duty Macadam (HDM) – a mixture of stones and fine material stabilised with bitumen. The material's strength is derived principally from the Particle Size Distribution, particle shape and origin of the stones and fine material as well as the engineering properties of the bitumen. The term "Macadam" means a combination of coarse and fine stones which are mixed and pressed together to create a mixture which is stronger than the sum of its parts.

Dense Bitumen Macadam (DBM) – similar to Heavy Duty Macadam but with less stringent requirements.

Hot Rolled Asphalt (HRA) – a mixture of mainly fine material with a little larger sized stone stabilised with bitumen. The material's strength is derived principally from the properties of the bitumen binder. Asphalt is a mixture of either tar or bitumen and fine material in which the particles need not be in intimate contact with each other. Asphalt occurs naturally, famously in Lake Trinidad but also elsewhere. HRA has been used as the principal surfacing material for UK roads for many years.

C10 Lean Concrete – a mixture of coarse and fine stones, cement and water similar to common concrete but with approximately 40% as much cement and water as normal concrete. It has a "Characteristic" Compressive Strength of 10N/mm^2. Characteristic Strength is a technical term and is the strength below which only one in 20 test samples is allowed to fall. This means the average compressive strength needs to exceed 10N/mm^2. The actual average compressive strength depends upon the variability of the material.

Cement Bound Material 3 (CBM3) – similar to C10 Lean Concrete but with an average compressive strength of 10N/mm^2 and a minimum compressive strength of 6.5N/mm^2 i.e. it is poorer than C10 Lean Concrete. The reason for both of these concrete being important to this case is that C10 lean concrete is the standard material used in the British Ports Association heavy duty pavement design manual (3rd Edition), the design method used worldwide for the design of port pavements, and CBM3 is a material

commonly used in UK road design and also used by Babtie in this case.

Cement Bound Material 4 (CBM4) – similar to CBM3 but with an average compressive strength of 15N/mm^2 and a minimum compressive strength of 10N/mm^2.

HDM is particularly stiff bitumen bound material requiring care in its manufacture and laying. It was introduced into highway pavement construction in the UK in the 1990s as an improvement on the previously installed Dense Bitumen Macadam (DBM) which had been found to fail prematurely from time to time. In the UK, the material properties of bitumen bound materials are specified by BS 4987: Part 1[5] and the way in which the material is installed are set out in the Highways Agency's "Specification for Highway Works" (SHW) [4].

The following properties of HDM are measured during its installation:

Binder Content

BS4987: Part 1[5] requires that the contractor should nominate a target binder content of 4.7% ± 0.6%, i.e. 4.1% to 5.3%. These are relatively low binder contents as compared with other bitumen bound highway construction materials and reflect the enhanced stiffness properties expected of HDM.

Bitumen Stiffness

The bitumen stiffness (as opposed to the HDM stiffness) is measured by its Penetration. Two Penetration values are commonly specified for HDM, 35 and 50[5]. Penetration is defined as the distance traveled by a needle being pressed into bitumen at a temperature of 25°C for five seconds by a force of 100 grams measured in tenths of a millimetre. The lower the value of Penetration, the harder the bitumen.

Density

Two different densities are measured when HDM is being installed, Refusal Density and Percentage Refusal Density (PRD). Refusal Density is the density which the material is capable of achieving when compacted very thoroughly. SHW[4] requires that when fully compacted, HDM must still have at least 1% air within the mixture. If less air remains, this suggests that the material will not perform as macadam should because it has become a solid mass of bitumen which will easily deform. The best HDM has a Refusal Density just above 1%. PRD is the density achieved during construction and should be close to Refusal Density. If the PRD is too low, this means that the HDM has not been well compacted and the material will be too weak. PRD must exceed 93% of Refusal Density.

HDM Stiffness and Deformation Resistance

Two engineering properties are measured during construction on material recovered by taking cores through newly installed material. The first is Indirect Tensile Stiffness Modulus (ITSM) which is a measure of the stiffness of the material and the second is Repeated Load Axial Test (RLAT) which is a measure of the material's deformation resistance[3]. In the ITSM test, a 30mm to 80mm long piece of the core is placed horizontally and is loaded briefly along one side until deformation causes the load to reduce. This causes the core to squash across the loaded diameter and to extend across the unloaded diameter at right angles to the loaded diameter. The load is applied briefly five times and the extension across the unloaded diameter is measured each time and an average recorded. ITSM is calculated by dividing the applied load by the extension of the unloaded diameter and the thickness of the core. This result is then multiplied by Poisson's Ratio (an elastic property of the HDM, normally about 0.35 at 20 °C) plus 0.27. HDM should achieve an average ITSM of at least 3,500N/mm^2 and this value would be

expected to double over the initial five years of the life of the pavement as the bitumen hardens. In the RLAT test[2], a cylindrical or square sample is cut to a length of between 40mm and 100mm. A compressive load pulse of duration one second is applied 1800 times over a period of an hour at a temperature of 30°C. The load value is set to achieve a pressure of 0.1N/mm^2 on the surface of the sample. The dynamic load stiffness modulus of the sample is calculated by dividing the applied pressure by the axial strain and is recorded after 10, 100, 1000 and 1800 load cycles. Both strain (compression divided by original length) and dynamic load stiffness modulus are recorded. The strain should not exceed 0.1 in newly installed material.

Aggregate Properties

Because HDM is intended to work as macadam, i.e. using aggregate interlock, the Particle Size Distribution of the aggregates and their shape is important. The particles must be uniformly graded and must have sufficient angularity to avoid deformation[5]. Macadam differs from asphalts in this regard. Asphalts rely upon the bitumen properties since the bitumen forms the solid matrix between the particles, whereas in the case of HDM, the bitumen merely coats the particles and it is intended that air voids remain within the mixture.

4. MAINTENANCE COSTS OF CONTAINER YARDS WITH LEAN CONCRETE AND HDM ROADBASES

In the UK example forming the case study for this Paper, the HDM overlay comprised 50,000m^2 at a cost of £1.6m. If lean concrete had been specified, levels would have dictated that part of the existing pavement should be removed. Whereas an HDM roadbase of thickness 120mm was installed, the requisite thickness for lean concrete was 250mm. Installing a lean concrete roadbase would have resulted in an additional cost of £UK900, 000.

After five years, because the container stacks had been relocated on two separate occasions, repairs were needed to 2,100m^2 of the 50,000m^2 pavement at a total cost of £UK90, 000. If damage inflicted by container corner castings had been made good before the damaged areas had been trafficked by Reach Stackers, this sum would have been reduced to £UK30, 000.

Of course, if containers had not been relocated as is often the case throughout the life of a container yard, then maintenance cost would have been zero. However, a container handling company should not be constrained to never relocate containers. Therefore, it would seem reasonable to attribute repair costs of £UK30, 000 every five years to a correctly maintained 50,000m^2 container yard with an HDM roadbase. This works out at £UK0.12/m^2 per annum or £UK9.60 per container stack per annum (doubling the area of an actual stack to account for aisles – all of these figures are averaged over the entire yard whether or not containers are stored).

Each five high container stack generates a storage income of £UK33, 000 per annum, against which £UK10 to be spent on maintenance is hardly burdensome. Interestingly, a 50,000m^2 five high container handling facility generates about £UK2, 500,000 in storage revenue per annum which approximates to the new building costs. From a cost standpoint, the maintenance requirement of an HDM roadbase container handling facility is very small in relation to the income which the yard generates. In the case of an overlay design, any cost analysis would show an HDM roadbase to be the most cost effective life cycle solution.

5. CONCLUSIONS

Where a designer provides a solution which will require a significant element of maintenance, the pavement owner must be made aware of the cost of that maintenance and must agree to this solution. So doing not only protects the designer's legal position but also helps the owner to plan the costs of maintenance. It remains the responsibility of the construction team to ensure that owners are fully apprised of the maintenance obligations associated with a specific design.

It is concluded that HDM is a suitable material for the roadbase of a pavement used for the storage of containers and is therefore often the best value solution for overlay strengthening projects. Providing maintenance is carried out to those zones deformed by corner castings before they are trafficked by Reach Stackers or Front Lift Trucks, the associated maintenance costs are likely to be small in relation to cost savings in using HDM. However, if heavy traffic is allowed to use an HDM pavement previously deformed by container casting feet, failure will develop quickly to a level where the yard will soon become unserviceable. This is not the case when a lean concrete base is used. In the case of a lean concrete roadbase, those pavers which have been damaged by container corner castings can remain in-situ with little further damage.

By using an HDM roadbase in container storage areas, so creating the situation where containers settle into the pavement surface by an amount equal to the downstand of their corner castings, the pavement can be designed to sustain loads generated by the underframes of containers rather than by corner castings. This allows significantly thinner pavements to be designed for container stacks. In cases where a yard operator needs freedom to relocate container stacks, design can be undertaken on the basis that the pavement is proportioned to sustain the loads imposed by container handling equipment only. This Paper shows that even in the unusually onerous case of an operator wishing to relocate containers twice every five years, maintenance of the deformed zones represents a very small sum in relation to the initial saving in construction cost and is very small in relation to the revenue earned by storing containers.

6. REFERENCES

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