Concrete block paving — survey of industrial applications in the UK

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Introduction

With the advent of containerization as a means of transporting goods from factory to distribution centre, new handling facilities have had to be devised which has necessitated the development of industrial sites and fast mechanical handling equipment.

Containerization of cargoes has prompted the design of ships capable of handling either vehicles loaded with containers (Ro/Ro) or containers only (Lo/Lo) and in each case a fast turn around is necessary if the economics of the system are to be maintained. The infrastructure back-up to the main distribution centres has resulted in a massive investment programme in providing industrial bulk handling sites near to and within the town industrial and shipping centres in the form of railway container depots and lorry container parks.

In the past the individual handling of goods did not necessarily require the provision of large paved areas but with the introduction of the unitized cargo handling system with its attendant high throughput new requirements for the design and construction of heavy duty pavings have had to be found. The characteristics of these are different to other forms of construction in as much as that they are frequently constructed over poor ground or on fill where high settlement conditions are to be expected. The loading requirements also are variable to the extent that there is a multiplicity of vehicle types and loadings including fork lift trucks, straddle carriers, side loaders, special tractor trailers and mobile gantry equipment, all capable of manoeuvering containers within confined spaces. Some of these vehicles have axle loadings in excess of 68 tonnes which require the adoption of pavement design methods other than those normally used in highway or airfield work.

As well as dynamic loading the pavement also has to withstand local high surface stress from static loads imposed on it through the application of jockey wheels and bearing pads of trailers, stabilizing jacks of mechanical handling plant and the foot plates of containers.

It has been found over recent years that industrial pavements are best served by the use of unitary form of precast concrete block paving, by virtue of its ability to accommodate movement, as it is now appreciated that this offers the best solution, particularly for areas where small and even large settlements occur.

The extremes of loading that can be expected on industrial pavements are distributed over a large area of blocks and only in rare instances where the sub-base has proved to be inadequate has local settlement occurred.

History

In 1825 Telford devised a system of road construction that was thought at the time to be a sound expedience against the traffic induced pumping of mud through the road surface. His plan, which he recommended to the parish of St George in London and which was then widely adopted, was to introduce a layer of lime concrete 150 mm in depth overlayed with granite setts 225 mm thick.

This form of sub-base did not function at all well as the lime binders or grout used could only develop a weak, friable layer, for the fine white limes which were favoured hardened slowly by atmospheric carbonation and not at all in wet conditions.

Where bad drainage to the road surface or sub-soils occurred, percolation of moisture into the sub-base resulted in softening of the limes and permitted mud pumping through the road structure. In later years as reported by Mitchell[1], who started using Portland and Roman Cement in place of lime, a sand bed was introduced to ease construction and to obtain a better surface level tolerance. This method is used up to this day where granite setts are laid down to form special feature surfaces and as recently as 1948 this approach was used in the construction of city streets in Scotland.

Creosote impregnated wood blocks is another form of construction which has used a unitary pavement surface. This was especially popular for city roads where heavy vehicular traffic used the pavement and it proved to be an economic alternative to granite setts. However, with the advent of bituminous materials there was a marked decrease in this construction method and eventually it fell into disuse.

Concrete block paving has been manufactured by British companies since 1960 but it was not until 1976 that any great interest was expressed. This was seen at the time as a means of providing a viable alternative form of construction for residential roads and lightly trafficked areas and research work carried out provided an analogy which agreed with the principles of design for flexible pavements as given in "Bituminous materials in road construction"[2].

Originally research work in this country was concentrated on the use of blocks for residential roads but with the pressing needs of industry an alternative to the then standard form of paving was required for other pavement categories which would be capable of withstanding heavier loading and remain unaffected by oil polution. The further research work which has been carried out and the practical experienced gained has now provided the ability to design pavements to cover many of these needs.

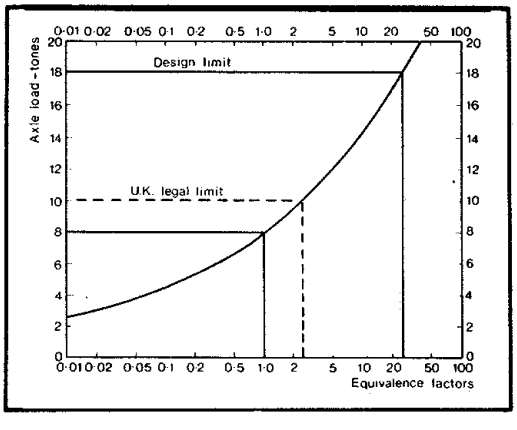
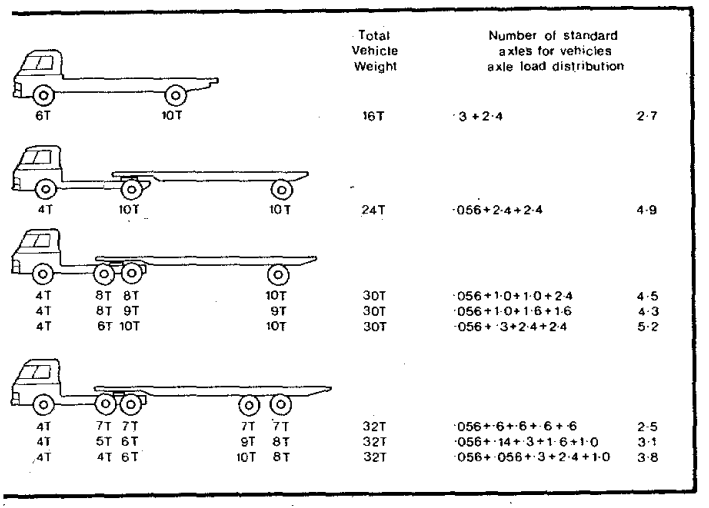


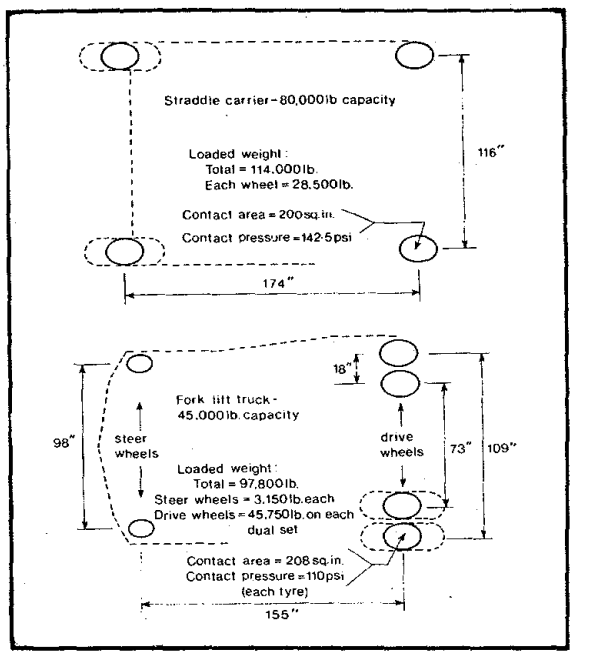
Figure 1: The relative damaging influence of different axle loads

Design philosophy

The design of industrial pavements is divided between those carrying



ıove. Figure 2: Damaging effect of loaded vehicles



ght. Figure 3: Wheel configuration and load data for straddle carriers and rk lift trucks. (Design example adopted from PCA)

ormal public road using commercial ehicles, specialized mechanical andling equipment capable of transorting very heavy loads over short istances and a combination of the wo.

Pavements in general should be esigned to resist excessive deformtion and early structural failure esulting from the cumulative lamaging effect of the vehicles using hem. The destructive influence or lamaging effect of axle loads, shown n Table 8 of Road Note 29 (Third Edition)[3], which ranges from 900 to 8,000 kg and is compared with a standard 8169 kg axle which has a lamaging factor of unity.

A design method given by Lilley nd Walker[4] includes a graphical epresentation of the relative lamaging influence of axle loads up o 18 tonnes, shown in Figure 1, and llustrates clearly the limitations of his design procedure.

The 18 tonnes figure is in excess of he design limitation imposed in European countries, as shown in Table 1, including the UK where the llowable single axle loads are given s 10 tonnes which equates approxinately to an equivalence factor of 2.4.

A close examination of some of the ehicles used to transport containers nd other types of commercial loads o distribution centres is given by Currer[5] and is illustrated in Figure 2. It shows clearly the distribution of oad and damaging effect of the ndividual axles.

To design a precast concrete block pavement for commercial vehicles, as with any pavement type, it is necessary o know the following:

(a) The design life.

(b) CBR value of the soils or equivalent data.

(c) An estimate of the total number

TABLE 1: Maximum axle or wheel loads permitted (tonnes)

Country	*Motorways*	*Main roads*	*Secondary roads*
Austria	Single axle 10 t Tandem axle 16 t	Single axle 10 t Tandem axle 16 t	
Belgium	Axle load 13 t	Axle load 13 t	Axle load 13 t
Czechoslovakia	Single axle 10 t	Single axle 10 t	Single axle 10 t
Denmark	Single axle 10 t		
France	Single axle 13 t Tandem axle 20 t (10 t per axle)	Single axle 13 t Tandem axle 20 t (10 t per axle)	
Great Britain	Single axle 10 t	Single axle 10 t	Single axle 10 t
Netherlands	Maximum wheel load 5 t	Maximum wheel load 5 t	Maximum wheel load 5 t
Italy	Single axle 12 t Tandem axle 19 t	Single axle 12 t Tandem axle 19 t	Single axle 12 t Tandem axle 19 t
Spain	Single axle 13 t Tandem axle 21 t	Single axle 13 t Tandem axle 21 t	Single axle 10 t Tandem axle 16 t up to 13 – 16 t respectively by special license
Sweden	Single axle 10 t Tandem axle 16 t	Single axle 10 t Tandem axle 16 t	
Switzerland	Single axle 10 t Tandem axle 16 t	Single axle 10 t Tandem axle 16 t	Single axle 10 t Tandem axle 16 t
West Germany	Single axle 10 t	Single axle 10 t	Single axle 10 t

of vehicles in the design life period.

(d) The number of and load on the different axles.

(e) In large, open paved areas some assumptions concerning the routing or channelization of traffic.

From this a thickness design can be worked out using the principles given in published design guides[3,4].

Specialized vehicles, as used in port areas or container depots, usually have axle loads close to or in excess of 18 tonnes and to enable a thickness design to be determined an Advisory Data Sheet[6] was prepared by the C&CA based on a concept of design developed by the PCA of America for "soil cement" pavements[7]. This allowed wheel loads of up to 45 tonnes to be included in the design which is well within the limits normally imposed on the dual wheel configuration of most specialized vehicles and is appropriate to vehicles which do not have axles in the Road Note 29 sense. To use this, it was necessary to adopt the assumption made by Knapton[8] in which he stated that blocks and laying course sand have load carrying capabilities similar to an asphaltic roadbase and surfacing 160 mm thick.

Vehicles such as fork lift trucks have in most cases dual wheel configurations. A typical example of this and that of the loading characteristics of straddle carriers is shown in Figure 3. In the case of the fork lift truck the combined loading effect on the pavement is equated into a single wheel load and by using the design procedure given in reference 6 a design thickness can be calculated.

An example of these loading types is shown in both Figure 4 where a loaded straddle carrier is seen traversing the block pavement at Ipswich docks and in Figure 5 where a fork lift truck capable of carrying a load on the front axle of 68,000 kg is traversing the block pavement at Grimsby docks.

To design for specialized traffic the following information must be known:

(a) The design life.

(b) Load repetitions during design life.

(c) The heaviest wheel loads applied to the pavement.

(d) Tyre contact areas.

(e) Wheel spacings (dual wheels).

(f) The bearing value or CBR value of the subgrade or sub-base if used.

Vehicles of all types in container depots tend in many cases to traverse identifiable pavement routes in each run and this channelizing has the effect of increasing the number of vehicle movements against that of the general area. However, it has not been considered expedient on many projects to accommodate this in the design as layouts cannot be deemed to be definitive and route discipline on partly filled sites is known to be lax.

Industrial applications

In considering the use of block paving engineers in this country were obviously impressed with the paving method and were quickly aware of its potential. From European experience it had been shown that blocks can be used in a variety of ways. The in-use versatility of this paving type has, to-date, been restricted to applications other than airfield pavements and high speed roads.

From an engineering point of view it has been found that there are many advantages to be gained not least the fact that the pavement can be trafficked immediately after the construction process has been completed.

In designing heavy duty industrial and commercial pavements, the selection of surfacing type to cope with the severe operating conditions has to be considered in relation to the other function requirements and in the industrial sphere of container and bulk handling these requirements are:

(a) Adequate strength under high static loads.

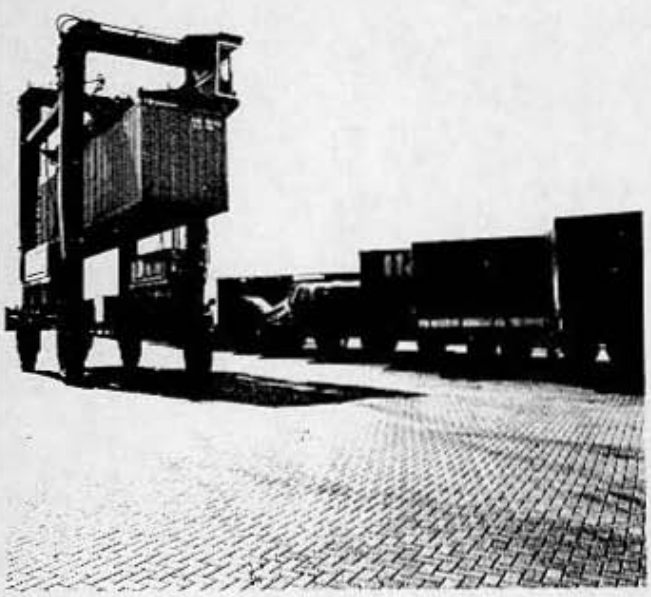
(b) Adequate strength under high wheel loads.

(c) Resistance to chemical attack, spillage and impact.

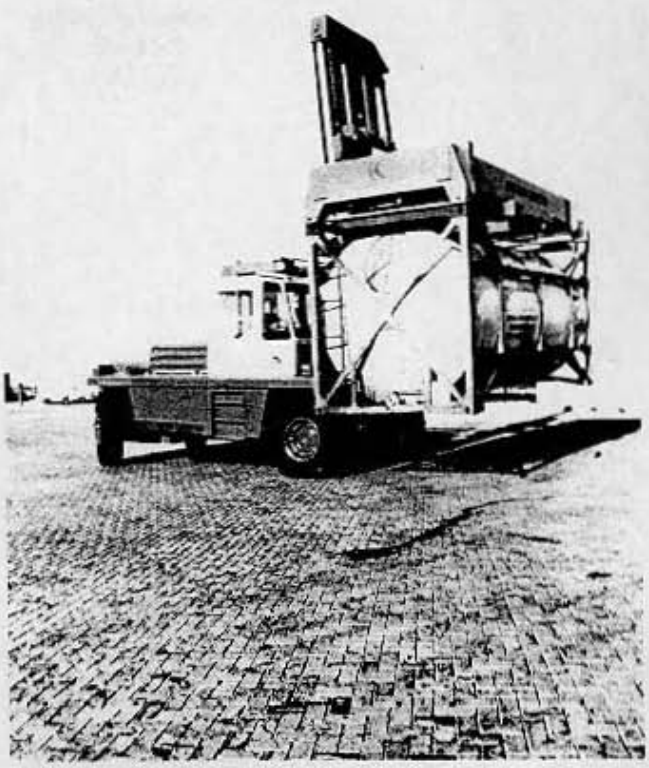
(d) Articulation under differential settlement.

In container handling areas and trailer parks where materials other than concrete have been used indentations in the surfacing is common, although to varying degrees, depending upon the stiffness of the surfacing material used and the loads imposed on it.

Much of the specialized handling equipment used is hydraulically operated and spillage of fluids can be prolific. The use of concrete paving blocks in these conditions has an obvious advantage over other flexible pavement types and when oil spillage and deposits of tyre rubber become impregnated to an unacceptable



Above. Figure 4: Straddle carrier, Ipswich Docks



Right. Figure 5: Fork lift truck, Grimsby Docks

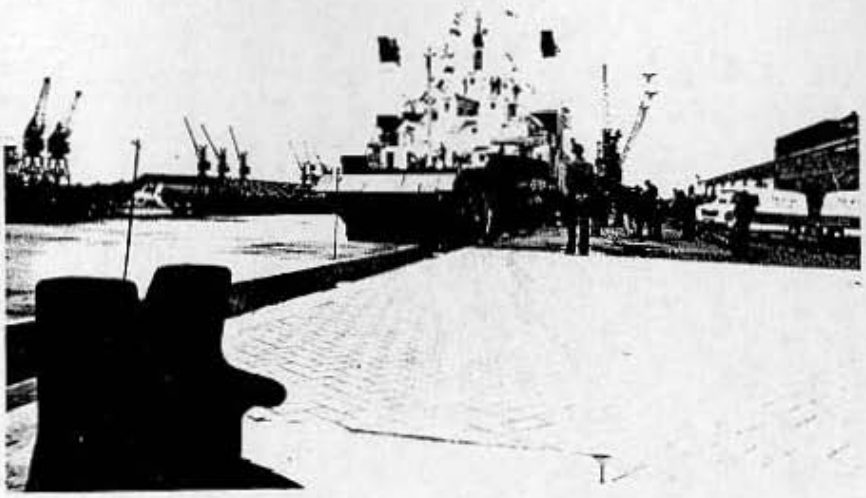


Figure 6: Grimsby Docks

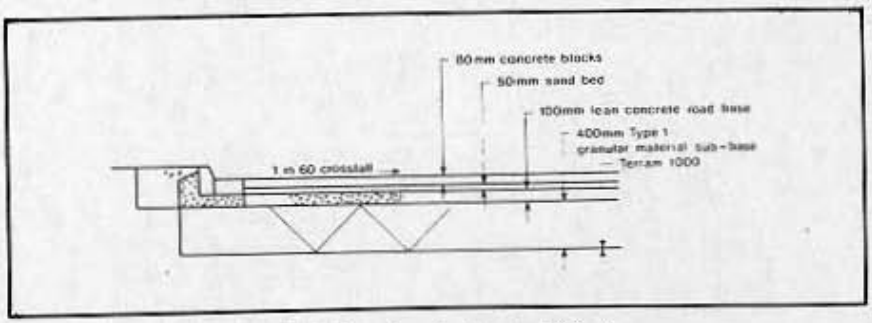


Figure 7: Cross section through dock paving, Ipswich and Grimsby



Figure 8: Rothersthorpe Service Station, M1 Motorway, Northampton

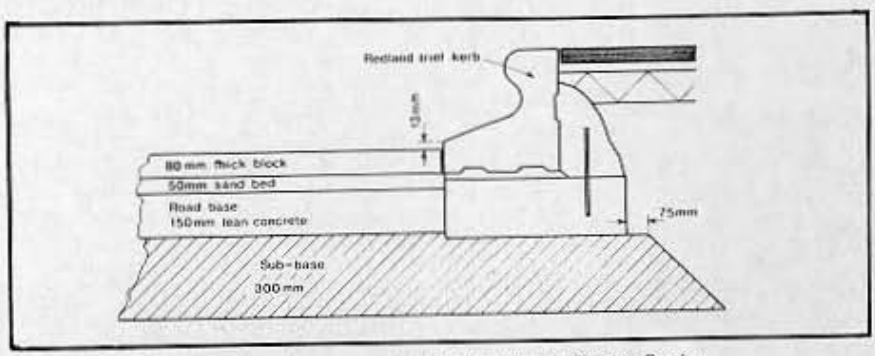


Figure 9: Cross section through pavement at Rothersthorpe Service Station

degree, the blocks can be cleaned with oil solvents.

Dock container depot

In the development of the dock area at Grimsby in Lincolnshire (Figure 6), 7000 m² of 80 mm thick blocks were laid to form a working platform to a container depot where fork lift trucks with a front axle load of 68,000 kg traverse the pavement daily. The pavement is constructed over made-up ground of pulverized fuel ash laid over a clay subgrade as shown in Figure 7.

This has proved to be successful and a further extension to the dock area is planned for the near future. This is just one example of many such installations in the UK.

Generally no problems are encountered when block paving is used to form a pavement except possibly in localized spots where some minor deformation can be expected depending on whether or not the pavement is founded on made-up ground. Minor deformation induced by the initial settlement of the subgrade soils can occur and when this is present in the trafficked aisles it can be accentuated by the channelizing of vehicles. However, this presents no real problem as the blocks can, when necessary, be lifted and relaid to the correct level. If differential, even severe differential settlement is to be accommodated, block paving offers a highly successful unique solution.

Petrol filling station

Concrete block paving is now being used extensively in the construction of commercial petrol filling station forecourts; Figure 8 shows one of these sited at Rothersthorpe Service Station, Northamptonshire, which has performed excellently under the continuous traffic loadings. A cross section of the pavement structure is shown in Figure 9.

Although it was originally thought, from an environmental point of view, to be undesirable to use this form of construction, because of the likelihood of petrol percolation through to the subgrade and possibly entering the drainage system, this has not proved to be the case in practice. The joints of concrete block paving seal themselves through the natural process of detritus forming in the joint and sealing the area from the passage of moisture, or in the case of petrol stations, petroleum spirits. Normally a cement bound roadbase or sub-base is used in such pavement designs and it has also been known to seal the joints of concrete block paving with a mixture of dry sand and cement to ensure that no liquids find their way into the substrata, especially at an early age.



Figure 10: London Heathrow Airport, bus terminal

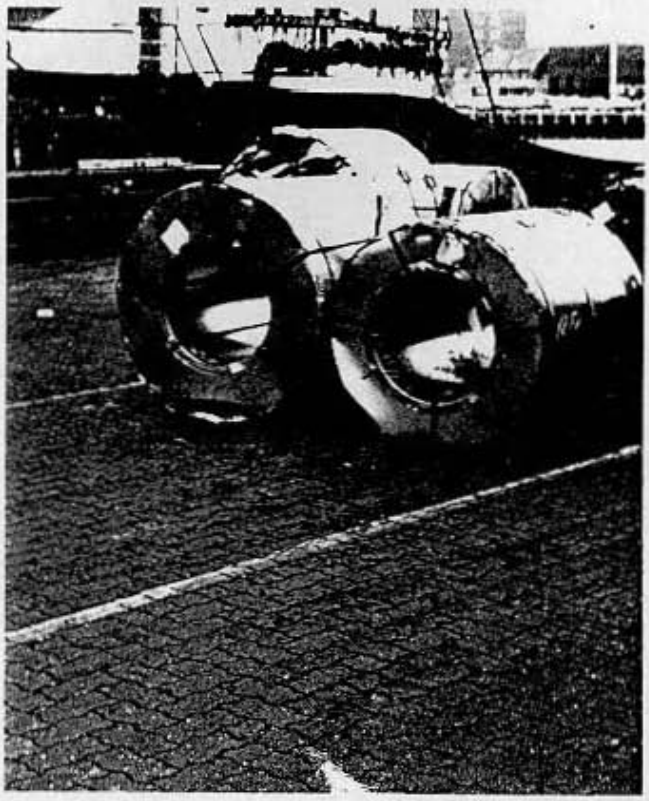


Figure 12: Poole Harbour

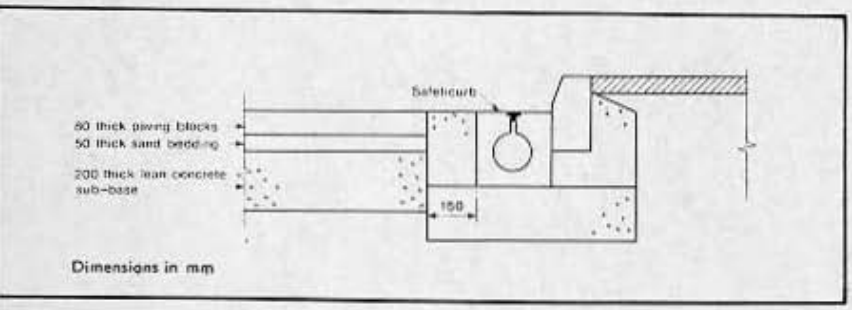


Figure 11: London Heathrow Airport. Cross section through pavement structure

Bus station

Another example of heavy duty commercial application of blocks can be seen in Figure 10 where blocks have been used to form pavements for the London Airport Central Bus Terminal. A continuous flow of traffic is in operation through this terminal and although a trial was implemented to assess whether or not a sand bed stabilized with cement would perform better than sand only at transition points between the block paved area and the adjacent concrete paved entrance road, information gained so far has not indicated any differences between the two methods. The construction used on this particular project is shown in Figure 11.

Other heavy duty harbour paving

At Poole Harbour, Figure 12, blocks were used to pave the area adjacent to the quay wall (a cross section is shown in Figure 13) where ships from the Continent unload their cargoes of coiled steel plate. These coils range in weight from 8 to 21 tonnes and although impact loading can be great, no surface deterioration in the paved surface is evident. Other areas of paving with the Poole Harbour complex exhibit the same characteristics under load where container vehicles arriving from the Continent are parked. Loads applied through the trailer structures can be extremely high and in measuring one of these it was found that a load of 8.6 tonnes was being exerted onto the pavement surface through two wheels supporting a single trailer leg. The measured contact area of each of the jockey wheels proved, from imprint, not to exceed 75 mm² in area. Although some improvement can be obtained for this loading situation by using skid-foot supports, as these spread the load over a much greater area, there is no real evidence from any of the industrial paved areas to suggest this is necessary as no unacceptable deformation occurs.

The bad practice of dropping trailer legs on block paving, like other materials, can produce some surfacing damage which in time is likely to require some block replacement.

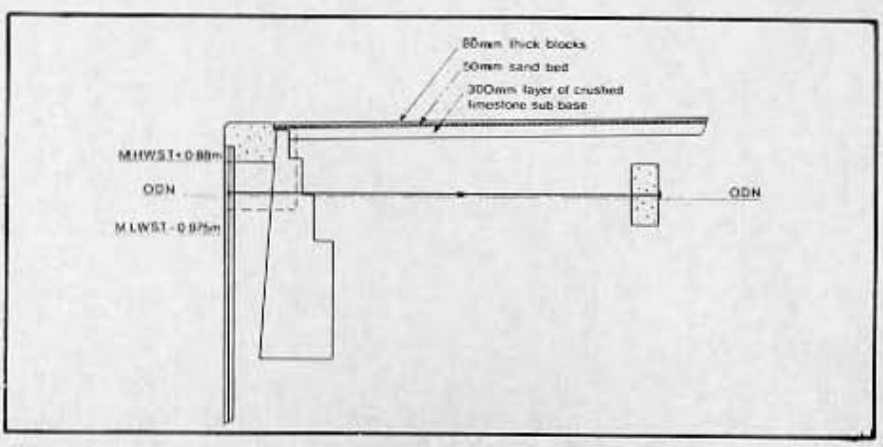


Figure 13: Poole Harbour. Cross section through pavement



Figure 14: Market at Darwen, Lancashire



Figure 16: Industrial pavement. Garton Sons & Co., London

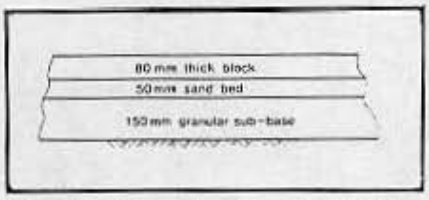


Figure 15: Cross section through pavement, Darwen

Also when trailers are being moved by tug it is not uncommon for them to be dragged from their bays on their supports, causing surface scoring. The use of skid-foot plates would reduce both of these potential problems.

Market square

The construction of block paved areas can enhance the aesthetic value of market squares by permitting the use of geometric designs that give length and breadth and feeling to a development. As can be seen in Figure 14, blocks laid to a market square in Darwen, Lancashire, radiate from the perimeter of the building forming an attractive and spacious platform. These were constructed on a sub-base of lean concrete as can be seen from the cross section shown in Figure 15.

Industrial pavement

The speed at which block paving can be constructed is extremely variable and a recent survey of contractor's output has shown this to be between 20 to 120 m^2 per man day. When access time is limited construction rate is of prime importance. This can be illustrated in the case of a shut-down job carried out over a Christmas holiday period at a factory in London, Figure 16, where a continuous process of manufacture dictated that reconstruction work to a paved area constructed many years previously, be carried out over a seven day period. This required the removal of the existing pavement, which consisted of a mixture of granite setts, concrete and bituminous surfacing, and the laying of a new sub-base, sand and blocks to enable vehicles to traverse the pavement again at an early age. From the cross section through the pavement, Figure 17, it can be seen that a drainage channel was also included in the construction, the whole being carried out over a three day period. The success of this operation proved the viability of concrete block paving for difficult paving or repairing work.

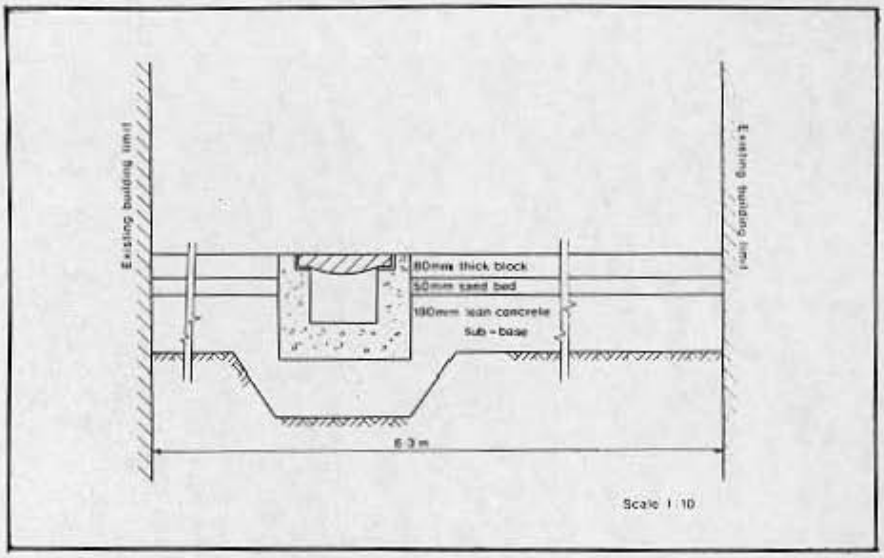


Figure 17: Cross section through pavement. Garton Sons & Co., London

Rail goods yard

In the field of rail transportation, there have been many developments carried out over the last 15 years in constructing container handling depots and goods yards.

The selection of pavement types for these is varied but one that has been very successful again uses concrete blocks. In Figure 18 a railway goods yard, at a depot in Wolverhampton, handling the shipment of steel, has used blocks between the rail track at crossings and in the general goods handling area. From the cross section, Figure 19, it can be seen that an angle bar has been welded to the

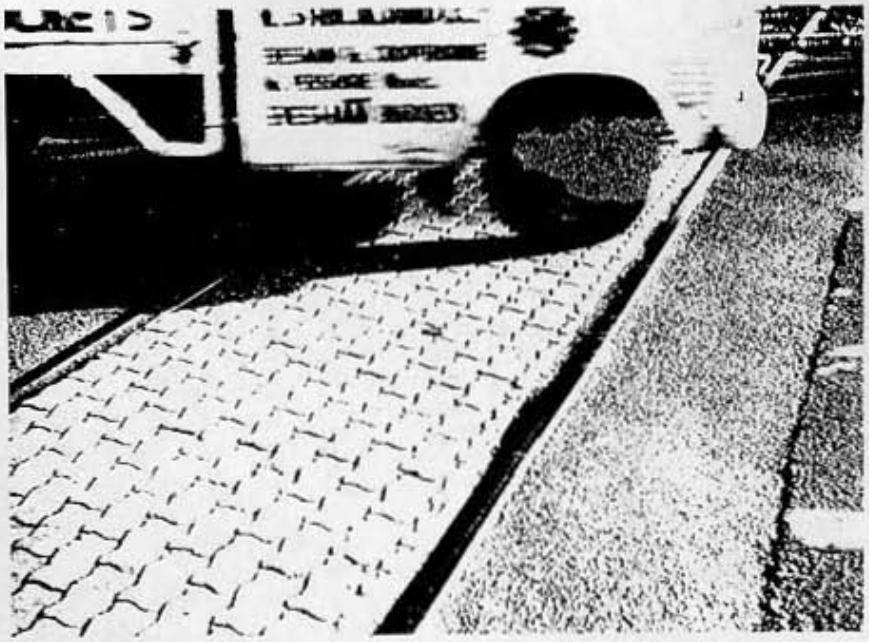


Figure 18: British Rail, Wolverhampton

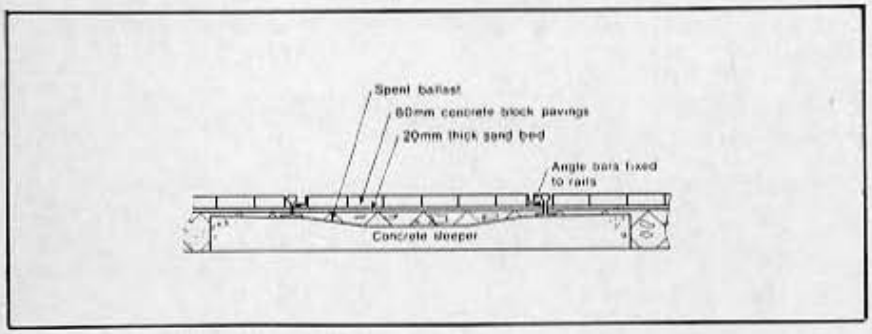


Figure 19: Cross section through pavement, British Rail



Figure 20: Embankment, Haringay Borough Council

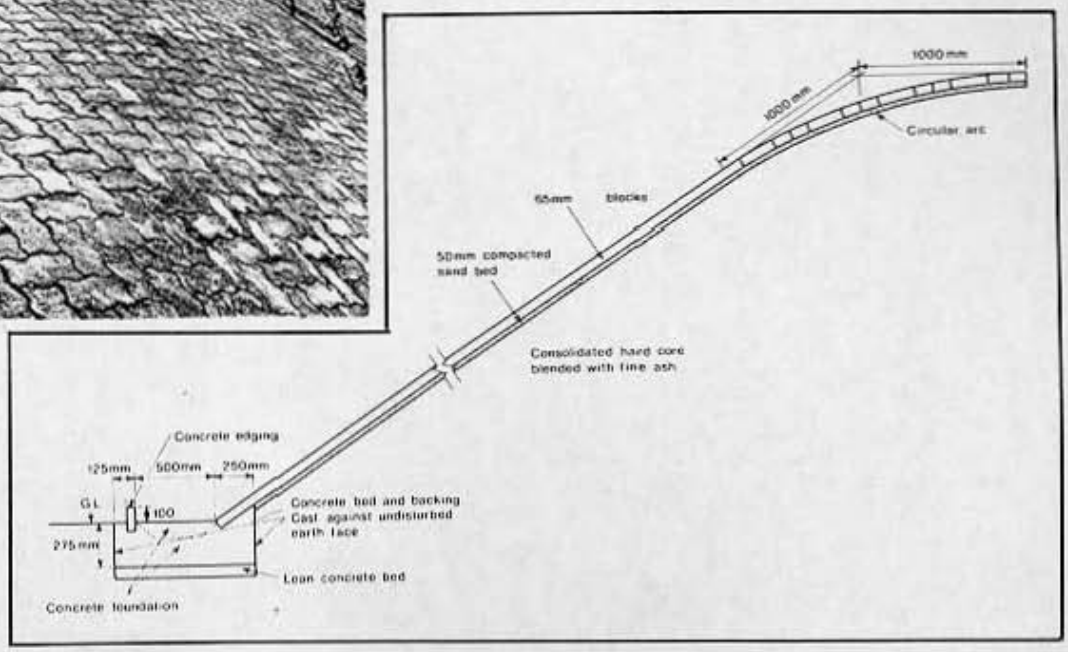


Figure 21: Cross section through embankment, Haringay

rail to provide space for the wheel flanges of the goods trucks to traverse the pavement at these sections without disrupting the paved surface. The extremes of loading and vibration from rolling stock has had no ill-effect on the bocks which were laid, on a sand bed, between the rails.

Embankment facing

The versatility of block paving in use is aptly illustrated in Figure 20 where 3000 m² of blocks 60 mm thick were used as a revetment facing to a road embankment some 7 m high with a slope of 30°. The project did experience some minor difficulties during its construction and in one case it was found necessary to increase the radius of curvature to 5 m, in place of the 2 m originally specified. It had been thought that the rate of discharge of surface water from the sloped embankment may wash out the sand joint but to-date there is no evidence to suggest that this is happening. A cross section of the work showing the drainage channel which also acts as a toe beam is shown in Figure 21. Surface water is carried along this channel to drainage points at 10 m centres where it is discharged into soakaways.

Blocks were chosen in preference to the more conventional forms of construction of either an earth fill seeded over to give cohesion to the soils or a reinforced concrete retaining wall to reduce width and land usage, as it was determined that the development of vertical and horizontal pressure would be contained by virtue of the overburden pressure applied by the blocks aided by their mechanical interlock.

Discussion

To-date the only problems which have come to light have been those of

TABLE 2:

Sand type, etc.		*Moisture content (%)*							
		2	4	6	8	10	12	14	16
Coarse or crushed sand	Surcharge factor	26	.36	**.42**	**.42**	.36	.27	20	.12
	Surcharge* (mm)	13	18	**21**	**21**	18	14	10	6
Medium sand (Zones 2 & 3)	Surcharge factor	.20	.25	**.25**	**.25**	.22	.20	.17	.14
	Surcharge* (mm)	10	13	**13**	**13**	11	10	9	7
Fine sand (Zone 4)	Surcharge factor	14	.24	.29	.30	.28	.25	.24	.21
	Surcharge* (mm)	7	12	15	15	14	13	12	11

* Surcharge associated with a 50 mm compacted thickness of laying course.

The bold figures indicate the normal working range when sand is stocked in advance, allowed to drain and is sheeted over.

detail and reflect, in some cases, the type of design assumption and contract interpretation problems that are prevalent in road and paving construction. These include:

(a) Surface level tolerance and drainage detail requirements.

(b) Localized surface deformation resulting from rotational movement of blocks at transitions with other types of pavement.

(c) Block thickness.

Surface level tolerance and drainage detail requirements

Where large areas of pavements are to be constructed, or where pavements with minimum drainage falls are required, control of the sand moisture content to a limit of between 6 and 8% is necessary in controlling the small amount of paving block settlement. In Table 2, an indication of the bulking factor related to sand type and grading is given as is the amount of surcharge to be used in attaining a 50 mm compacting depth of sand beneath the block paved area required by specification. By controlling this factor the surface level tolerance of the pavement can be retained at that achieved during the construction process. Any real variation in this factor can result, in these particularly strict circumstances, in small uneven settlement when the sand laying course eventually dries out. This aspect of carefully controlled workmanship is worthy of consideration as is the far more important requirement to maintain good surface regularity on the roadbase or subbase and a constant laying course sand thickness.

These factors are obviously of importance where minimum falls to drainage channels are required. From a design point of view large areas of paving can present problems with regards to surface drainage if the design work is not carefully undertaken.

Several methods are available to meet this requirement including the use of slotted precast concrete drainage units, but where reliance is placed on the creation of drainage channels within or to the side of the block paved surface, it is necessary to bed either the blocks being used in the channel area or the precast concrete channel units on concrete or cement/sand mortar to retain continuity of level. The adjoining sand bedded paving should be laid slightly proud to accommodate any minor settlement.

Localized surface deformation resulting from rotational movement of blocks at transitions with other types of pavement

Where transitions occur in block paved areas from one type of surfacing to another, and also at points adjacent to gullies and manhole covers, a similar treatment is required. Rotation of the blocks at these points has been known to occur and, in an effort to overcome this, stabilization of the sand laying course for a distance of approximately 1 m from the transition line has been used to minimize the risk.

Block thickness

Most of the industrial pavements in the UK surfaced with blocks all use 80 mm thick blocks, some areas being in rectangular blocks while others use a proprietary shape. To-date these have all performed well when provided with a suitable base and sub-base. In some cases areas of concrete block paving, subjected to continuous heavy commercial traffic, have exhibited isolated or group block cracking. Although this can be classed as an undesirable feature it is also worthy of note that to-date even a 6% block cracking rate has not affected the performance of the pavements. Should rectification be required at some future date, this can be easily undertaken.

Conclusion

The principal factors affecting the design of concrete block paved areas are loading and the characteristics of the subgrade. When these two factors are taken into consideration, a thickness design can be determined by using published material to obtain a pavement with a long life and low maintenance costs. In subgrade settlement areas precast concrete blocks offer the best solution in overcoming the problems. In these conditions the functional ability of concrete block paving to articulate permits deformation of the pavement without undue loss of the structural integrity. Blocks also have the advantage of offering an attractive method of surfacing which is not affected by oil spillage and is easy to lift and replace when circumstances require such treatment.

In commercial and industrial sites, block paving can be used in almost any situation to provide an economic system of construction which requires the least plant and a pavement which is usable immediately after completion of the construction process.

Acknowledgements

The help and co-operation of the following are acknowledged:

C.E. British Transport Docks Board, Lincolnshire.

Blue Boar Group, Hancock & Co., Milton Keynes, Buckinghamshire.

The Harbour Engineer, Poole Harbour Commissioners, Poole, Dorset.

The Senior Engineer, Ipswich Port Authority, Ipswich, Suffolk.

British Airports Authority, London SW1V 2RP.

Divisional Civil Engineer, British Rail (London Midland Region), Birmingham B1 1TD.

Eastern Gas, British Gas Corporation, Potters Bar, Hertfordshire.

Borough Engineer, Borough of Haringey, London N8.

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