LAYING COURSE MATERIALS: SPECIFICATION AND PERFORMANCE

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Summary

The laying course is an essential component of a concrete block pavement. It is required primarily to provide an even surface on which to lay the pavers and to accommodate accepted tolerances, both in the finished surface level of the roadbase and in the manufactured paver thickness. Laying course materials, layer thickness and alternative methods of placement are discussed, together with different approaches to block laying and the use of spacer nibs on pavers. Three different methods of test to assess the resistance of laying course materials to mechanical degradation are described. The results of these tests on a range of six materials are presented and compared. It is shown that the results from the three types of test are highly corelated and that each ranks the materials in the same order with respect to degradation. The use of coarser laying course materials in certain countries is also discussed. It is concluded that more case histories are required in order to establish criteria for the acceptance or rejection of laying course materials for critical loading conditions.

Introduction

In concrete block paving the pavers are placed on a thin laying course of fine aggregate. The materials specified for the laying course vary from country to country, particularly with respect to the maximum particle size permitted. Procedures for placing both the laying course material and the pavers themselves also vary. Traditionally pavers have been laid into loose sand and it has been expected that some of the bedding sand would rise up into the joints when vibratory compaction was applied to the paved surface. Particle size distribution, method of laying course placement and compaction of the pavers and of the laying course are inter-related and alternative approaches are now being tested. The laying course provides an even surface on which to lay the pavers, it accommodates the manufacturing tolerance on block height, provides uniform support and avoids stress concentrations which could be damaging to the pavers. Located high in the pavement structure, the laying course is subjected to repeated applications of high stress caused by the passage of vehicles over the pavement. The ability of the laying course material to

withstand these repeated stress applications without significant breakdown can be crucial to the continued integrity of the pavement. Several different test methods, available to measure the ability of a laying course material to resist mechanical degradation, are described. Results from three of these tests are presented and compared.

Laying Course

The laying course is an essential component of a concrete block pavement. It is required primarily to provide an even surface on which to lay the pavers and to accommodate accepted tolerance in the finished level of the roadbase and the manufacturing tolerance on paver thickness. In the case of structural block pavements subjected to critical loading conditions, such as repeated, channelised heavy loads, for example at bus stops or in container handling yards, the performance of the laying course material in service can be critical to the satisfactory performance of the pavement.

Thickness

The choice of thickness of the laying course is a compromise. Sufficient thickness is needed for the laying course to fulfil its functions but an excessively thick layer is a potential source of weakness and of settlement under traffic. A thickness of 50 mm after compaction was widely specified in Europe for a long time and is currently specified in the U.K. [1], based on a roadbase surface level tolerance of ±15 mm. This is likely to be satisfactory for the majority of block pavements. Where a closer tolerance on roadbase surface level can be achieved, the laying course thickness may be reduced but *"in no case should the material be less than 25 mm thick at any point"*[1]. In critically loaded areas there has been a trend towards the least practical thickness of laying course in order to minimise settlement under secondary compaction. In Australia this led to a recommended thickness, after compaction, of 20 to 40 mm, (with an absolute minimum, at any point, of 15 mm.) In Belgium, a thickness of 30 to 50 mm after compaction is specified. These applications are for material having a maximum particle size of 5 mm. Where pavements are to carry heavy loading, the laying course thickness can be kept small if the roadbase surface tolerance can be reduced. Shackel [2] suggests that this tolerance should be -0, +10 mm from design level with a maximum deviation of 10 mm under a 2 m. straight edge. In addition, where the roadbase is constructed of unbound aggregates, it is desirable for the surface to be blinded with a choke stone of 10 mm maximum size so as not to lose bedding sands into the void space in the roadbase.

Materials

In many countries, including Britain, Australia, Canada and the United States, it is usual to specify a well graded material having a maximum particle size of 5 mm and to limit the fines content smaller than 75 μm to 3% or less. It has been recommended [3] that for critical cases of heavy, channelised traffic only naturally occurring silica sand, having virtually no material finer than 75 microns, should be used in the laying course. This recommendation resulted from a study

of block pavement failures in which the bedding sand had broken down under traffic action and fines in suspension had been expelled through the joints. This differs from the conventional viewpoint that crushed granular materials compact more easily to a dense, stable state resulting from their higher angles of internal friction. Sharp and Simmons [4], for example, say that *"sands with similar sized grains and/or spherical shaped grains are not recommended as the grains act like balls-bearings and move about under the pavement, resulting in rutting"*. Shackel [5] also found *"that, for similar sand gradings, block pavements laid on angular sands perform better than pavements laid on rounded sands"*. In other countries coarser laying course materials may be specified. For example, a mixture of crushed stone and chippings graded 0 - 8 mm laid over a sand-cement roadbase has been used at the Port of Rotterdam [6]. In Norway the maximum particle size is increased as a function of the severity of pavement loading. For light traffic a particle size range of 0 - 4 mm or 0 - 6 mm may be specified. For average traffic the range would be 0-8 mm, for applications supporting high, concentrated loads 0 - 10 mm has been used and in a few very special cases 0 - 16 mm has been used [7]. In Belgium also, the maximum particle size is varied as a function of the traffic loading [8]. For ordinary roads carrying moderate traffic a well-graded mixture of 0 - 4 mm sand with less than 3% finer than 63 microns is specified. For pavements subjected to relatively heavy traffic, such as city streets and bus stops, a continuous grading of 0 - 7mm with a maximum of 3% finer than 63 microns is specified, or a mixture of 40% crushed sand 0 - 2mm and 60% of 2 - 7mm sized stone has been used successfully. In order to obtain even greater stability this material is sometimes cement stabilised.

Placement

There are four approaches to the placement of the laying course material. Where the traditional craft method of block pavement construction is used, the bedding sand is only roughly screeded to give sufficient thickness of loose sand. The paviour works in the sand facing the completed part of the pavement and uses a hammer, first to level the sand and then to lay and seat each paving block. In the lay-down method of hand placement the sand is carefully screeded loose to a thickness which will give the required 25 - 50mm after compaction. The loose sand is not disturbed and the block layer works, facing the sand from the already constructed part of the pavement. In both these methods plate vibrators are run over the surface of the blocks to produce a level surface. It is expected that some of the bedding sand will be forced into the joints between the pavers, that an even surface will result and that the bedding sand layer will be compacted. For example, Lilley [9] states that for blocks laid on loose sand, this should work up into the joints by 15 to 30mm during vibration. In the third method, which is, for example, one of two specified in British Standards [1], part of the sand is precompacted using a vibrating plate compactor and a further layer is then screeded to give a loose surface , 15mm thick, on which to place the paving blocks. In the fourth method, the laying course material is compacted to the required finished thickness [7] and the pavers are laid, usually mechanically, on the compacted surface.

Block Laying

The blocks can be placed on the laying course (i) by the traditional craft method, (ii) by the hand lay-down method or (iii) mechanically in clusters. The method of placement of the laying course must be consistent with the method by which the blocks will be placed. Using the traditional craft method, the paviour, working in the loose sand, places each block and adjusts the sand thickness to support it. In the hand lay-down method, the pavers are placed on a pre-screeded laying course which may be loose or may have been partly precompacted. Using mechanical block laying, the laying course will normally have been partly precompacted but may in some cases have been precompacted to the required finished thickness. This would imply the need for greater compactive effort on the surface of the pavers to adjust relative paver position to compensate for the ±3 mm tolerance on manufactured paver height. It would also imply that the laying course material was not expected to rise up into the joints between pavers.

Spacer Nibs

Where pavers are laid mechanically, they are lifted by mechanical, hydraulic or vacuum clamps in clusters of approximately one square metre or fifty blocks. In order to ensure a minimum joint width of approximately 2mm between adjacent pavers, after having been held clamped together, pavers generally have vertical spacer nibs cast integrally on their vertical faces. These spacer nibs are also useful in achieving a uniform laying pattern by hand laying. Using pavers without spacer nibs, compacting pavers into a loose sand layer was necessary in order to secure the blocks in the prescribed pattern. Where the pattern is ensured by spacer nibs and the pavers are mechanically laid, the view has been expressed [7] that the pavers can be placed on a coarser, precompacted material and that interlock of the pavers can be achieved by proper selection and placement of the jointing sand. In these circumstances it is no longer considered necessary for any laying course material to rise up into the joints. It has been the writer's own experience, in constructing pavements in the laboratory, that if vibratory compaction is applied to pavers, without spacer nibs, placed on an unyielding surface, the laying pattern is rapidly destroyed and inconsistent joints widths result.

Degradation

In block pavement failures attributed to laying course material deficiencies, the mechanism suggested is that of breakdown or degradation of particles to produce fines, which are subsequently washed away or squeezed out of the joints as a paste. The consequent volume decrease causes relative movement of the pavers, rutting and loss of interlock. It is argued that if the particles are highly resistant to degradation and are large enough not to go into suspension nor to form a paste, this mechanism should not occur. This has led to consideration of possible tests which could serve to identify laying course materials unsuitable for block pavements subjected to critical loading conditions, for example heavy, channelised vehicle loading.

Degradation Tests

Three tests are available to assess the durability of fine aggregate as a block pavement laying course material. Two of these are ball-mill tests in which steel balls are present to accelerate the wear and break-down of the aggregate particles. These are analogous to a mini-Los Angeles abrasion test and differ in the quantity of material tested and in the aggressivity of the charge of grinding medium. The third test is an attrition test in which no grinding medium is present.

Lilley and Dowson Durability Test

This test was developed in the U.K. as a result of collaboration between the then Cement and Concrete Association and a major paver manufacturer. It was developed specifically for bedding sands used in concrete block paving and was first reported at the third international conference on concrete block paving [10]. A representative sample of at least 5kg of sand is obtained and thoroughly mixed. This is then reduced by riffling, to a sample of 1.2kg, which is dried for twenty-four hours in an oven at 105-110°C. From this main sample, three sub-samples, each of 200g, are obtained by further splitting, using a riffle box. Each sub-sample is sieved dry, recombined and placed in a porcelain jar of one litre nominal capacity, together with two 25mm diameter, stainless steel ball bearings having a mass per pair of 135 ± 3 g. The bottle lids are then secured in place and the bottles are rolled at 50 ± 1 revolutions per minute for six hours ± 5 minutes, i.e. for approximately 18 000 revolutions. The samples are then carefully removed from the bottles and each is re-sieved. The average of the three values of percentage passing each sieve is determined and recorded to the nearest whole number. The arithmetic difference between the percentage passing each sieve, before and after the test, is known as the degradation value for that sieve size.

Micro-Deval Degradation Test

The micro-Deval test was originally developed in France as a test for coarse aggregate. More recently it has been adapted in a modified form, by the Ontario Ministry of Transportation, for the evaluation of the quality of fine aggregate for concrete and asphalt [11],as a replacement for the sulphate soundness test. The method, which is the subject of a Ministry specification [12] is as follows. A representative bulk sample of the fine aggregate, passing a 4.75mm sieve, is obtained. From this, two samples are obtained by splitting, one of 700g, the other of 250g. Each sample is washed separately over a 75μm sieve to remove particles finer than 75 microns. The samples are then dried in an oven to constant mass. From the 700g sample, a sub-sample of 500 ± 5g is obtained by splitting. This is saturated for 24 ± 4 hours, after which the excess water is poured off and the sample placed in a five litre stainless steel jar, with 750ml of tap water and a charge of 9.5 ± 0.5mm diameter stainless steel balls, having a mass of 1250 ± 5g. The bottle is sealed and rotated at 100 ± 5 rpm for fifteen minutes ± 10 seconds. After removal of the steel balls on a 6.7mm sieve, the aggregate is washed over a 75μm sieve. The material retained is dried, in an oven, to constant mass and weighed. The micro-Deval abrasion loss is calculated as the loss of mass, expressed as a percentage of the initial mass, to the nearest 0.1%.

Modified Attrition Test

The Deval attrition test for the determination of resistance to wear by attrition was included in a British Standard [13] prior to 1960 and in the American Society for Testing and Materials Standard D2-1968 up to 1972. The test is still used by British Rail for track ballast, for which the material tested passes a 2 inch (50mm) sieve and is retained on a 1½ inch (37.5mm) sieve. This test has been adapted to suit bedding sand size particles by reducing the volume of the test cylinder in the ratio of maximum particle sizes, i.e. 50mm: 5mm or a factor of ten. Triplicate samples of bedding sand, each having a mass of 500g, are prepared. Each is placed, together with an equal mass of water, in a stainless steel test cylinder 150mm in length and 100mm in diameter. The cylinders are mounted on a shaft at an inclination of 30° to the axis of rotation. After the cylinder covers have been bolted in place, the shaft is rotated at 30 to 33 revolutions per minute for ten thousand revolutions. No grinding medium is added; wear takes place as a result of the movement of the sand grains over one another. As the test cylinders are inclined relative to the axis of rotation, the particles move from end to end of the cylinder, in addition to being rotated. In the original test on coarse aggregate ballast, on completion of the test, the material is sieved through a 2.36mm sieve and the ratio of the loss of weight to the original sample weight is expressed as a percentage. In the test as modified for fine aggregate bedding sand, the sample is re-sieved through the full set of sieve sizes from 4.75mm to 75μm, on completion of the designated number of rotations.

Test Modifications

In the degradation tests as carried out in the work reported, a number of minor modifications were introduced in order to make the different tests more directly comparable. In the preparation of samples for each of the tests, the bulk representative sample was sieved wet through the range of sieves shown in Table 1. The required sample mass was then constituted by combining the necessary individual masses retained on each sieve in the series. In each of the three test types, a mass of water equal to that of the aggregate sample was also placed in the test bottle. After testing , each sample was re-sieved wet through the same set of sieves. Particle size distributions before and after each test were compared.

Testing Programme

Samples of six different bedding sands, varying in type from a natural silica sand to a manufactured sand of limestone screenings, were subjected to each of the three tests described. In order to eliminate particle size distribution as a variable, each sand was sieved through the set of sieve sizes shown in Table 1.

Sieve Size mm	4.75	2.36	1.18	0.60	0.30	0.15	0.075
% passing	100	90	70	47	20	7	0

Table 1. Sieve sizes and standard sample grading

Each sample was then reconstituted to the grading shown in Table 1, by combining the required mass retained on each sieve in the series. The grading selected corresponds closely to the middle of the grading envelopes specified for bedding sands in Britain and Australia, but with no particles finer than 75 microns. All sieving was carried out wet. Each test was carried out in triplicate and each sample was re-sieved through the standard set of sieves after degradation. Thus changes in grading over the full range of particle size could be observed.

Test Results

The particle size distribution obtained by averaging the three samples for each test on a silica sand (No.1) and on a "sand" consisting of crushed limestone (No.6). are plotted with the initial grading in Figures 1 and 2. These represent the extremes of the materials tested. The mean values of percentage passing the 75μm sieve after degradation by each of the three test types are shown in Table 2 for each of the sands.

Sand No.	1	2	3	4	5	6
Lilley & Dowson	7.1	14.5	15.6	19.9	23.3	39.9
Micro-Deval	4.6	10.2	12.0	13.5	17.7	31.5
Attrition	1.5	4.2	4.9	6.4	6.5	13.3

Table 2. Percentage passing 75μm sieve after degradation (each point mean of three values).

It can be seen that each of the three types of test ranks the sands in the same order. A statistical analysis of variance showed the data to be significant at the 95% confidence level. Differences between the tests accounted for approximately twice as much of the variance as that due to differences in the material properties.

Correlation

As the Lilley and Dowson test has been most widely used to characterize the resistance to degradation of bedding sands, linear regression analysis was carried out to examine correlation between results from it and those from each of the other two tests. Results for both the micro-Deval test and the attrition test were found to be highly correlated with those from the Lilley and Dowson test. For the six sands tested, the following linear relationships were established. Within the range 4.6 to 31.5 for micro-Deval and 1.5 to 13.3 for the attrition test, these relationships permit a value of Lilley and Dowson degradation to be estimated from measured values from either the micro-Deval or attrition tests.

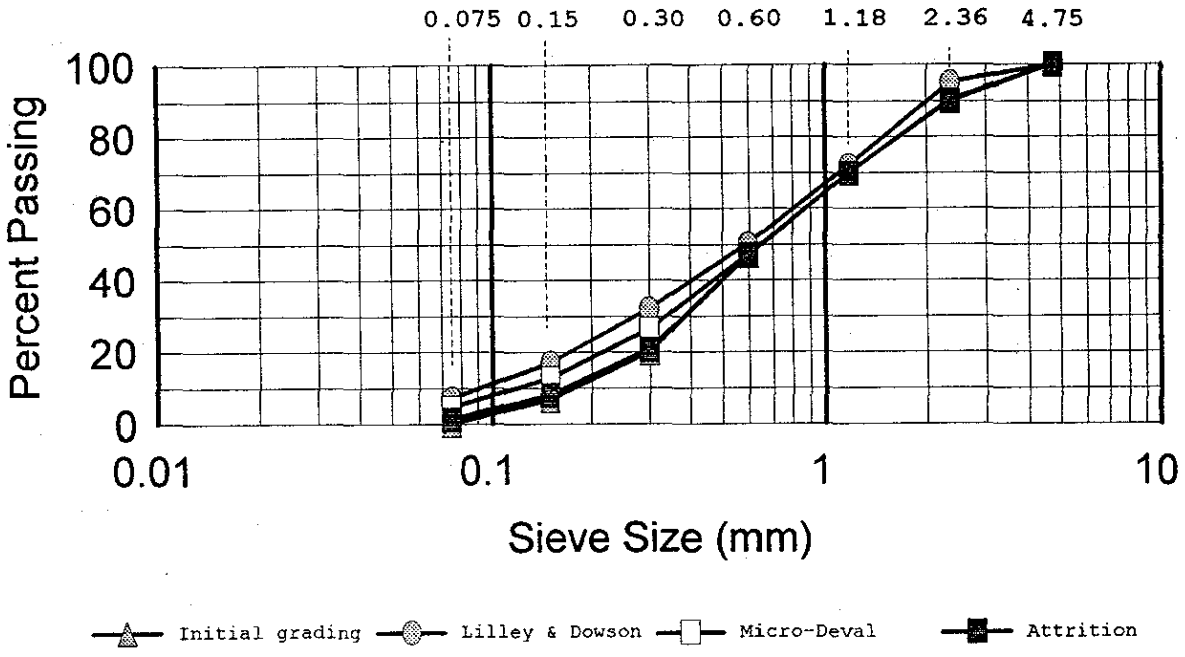

Figure 1 - Degradation of silica sand

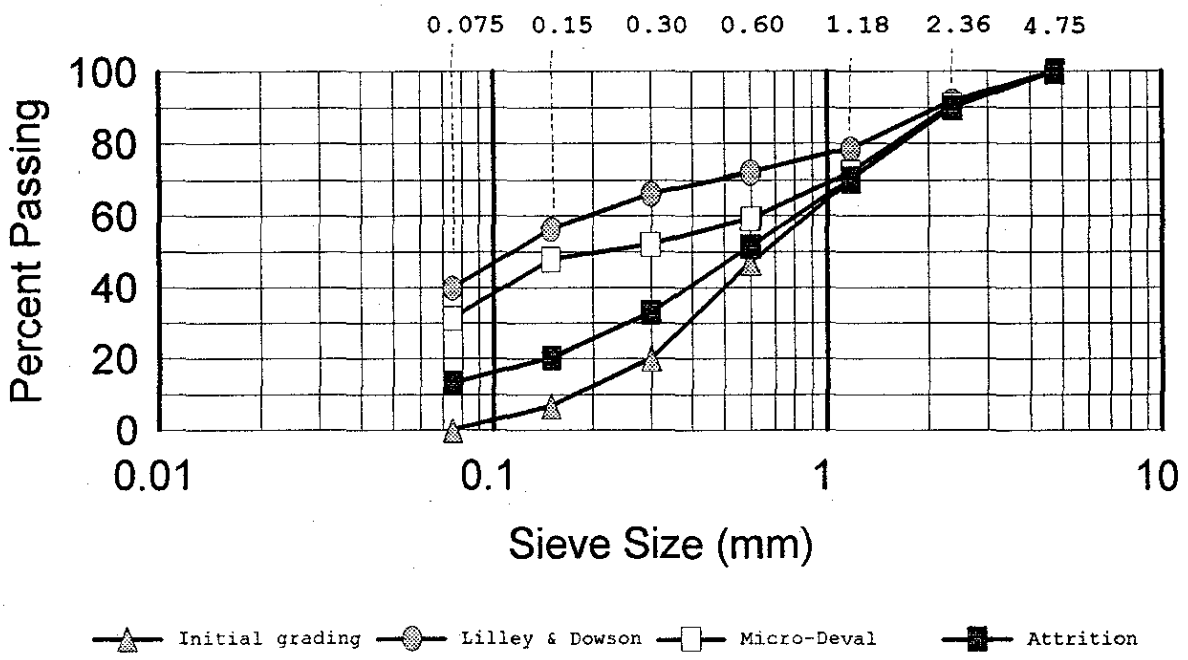

Figure 2 - Degradation of limestone screenings

Micro-Deval	$L = 1.97 + 1.21\ M$
Attrition	$L = 2.85 + 2.81\ A$

Where M = micro-Deval, A = attrition and L = Lilley and Dowson, all values being percentage of fines passing a 75 micron sieve on completion of the test. In both cases the coefficient of correlation is greater than 0.99.

Discussion

It is desirable that a laboratory quality control test should reproduce the in-service conditions of the material tested and that a relationship be established between in-service material performance and numerical values obtained in the quality control test. In this way an acceptance criterion for the material can be established for a particular application. It can be argued that the attrition test most closely reproduces the conditions which may give rise to degradation of a block pavement laying course material. The purpose of adding the steel balls in the two abrasion tests must be to accelerate particle breakdown rather than to simulate in-service conditions. Based on a limited sample of six sands, each of the three tests ranks the laying course materials in the same order of resistance to mechanical degradation in the presence of water, as characterized by the quantity of particles finer than 75 microns produced during the test.

The use of the steel balls as a grinding medium would appear to be justified on the basis that the test can be completed more quickly and yet ranks the materials in the same order as does the attrition test in which in-service conditions are more closely reproduced.

Insufficient data are available to permit a statistical correlation between laboratory test values and block pavement performance. For the present it would seem prudent for structural block pavements subjected to severe loading conditions, to select a laying course material having the best possible resistance to mechanical degradation. In practice this means a sand which is made up wholly of quartz. More case studies are required to establish a numerical degradation criterion based on degradation test values of laying course materials used both successfully and unsuccessfully. Extending the work described in this paper to a larger number of materials could establish corresponding acceptance criteria according to each of the test methods used.

Alternative Approach

An alternative approach, to the rigorous selection of the most resistant bedding sands through quality control tests, is being pursued in Belgium, the Netherlands and Norway. In the latter countries, progressively more coarsely graded fine aggregates are being used as laying course materials under severely loaded pavements.

When selecting laying course materials, several other factors have to be co-ordinated, these include: roadbase material and roadbase surface level tolerance, method of preparation of the laying course, type of pavers (spacer nibs or not), method of paver placement, joint filling and compaction.

The ultimate test of the acceptability of laying course materials and associated construction details, is performance of the pavement in service. Case histories are required to validate both

approaches, selection of degradation-resistant 0 - 5 mm sands and the use of more coarsely graded materials together with modified construction details.

Conclusions

1. It has been shown that, for a range of six materials tested, one attrition and two abrasion tests each ranked the materials in the same order based on mechanical degradation in the presence of water and that the results of the three test methods are highly correlated.

2. Extending the work to a larger range of materials would produce relationships enabling a test result from any one of the test methods to be interpreted numerically according to either of the other two methods.

3. For block pavements subjected to critical loading conditions, the two approaches to selection of laying course materials currently being pursued, have been reviewed.

4. Case studies of successful and failed block pavements are required to establish numerical acceptance criteria for the quality control of laying course materials, either in terms of degradation limits for sand-size materials or grading specifications for coarses materials.

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