INTERLOCKING CONCRETE BLOCK PAVEMENTS FOR COLD CLIMATES

ANTHONY N.S. BEATY, PROFESSOR OF CIVIL ENGINEERING, ROYAL MILITARY COLLEGE OF CANADA
P.O. Box 17000, Stn. Forces, Kingston, ON, K7K 7B4, Canada.
TEL +1-613-541-6000 Ext. 6393 FAX +1-613-545-8336
E-Mail beaty-a@rmc.ca

ABSTRACT

Although interlocking concrete block pavements are used extensively in tropical and temperate regions, they have as yet been little used in cold climates. The nature of interlocking concrete block pavements is briefly presented. The key elements constituting a high quality block pavement, to support traffic or industrial loads, are described and the approach to their design summarized. The problems posed by the construction and maintenance of pavements over permafrost and some of the special techniques evolved to overcome these problems are reviewed. In the context of these particular problems of pavements in the northern environment, the advantages and design of interlocking concrete block pavements are discussed and a typical cross-section, for use in permafrost areas, is proposed.

1. INTRODUCTION

The use of interlocking concrete blocks for structural pavements, carrying traffic and industrial loads, has increased steadily throughout the world over the past thirty years. In many industrialized countries concrete block paving has become the preferred form of surfacing in ports and container handling yards, where extreme loads are transmitted to the pavement by mobile handling equipment. In spite of this acceptance in tropical and temperate parts of the world, the use of concrete paving blocks for load-bearing pavements in remote, permafrost areas does not yet seem to have been considered. This form of paving has a number of advantages particularly relevant to the solution of problems posed by the construction of roads in permafrost areas. Permafrost underlies twenty per cent of the world's land area. Half of the territory of Canada and of the former Soviet Union lies within the permafrost zone [1]. It is also significant in China, Scandinavia, Alaska, and Greenland. In Canada, the population of the permafrost area is very small and construction problems due to permafrost are accentuated by remoteness. In the Commonwealth of Independent States and China, however, the permafrost areas are more heavily populated and large population centres exist. In this paper the concept of the application of concrete block paving to structural pavements in remote northern areas subject to permafrost is presented.

2. ELEMENTS OF CONCRETE BLOCK PAVING

An interlocking concrete block pavement is a flexible pavement in which the surfacing consists of high quality, high strength, concrete pavers laid on a thin layer of selected sand referred to as the laying course or bedding sand. The required thickness and material properties of the base and sub-base depend on the strength of the underlying subgrade soil and on the anticipated traffic loading. The key elements of a concrete block pavement are the pavers, the bedding sand, the joints, the jointing sand, the edge restraint and the laying pattern. General details of these elements have been extensively discussed elsewhere and the following remarks are confined to factors of particular reference to cold climate applications.

2.1 Pavers

Many of the countries, in which concrete block paving is extensively used, have issued specifications for pavers. For applications in permafrost areas, the most relevant specifications are those which include a requirement to perform satisfactorily in cold climates, in which freeze-thaw durability is an important concern. In Canada, pavers are governed by a Canadian Standards Association standard [2]. The average compressive strength is not to be less than 50MPa after 28 days, with no individual test value less than 45 MPa. To ensure durability in Canadian winter conditions, pavers should lose no more than 1% of their initial dry weight when subjected to 50 cycles of freezing and thawing while fully immersed in a 3% saline solution.

2.2 Bedding Sand

The pavers are laid on a layer of bedding sand. The main functions of this laying course are to provide an even surface on which to lay the blocks, to accommodate the manufacturing tolerances in block thickness, to accommodate accepted tolerances (± 15mm) in the surface level of the base, to provide uniform support for the blocks, to avoid stress concentrations which could cause damage to the blocks and to fill the lower part of the joint spaces between adjacent blocks in order to develop interlock. The material used for the laying course is a clean, washed sand typical of that used to make concrete. Suitable gradings have been specified in Britain [3] and in Australia [4]. In permafrost conditions it is considered that the amount finer than 75 microns should be limited to 3 % and that for pavements subjected to severe loading, such as channelised traffic, there should be no particles smaller than 75 microns. It is essential that the sand particles not break down under repeated loading. Particle shape and mineral hardness contribute to this; flaky or elongated particles are fragile and should be avoided. It is considered that the Moh's hardness of the predominant minerals should be at least 5.5. In order to avoid fragile particles it is useful to subject bedding sands to a degradation test such as that developed by Lilley and Dowson [5]. It has been suggested [6] that, for the laying course of concrete block pavements subjected to traffic or industrial loading, only naturally occurring silica sands should be used.

2.3 Joints

Sand filled joints are an integral part of a concrete block pavement. They permit the block surface course to behave flexibly by allowing some articulation of individual blocks and they provide the structural interlock necessary for stresses to be distributed among adjacent blocks. Joints need to be sufficiently wide to allow this flexible behaviour, but not so wide as to permit excessive

movement of the pavers. Joint widths should lie in the range 2 to 4 mm with a preferred size of 3mm. Those wider than 5 mm should not be accepted. 2 mm wide spacer ribs cast integrally on the vertical surfaces of the pavers ensure minimum joint width and assist in rapid placement of the blocks. There are no requirements specific to joints in cold regions.

2.4 Jointing sand

The sand used to fill the joints between individual paving blocks should be a fine, washed sand. Suitable gradings have been specified in Britain [3] and Australia [4]. It is, however, considered that in permafrost areas, the amount passing the 75 micron sieve should be less than 3 % to ensure that the material is non-frost - susceptible. The filled joints provide both translational and rotational interlock and also greatly reduce the ingress of water. Well-constructed concrete block pavements with normal crossfalls are considered substantially waterproof after an initial period of settling-in under traffic. Joint sealing is not generally necessary but may be useful in special cases. In permafrost applications, joint sealing is recommended if the pavement will be subject to frequent de-icing and snow removal operations. The performance of joint sealers used in temperate regions will need to be verified over the range of temperature experienced in permafrost areas.

2.5 Edge restraint

A key element of a concrete block pavement is edge restraint which resists lateral movement of the blocks and prevents loss of sand from the laying course. For block pavements supporting traffic, the edge restraint should be a concrete kerb or combined kerb and gutter, extending well below the laying course and bedding and haunched in concrete to prevent movement. If effective edge restraint is not provided, lateral movement of the blocks will occur, due to traffic stresses, resulting in loss of structural interlock and failure of the pavement. In cold regions, edge restraints will need to be carried down below the depth affected by seasonal movements caused by cycles of alternate freezing and thawing.

2.6 Laying pattern

The laying pattern chosen for interlocking concrete block pavements to support traffic loads should be resistant to horizontal creep. The integrity of the pattern should not be affected by traffic stresses as this can lead to opening of the bond fines with consequent loss of interlock. In practice it has been found that 45° herringbone bond performs best and should always be used on pavements supporting traffic loads.

3. DESIGN OF CONCRETE BLOCK PAVEMENTS

Interlocking concrete block pavements are usually designed as flexible pavements with the blocks and laying course being substituted for the bituminous surfacing using material equivalence factors. It is generally accepted that an 80 mm thick paver laid on bedding sand having a thickness of 30 mm after compaction is equivalent to 110 mm of dense hot mix asphalt [7]. Material equivalence is based on the load spreading capability of the materials. Where a pavement surfaced with concrete blocks is being compared to a design having an unbound

granular surfacing, it would be reasonable to consider an 80 mm paver equivalent to 160 mm of high quality granular base material. As with all flexible pavements, the thickness required for a concrete block pavement depends on the subgrade strength, the traffic loads and the stress-strain characteristics of the materials constituting the pavement layers.

3.1 Subgrade

The most widely used method to characterise subgrade strength is the California Bearing Ratio (CBR). On soils having a CBR value of five or less, the subgrade must be protected from weakening by weathering and construction traffic. This is achieved by covering the subgrade with a low-cost, unbound, non-frost-susceptible, granular material having a thickness of between 250 mm and 600 mm depending on the CBR value. Every effort should be made to minimise the disturbance of weak subgrades. In permafrost areas this is critical.

3.2 Traffic

Paved surfaces over permafrost are generally situated in remote areas of low population density, where the types of vehicle constituting the traffic will be limited find known. In this case, the most appropriate approach will be to establish typical axle loads for each vehicle type and to convert these to equivalent standard 80 kN axles using the formulae established from the AASHO road test [8]. Allowance for expected traffic growth should be made and the predicted equivalent standard axle loads summed over the desired design life of the pavement. This approach is used for design of pavements in ports and container handling yards [9].

4. PAVEMENTS IN PERMAFROST AREAS

The construction of roads or runways over permafrost raises a number of difficulties, which include:-

- thermal degradation
- thaw settlement
- frost heave
- drainage
- shortage of construction materials, particularly for surfacing
- costly maintenance

In permafrost areas, in addition to the requirement that a pavement should provide an even surface, which will allow safe passage of vehicles even during the critical spring thaw period, the pavement needs to be designed and constructed in such a way as to prevent thermal degradation of the subgrade and right-of-way [10]. The principal problem in constructing roads~in permafrost areas is that any disturbance of the natural vegetative ground cover or of the natural terrain, tends to disturb the thermal equilibrium. This causes thawing and settlement. Cycles of freezing and thawing produce ice lenses and give rise to frost heave. The basic principle of pavement construction over permafrost is to cause the minimum disturbance possible. The standard temperate climate approach, which is to remove vegetation and organic topsoil, as the first step in construction is inapplicable in permafrost areas. A further potentially serious problem is that

of drainage. Although precipitation is generally modest in northern regions, the underlying permafrost presents an impermeable barrier to ground water flow, which is therefore confined to the active layer, where all run-off accumulates. Conventional drainage ditches alongside the road cannot usually be successfully established in permafrost areas. Granular materials, of the quality normally specified for road construction in more temperate areas, are either not available or can only be obtained with difficulty, at high cost and in limited quantities. To achieve gradings of granular materials commonly specified in the south would often require extensive washing and screening. Granular materials derived from sedimentary or metamorphic rocks often perform poorly in the northern environment. Pit and quarry operations in permafrost areas put thermal equilibrium at risk. Hauling large quantities of granular materials in remote permafrost areas, where few roads exist, also poses many problems.
Most pavements in permafrost areas are surfaced with unbound granular materials which move under traffic action. The harshness of the thermal environment produces heaving and settlement of the road surface and damage to embankment slopes. These factors result in high maintenance costs.

A number of special techniques have been established for use in maintaining thermal equilibrium of permafrost in the vicinity of pavements and associated embankments or for the control of frost heave. These include:-

- insulation
- peat underlay
- geotextiles
- air ducts
- thermosyphons
- snow management
- pavement colour

4.1 Insulation

The State of Alaska has been experimenting with the use of insulation in road embankments for the control of both frost heave and thaw settlement under embankment side slopes [11]. Of the types of insulation tested, extruded polystyrene foam boards were found to be the most effective. In an experimental installation on the MacKenzie Highway near Inuvik [12], the use of 90mm thick extruded polystyrene boards was found to be effective in controlling permafrost degradation. The aim of using insulation, in the embankment, in conjunction with gravel fill, is to maintain the active permafrost layer within the non-frost-susceptible fill material and to prevent it from penetrating the underlying thaw- unstable permafrost soils.

The use of insulation also allows a reduction in the thickness of granular embankment required. In Sweden, it has been calculated that for the same frost protection, an embankment, combining insulation and gravel, costs less to construct than its equivalent in gravel alone [13].

4.2 Peat underlay

Peat has a very high moisture content and therefore high thermal mass, resulting in its use in Norway [14] as early as 1903, as a soil replacement layer under railways and roads for the control

of snow cover from the embankment slope was also reported to be beneficial, but less effective than snow sheds.

4.7 Pavement colour

In permafrost areas it is desirable for the pavement surface to absorb as little solar radiation as possible in order to cause the minimum possible disturbance to the thermal equilibrium of the permafrost. To achieve this, black asphalt pavements have been painted white, for example at Fairbanks, Alaska [20] at Thule, Greenland [21] and at Alert, N.W.T.[22]. It has been found [16] that although white paint is very effective in reducing heat absorption, it becomes very slippery when wet and wears away very rapidly under traffic, necessitating costly annual repainting.

5. CONCRETE BLOCK PAVING FOR PERMAFROST AREAS

5.1 Advantages

Concrete block paving offers a number of potential advantages for paved surfaces in permafrost areas. These include:-

- the relative simplicity of laying a block pavement compared to asphalt or concrete slab pavements, no paving train or mixing plant is required and the blocks can be laid manually by relatively unskilled labour
- factory manufacture of pavers ensures consistent high strength and good dimensional control thus alleviating the difficulties of achieving good quality control of asphalt or concrete manufacture in the northern environment
- block pavements can tolerate larger vertical deformations without distress than asphalt or concrete slab pavements
- in the event of excessive differential movement, local damage, or the need to gain access to services beneath the pavement, concrete blocks can be lifted, the affected area corrected or re-installed and the pavers cleaned and relaid
- a correctly installed block pavement needs virtually no structural maintenance
- pavers are unaffected by freezing conditions
- pavers are non-polluting and environmentally neutral
- pavers can be transported in small quantities, for example on a space available basis in the small aircraft which often serve communities in remote, permafrost areas
- block pavements are capable of supporting heavy loads and tracked vehicles and are suited to low speed aircraft taxi-ing and manœuvring areas
- experience with concrete block road pavements over many winters has shown them to be resistant to de-icing chemicals and to be unaffected by normal snow plough operations
- block pavements have low maintenance costs

5.2 Colour

Concrete pavers can be produced in a wide range of colours by a number of different means.

They can be made in light colours so as to minimize the absorption of solar radiation and associated disturbance of the thermal equilibrium of the permafrost often produced by asphalt surfacing. In order to produce a light coloured paver the following methods are available:-

- the use of white cement, the addition of a white pigment and the selection of light coloured aggregates to make the entire block as light coloured as possible
- the use of two mixes, a normal one for most of the block and a light coloured topping mix for the upper 5 - 20 mm of the block
- painting their surface with a white epoxy resin paint
- making their surface light-reflecting by addition of Ballotini to the surface paint
- use of a flame-spray technique to apply a polymer powder to the surface giving an intense colour

For use in remote, permafrost areas it would be preferable to incorporate the light colour as an integral part of the block because then there would be no surface colour to wear off and the natural concrete surface would offer better skid resistance than a painted surface. Thus a white paver would offer the advantages of white paint without the disadvantages.

5.3 Design

In permafrost areas, the first principle of pavement design is to minimise disturbance of the existing terrain and to maintain thermal equilibrium. If the active layer can be kept within the non-frost-susceptible materials of the road structure, adequate subgrade support will be provided by the frozen ground. Where this is not the case, support provided by the active layer in its thawed state is likely to be weak. The design of the pavement structure to meet these conditions will be affected by the choice of concrete block paving to the extend that (a) white pavers reduce the depth of thaw resulting from heat absorption by the pavement surface and (b) the block pavement surface will shed run-off from precipitation more effectively than an unbound gravel surface.

In concrete block pavements, the base generally consists of either crushed rock or cement stabilised materials. As cement treated bases have been shown to perform well in Alaska [23] they would be the preferred choice because (a) a lesser quality granular material can be used stabilised than unbound, (b) generally a smaller total thickness of pavement structure will be required, and (c) the surface of the cement stabilised base can be finished to a closer tolerance than can an unbound base. A minimum thickness of 150 mm of cement stabilised base is recommended. The surface of the base should be shaped to give a crossfall of 2½ % and longitudinal slope for drainage of 1¼ %. The surface of the base should be sealed with a bituminous primer or an impervious geotextile. This will assist curing and prevent loss of bedding sand as cracks develop in the base. The thickness of sub-base will be determined either from traffic loading considerations or by the need to provide insulation. The use of approximately 100 mm of expanded polystyrene board insulation beneath the base is to be recommended. A typical cross-section of a concrete block pavement proposed for use in permafrost areas is shown in Figure 1.

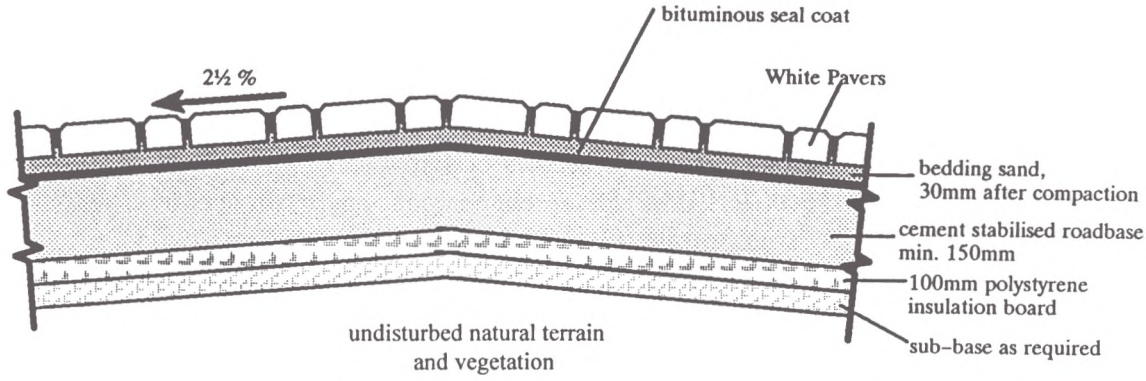

Figure 1 Conceptual concrete block pavement cross-section over permafrost

6. CONCLUSIONS

1. The use of interlocking concrete block pavements, to support traffic and industrial loads, is well established in tropical and temperate regions, but has not yet been tested in remote northern areas, where permafrost occurs.

2. Examination of the problems of construction and maintenance of pavements over permafrost and of certain advantages of concrete block paving compared to conventional sealed and unsealed pavements in these areas has led to the concept of the use of concrete block paving in permafrost areas.

3. A typical cross-section of a concrete block pavement for permafrost areas has been proposed.

REFERENCES

1. Brown, R.J.E. (1970) Permafrost in Canada, University of Toronto Press.
2. Canadian Standards Association (1985) Precast concrete pavers, Standard CAN3-A321.2-M85
3. British Standards Institution (1989) Precast concrete paving blocks, Code of practice for laying, BS6717:Part 3.
4. Cement and Concrete Association of Australia (1986) Interlocking concrete road pavements. A guide to design and construction, Publication T35.
5. Lilley, A.A. and Dowson, A.J. (1988) Laying course sand for concrete block paving, Proceedings of the 3rd. International Conference on Concrete Block Paving, pp. 457-462.
6. Cook, I.D. and Knapton, J. (1992) Bedding course sands, Proceedings of the 4th. International Conference on Concrete Block Paving, Vol. 2, pp. 285-294.
7. Knapton, J. (1989) Structural design of pavements with concrete blocks or clay pavers, Seminar on the Economics and Engineering of Concrete Pavements, University of New Brunswick, May.

8. Liddle,W.J. (1962) Application of AASHO Road Test results to the design of flexible pavement structures, Proceedings of the 1st International Conference on the Structural Design of Asphalt Pavements, Vol. 1, pp. 42-51.
9. Knapton, J. (1988) The structural design of heavy duty pavements for ports and other industries, 2nd. Edition, British Ports Federation, London.
10.Cowé Falls, L.G. and Haas, R. 91980) Pavement design for permafrost conditions: structural and thermal requirements, Transportation Research Record No. 755,. pp. 30-35.
11.Esch, D.C. (1986) Insulation performance beneath roads and airfields in Alaska, Proceedings of the 4th. International Conference on Cold Regions Engineering, pp. 713-722.
12.Johnson, G.H. (1978) Performance of an insulated roadway on permafrost, Inuvik, N.W.T., Proceedings of the 3rd. International Conference on Permafrost, Vol. 1, pp. 548- 553.
13.Gandahl, R. (1982) The use of plastic foam insulation in roads, Proceedings of the 4th Canadian Permafrost Conference, pp. 570-576.
14.Skaven-Haug, S. (1959) Protection against frost heaving on the Norwegian railways, Geotechnique, Vol. 9, No. 3, pp. 87- 106.
15.McHattie, R.L. and Esch, D.C. (1983) Benefits of a peat underlay used in road construction on permafrost, Proceedings of the 4th. International Conference on Permafrost, pp. 826-831.
16.Esch, D.C. (1988) Roadway embankments on warm permafrost, problems and remedial treatments, Proceedings of the 5th International Conference on Permafrost, Vol. 2, pp. 1223 - 1228
17.Henry, K. (1988) Use of geotextiles to mitigate frost heave in soils, Proceedings of the 5th International Conference on Permafrost, Vol. 1, pp. 548-553.
18.Zarling, J.P., Connor, B. and Goering, D.J. (1983) Air duct systems for roadway stabilization over permafrost areas, Proceedings of the 4th. International Conference on Permafrost, pp. 1463 - 1468.
19.Zarling, J.P., Connor, B. and Goering, D.J. (1983) Thaw stabilization for roadway embankments, Proceedings of the 5th. International Conference on Permafrost, Vol. 2, pp. 1352-1357.
20.Berg, R.L. and Aitken, G.W. (1973) Some passive methods of controlling geocryological conditions in roadway construction, Proceedings of the 2nd International Conference on Cold Regions Engineering, pp. 581-586.
21.Fulwider, C.W and Aitken, G.W. (1962) Effect of surface colour on thaw penetration beneath an asphalt surface in the arctic, Proceedings of the 1st. International Conference on the Structural Design of Asphalt Pavements, Vol.1, pp. 581-586.
22.Wojcik,A.S.E., Jarrett, P.M. and Beaty, A.N.S. (1983) Cold mix asphalt stabilisation in cold regions, Proceedings of the 4th. International Conference on Permafrost, pp. 1402- 1406.
23.Vita,C.L., Rodney, J.W. and Vinson, T.S. (1988) Bethel airport CTB pavement performance analysis, Proceedings of the 5th International Conference on Permafrost, Vol. 2, pp. 1330- 1335.