PAVE 92

BEDDING COURSE MATERIALS

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SUMMARY

This paper considers the requirements of a bedding material from the fundamental and theoretical point of view. On this basis appropriate criteria for a bedding material are proposed. These criteria are then checked against the practical requirements, and against actual construction and performance experience when a bedding material with the recommended characteristics is used in concrete block pavements.

These considerations suggest there is scope for re-examination of some current practice. The main criteria identified are a requirement for an aggregate with a topsize of not more than 9.5 mm, graded to comply with $p = 100\ (^{d}/_{D})^{n}$ where $0.45 < n < 1$ and not more than 4% finer than 75 μm. A limitation on the plasticity of the fine fraction is beneficial.

INTRODUCTION

The bedding sand layer or bedding course is the layer in an interlocking concrete block pavement between the blocks and the basecourse. The role of the bedding material can be crucial to achieving satisfactory pavement performance.[16]

Consideration of the attributes required of a bedding material suggests it is similar to an unbound basecourse material, but with the additional requirement that the blocks are able to bed into it. Thus much of the existing knowledge of unbound basecourses for pavements with thin bituminous surfacings can be applied to bedding course materials.

While much research has been carried out into unbound basecourses and much is known about it, it is a complex subject with potential for considerably more research if we are ever to fully understand it. Thus any attempt to define the requirements of a bedding sand by considering it from a fundamental/theoretical approach will be a combination of art and science.[2]

FUNCTIONS

The bedding course is primarily included in a concrete block pavement to level out any minor shape deficiencies in the basecourse surface, to allow blocks to seat firmly over their entire bottom face, and to absorb minor differences in block thickness.

Having included a bedding course it is required to have a number of attributes if the entire pavement is to perform well; the bedding course material must be hard and durable, it must allow blocks of various thicknesses to seat, it must be resistant to shear, it must provide the blocks with restraint to horizontal movement, it must be compatible with the jointing sand, it must be tolerant of saturation, and it must be able to be constructed and within the required layer thickness.

A desirable, but I suspect not essential, additional attribute is the ability for portions of the bedding material to penetrate up into the joints between the blocks.

ATTRIBUTES REQUIRED

Durability

The rock from which the bedding course is produced will have a direct influence on the performance of the aggregate. Some aggregates can weather under an environment similar to that of a road pavement [4], some of these can release highly plastic minerals eg montmorillinite; but whether this actually occurs in a pavement is less clear.

Part of the evaluation of an aggregate should be consideration of the likely products of weathering. This can be done by known previous performance, geological examination, and/or laboratory testing.[1]

Hardness

The individual particles must be hard enough to resist crushing during construction and under traffic. This will be partly influenced by the particle size distribution, the more well graded the aggregate the greater the surface area of individual particles in contact with other particles, so the less the individual crushing forces.[1] The rigidity of the subgrade also has an influence on required hardness, a less rigid subgrade causes more pavement deflection under traffic and hence more particle to particle rubbing. The shape of the individual particles also has an effect, with angular or flakey particles being more prone to crushing.

Crushing resistance can be determined by laboratory tests such as crushing resistance [5], that described by Lilley [6], or for vesicular particles by testing for lightweight particles [5]. Previous performance can also give an indication, but needs to be interpreted with caution.

Particle Size Distribution

The particle size distribution (grading) is one of the most fundamental properties of an aggregate.[3]

For a continuously graded aggregate the grading can be expressed by the equation

$$p = 100 \quad ({}^{d}/_{D})^{n}$$

where p = percentage passing sieve size d, and D is the maximum particle size. n is known as Talbots n.

For maximum stability and shear resistance the aggregate grading should conform to this grading, be well compacted, and have an n of about 0.5. This is because in a well (dense) graded aggregate the larger stones will be well supported within a close packed mass of small particles. Hence the contact surface area will be larger, so the material will be more stable and more resistant to shear deformation than open graded or gap-graded materials.[1][2][7] Conversely the denser and finer the grading the lower will be its permeability, and the more sensitive it will be to moisture: high water contents will develop positive pore pressures and reduce the materials strength, conversely low water contents will develop high suction forces so increasing strength, stiffness and resistance to repeated load.[1] [7]

Permeability and sensitivity to moisture, are important considerations for bedding under block pavements. It is widely accepted that the sanded joints between blocks admit water early in the pavements life. We suspect that while the joint permeability will decrease dramatically with time and traffic the joints will never become impervious to water.

The severity of the traffic loading is another factor. Heavy duty pavements require a high degree of stability and resistance to shear in a bedding material.

From the above and references [1] and [7] we can draw the following conclusions.

- Bedding materials with a Talbots n of less than 0.40 should not be used. The high fines content of these materials makes then moisture sensitive, gives low permeability, and in the extreme could lead to dilation and rapid failure.

- Bedding material with a Talbots n of 0.4 to 0.45 could be used, but the fines content makes them fairly moisture sensitive. Given the likelihood of some moisture infiltration through the joints these materials are best avoided except for lightly trafficked pavements.

- Bedding materials with a Talbots n of 0.45 to 0.6 will give a very stable bedding material. Such a material will be suitable for heavy duty pavements in a dry climate. With a limitation on the proportion passing 150 μm, and a restriction on the use of aggregates with $0.45 < n < 0.5$ to light duty pavements, they should also be suitable for heavy duty pavements in wet climates given attention to joint filling and drainage of the bedding layer. (This really needs further research to determine moisture contents and suction pressures in bedding materials in actual block pavements. The technology to measure these is available [eg 19].)

- Bedding material with a Talbots n of 0.7 to 1.0 will give a stable bedding material with reasonable permeability and reduced sensitivity to moisture. Stability and resistance to shear will be good, but will be less than that of a material with an n of 0.4 to 0.6.

- Bedding material with a Talbots n of 2 or greater, while having low sensitivity to moisture and good permeability, will have much less stability and shear resistance than a more densely graded aggregate. As such it is not suitable for heavy duty pavements, and may result in rutting or loss of surface shape under traffic on even light duty pavements.

The above discussions are all based on aggregates that conform to $p = 100\,(^{d}/_{D})^{n}$. New Zealand has performed a lot of research into the performance of unbound basecourses. One of the indications of this research is that continuity of the grading is very important for stability and shear resistance of an aggregate.[eg 1] The shape of the grading curve should be smooth, the aggregate should not have even a suggestion of being gap graded.

This means that the grading curve of the actual bedding material should conform to $p = 100\ (^{d}/_{D})^{n}$. When the percentage finer than versus sieve size is plotted on log-log paper it should be a straight line.

One of the implications of this is that it is not enough to specify the required grading of a bedding material merely by defining the limits of an envelope. Some form of grading shape control is necessary to ensure the continuity of grading within the envelope. This control appears even more important than the Talbot n (at least for $0.4< n <0.6$).[9]

I will not detail how to control the shape of the grading curve in a specification. One option is to specify ratios of percentage passing various sieves [eg 10], other methods are currently under development in New Zealand.[8][18]

Density

Compaction is necessary to increase the density, which increases the bedding materials stability and resistance to shear, and prevents further densification under traffic with consequent wheel track rutting. Increasing density decreases permeability, but control of the grading can control permeability.

Over densification at constant moisture content can bring basecourse materials to saturation [11], however this is unlikely to be a problem with bedding materials as the amount of fine and plastic materials are limited to increase shear strength and permeability.

Texture

The texture of the surface of the individual aggregate particles has an influence on the shearing resistance of the bedding material. After compaction highly textured particle surfaces give greater stability and shearing resistance than smooth rounded particle surfaces. However a highly textured aggregate is more difficult to compact.[1]

The influence of particle surface texture on shear resistance is less powerful than that of particle size distribution.

To partly compensate for the reduction in shear resistance a Talbots n increases from 0.6 to 1.0 the degree of surface texture of the particles should be increased, at least for the more heavy duty pavements.

Shape

Shape of the individual particles can vary from rounded, to angular, to cubic, or platelike (flaky). The shape appears to have little or no effect on the shear resistance of an aggregate. Its greatest effect is on the grading-maximum density relationship.[1] Flaky particles can also contribute to densification under traffic with attendant wheel track rutting.

Maximum Particle Size

Some overseas basecourse research has shown that aggregates with large (40 mm) maximum particle size are more rigid (greater shear resistance) than those with small (20 mm) maximum size.[17] In spite of this New Zealand research has failed to show a difference in performance between 40 mm and 20 mm top size aggregates.[1]

Maximum particle size, therefore, should relate to the thickness of the bedding course layer. One rule of thumb for this is a maximum particle size of $\leq 0.75x$ (compacted layer thickness).[12] For a bedding course of 20 to 25 mm compacted thickness this suggests a maximum particle size of 9.5 to 15 mm. However a smaller maximum size will allow easier levelling of the bedding course, and reduce any likelihood of problems relating to localised thinning of the bedding layer or segration.

This suggests a maximum particle size of about 9.5 mm is appropriate for a bedding course of around 25 mm compacted thickness.

The above mentioned lack of sensitivity to maximum particle size suggests that topsizes smaller than 9.5 mm may also perform well. However some limitation on minimum topsize is necessary as finer materials are more moisture sensitive, also the closeness of conformity of the grading to $p = 100\ ({}^{d}/_{D})^{n}$ becomes more critical to ensure adequate shear resistance. A minimum topsize of 4.75 mm is preferred. A minimum topsize of 2.36 mm may be acceptable with adjustment to the grading when using this topsize to ensure Talbots $n \geq 0.5$ to limit sensitivity to moisture.

Fines and Permeability

The quality and quantity of finer material can have a fundamental effect on the properties of a bedding material. In particular shear resistance, permeability, and sensitivity to moisture are affected.

For any given quantity of fines the activity, such as the plasticity, of these fines can be particularly influential. The influence will depend on the degree of plasticity, the quantity of fine material, and the moisture content, it is also related to the particle size distribution of the bedding material. The denser the grading the greater the effect of any given quantity of plastic fines.

The detrimental effects can be controlled by limiting the plasticity of the fines (eg by plasticity index or clay index tests) and/or by limiting the quantity of fines, especially the percentage passing 75 μm.

For unbound basecourse in pavements with thin bituminous surfacings Bartley [2] suggests as a guide that the product of (% finer than 75 μm) x (Plasticity index) should be less than 50. Bedding sand is likely to be wetter than basecourse because of water permeating through the joints between the blocks, so this guide should not be used for bedding materials for heavy duty pavements. Possibly it provides reasonable guidance for lightly trafficked block pavements. (Research is required into the actual moisture conditions, soil suction, and live load imposed stresses on bedding courses in block pavements) but fines in bedding courses for heavy duty pavements should be of nil or very low plasticity.

Permeability of the bedding course (and a drain) is desirable to allow any moisture entering through the joints to drain away. This is to prevent saturation and encourage the development of suction forces between the individual particles. Permeability is strongly related to grading [7] so an open graded material is much more permeable than a dense graded material. However permeability can be increased for any given grading by limiting the quantity of fines. From reference [17] a maximum of 4 to 6% passing 75 μm should allow reasonable permeability.

By limiting the amount passing 75 μm to 4% adequate permeability and little concern over plasticity should result. For medium to heavy duty use pavements some limitation on plasticity (or clay index) would be prudent.

PRACTICAL CONSIDERATIONS

Block Seating and Levelling

It is essential that paving blocks of various thickness (eg ± 3 mm in thickness) are able to be pushed into the bedding sand such that the upper most surface of the block pavement is level. Also the blocks need to be supported over their entire base area to prevent rocking. These requirements dictate that some liveliness is required in the bedding sand.

Primarily this liveliness can be provided by limiting the quantity of fine particles in the bedding material, eg to 5% or less passing 75 μm. The particle size distribution also has a big influence, the more open the grading the more lively. Rounded particles are also more lively than angular or highly textured particles.

Equilibrium Moisture Content

Prior to laying bedding course material is usually stockpiled. The stockpile is likely to be exposed to the rain, but will drain under gravity. An amount of water will remain after this free draining. (Equilibrium moisture content after[7]) Well graded materials contain a relatively high fines content so retain much larger quantities of water than open graded materials.[7]

The fine fraction of dense graded bedding materials may pump up through the joints between blocks under compaction if laid and compacted soon after rain. In areas subjected to heavy frost they will take longer to thaw to allow construction of the bedding course than would a more open material.

To minimise these problems a near single sized medium or coarse sand would be needed. However this conflicts with the previously discussed requirements for stability. A reasonable compromise seems to be to control the grading and fines content as discussed above, as a competent experienced laying contractor will learn how to handle his particular bedding materials.

Construction

Dense graded materials are less likely to segregate, and are more easily worked than open graded aggregates.[14] A high percentage of fine particles (eg ≥10% passing 75 μm can make levelling of the bedding course during construction, and tying into the previous days construction more difficult.

Jointing Sand Compatibility

The grading of the bedding material needs to prevent infiltration of the jointing sand. Typical compatibility requirements are [12]:

$$\frac{d_{15}\text{ (bedding)}}{d_{85}\text{ (joint)}} < 5 \qquad\qquad \frac{d_{50}\text{ (bedding)}}{d_{50}\text{ (joint)}} \le 5$$

Assuming a fairly fine jointing sand with d85 = 450 μm and d_{50} = 250 1m gives the requirements for the bedding material of

$$d_{50} \le 6\text{ mm} \qquad d_{15} < 2\text{ mm}$$

These requirements are compatible with the requirements discussed above.

PRACTICAL EVIDENCE

The conclusions drawn in this paper suggest a variation to current practice should be considered. As the considerations in this paper have been fundamental and theoretical, some practical evidence to support our proposals should be considered.

CBR

One practical measure of the stability and resistance to shear of a bedding sand is the CBR test. CBR tests [15] on a number of New Zealand aggregates are shown in Table 1.[20] Compaction was with the material at its equilibrium moisture content.[7] Grading curves for each sand are shown in Figure 2.

Sample Name	Particle Texture	CBR	
		unsoaked	soaked
Mercer Sand/E.Tamaki AP7	part crushed, part rounded		100
Christchurch unwashed crusher dust	crushed	65 *	75 *
Kings Paving Sands	rounded		30
Melling blended sand	rounded	25 *	
Mercer Sand	rounded		19 *
Wainui Beach Wellington	rounded	11 *	13 *

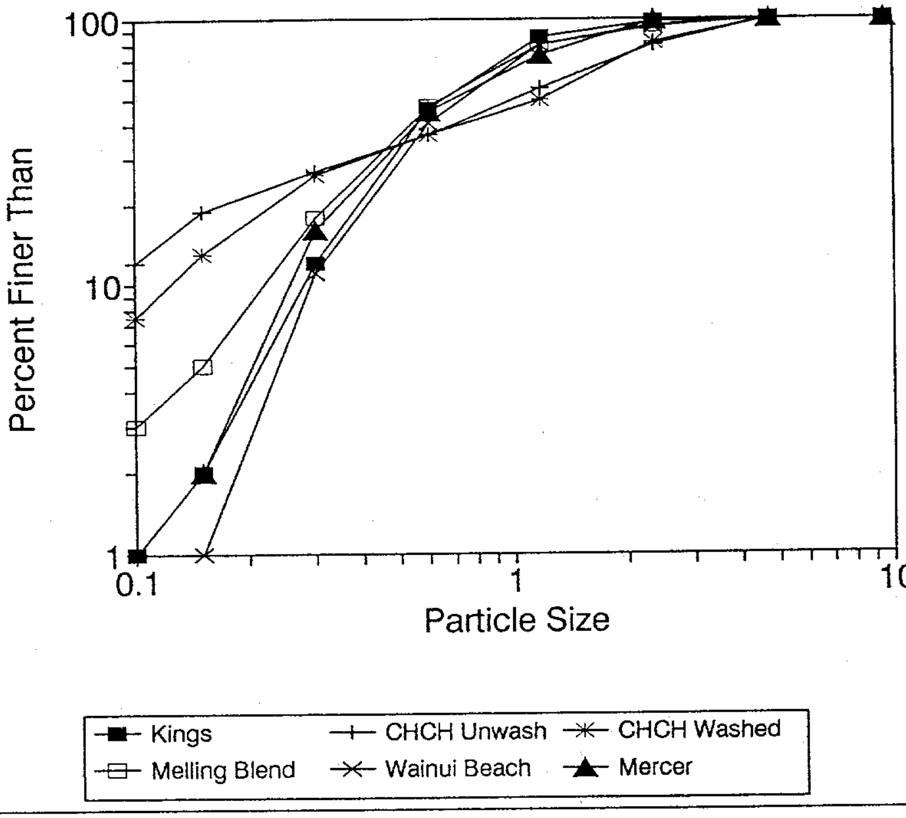
* 2 kg surcharge used for CBR test

TABLE 1 CBR TEST RESULTS

This shows that some of the aggregates in use as bedding material in New Zealand have low CBR's eg 11, 19. For a layer so high in the pavement these CBR's seem very low. This raises questions about its shear resistance; use of these bedding materials could result (and maybe has) in loss of pavement shape.

Table 1 and Figure 2 also demonstrates our earlier statements that varying the grading and to some extent the quantity of fines and the surface texture of the bedding material has a major influence on the CBR ie stability and shear resistance.

FIGURE 1
BEDDING MATERIALS GRADING CURVES



ACTUAL PAVEMENTS

A bedding material that conforms with the requirements proposed in this paper has been in use in Christchurch, New Zealand for some two years. This Christchurch washed Barmac material is sourced from geologically recent alluvial river deposits, crushed and washed. It is well graded conforming to the equation $p = 100\ ({}^{d}/_{4.75})^{0.50}$, with 5% passing the 75 μm sieve.

After personally constructing many thousands of square metres of block paving incorporating this bedding the author of this paper drew the following conclusions:

- It is easily worked and his workmen are happy to use it.
- Heavy rain on the stockpile or screeded bedding material will saturate it. Block laying must then stop, but it unsaturates quickly.
- Compacting blocks on this bedding when it is saturated causes "pumping" of fines up between the blocks.
- Little of the bedding material penetrates up between the blocks during plate compaction when the material is at normal "equalibrium" moisture content.
- It is easy to tie subsequent areas of pavement into, eg the next days paving, or trench reinstatement.
- This bedding should be compacted after the blocks have been laid. It is not able to be precompacted before the blocks are laid.

- It does not "compact" much, eg a 40 mm loose thickness layer will compact to about 30 mm. This should give a smoother pavement surface.
- While this bedding sand has not been used when machine laying blocks, it is usupected that it will be suitable if only light compaction is applied to the bedding prior to block laying. Alternatively machine laying of blocks should e practicable if the bedding material is laid to a compacted depth of 20 mm or less.
- Indications are it produces long lasting pavements that hold their shape.

This evidence seems to support the theoretically derived requirements for a bedding course material.

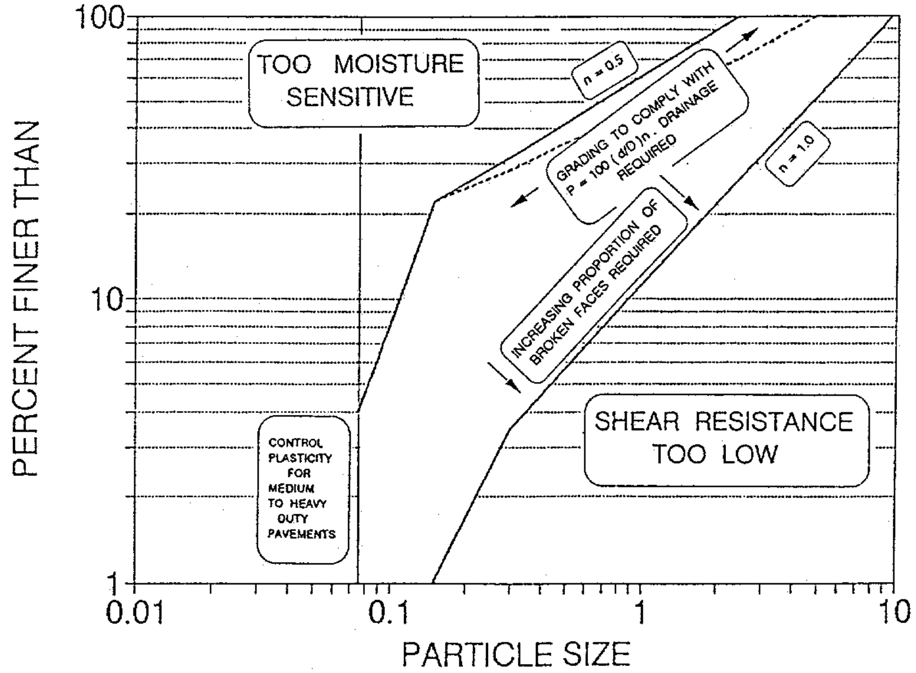
CONCLUSION

By approaching from fundamental/theoretical considerations the requirements for a bedding course material can be defined. In summary such a material would have the following attributes:

- The aggregate particles should be hard and durable.
- Grading should comply with the equation $p = 100\ (^d/_D)^n$ where n lies between 0.45 and 1.0.
- Drainage of the bedding course should be provided, at least for gradings with n between 0.45 and 0.6.
- The proportion passing the 75 μm sieve should be 4% or less.
- Textured (crushed) aggregate should be used, at least for heavy duty pavements, and for gradings with n greater than 0.6.

These requirements are summarised on the graph below, Figure 2.

FIGURE 2
PROPOSED GRADINGS FOR BEDDING MATERIALS



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