TRANSPORT and ROAD
RESEARCH LABORATORY

Department of the Environment
Department of Transport

TRRL SUPPLEMENTARY REPORT 831

ERRORS IN THE SAMPLING AND TESTING OF SUB-BASE AGGREGATES

by

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Crowthorne, Berkshire
1984
ISSN 0305–1315

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Ownership of the Transport Research Laboratory was transferred from the Department of Transport to a subsidiary of the Transport Research Foundation on 1st April 1996.

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ABSTRACT

Specifications for sub-bases are based on knowledge that has been gained from past performance of a wide range of aggregates in conjunction with results of tests that define relevant properties.

To assess the suitability of an aggregate samples have to be tested but it is extremely difficult to take a truly representative bulk sample of a large batch of material and to prepare that sample for test in a way that entirely excludes errors. This means that in those cases where a material just passes or just fails to meet a specification limit doubts can exist between customers and suppliers as to whether acceptance or rejection is really justified; it is therefore important to be able to make reasonable allowance for the errors likely to arise from deficiencies in sampling and testing.

This report describes work done to establish the precision of some of the tests used to assess sub-base aggregates.

1. INTRODUCTION

Large quantities (c. 20 million tonnes/year) of unbound sub-base materials are used in road construction. Specifications for these aggregates are based on knowledge that has been gained from past performance of similar aggregates in conjunction with results of tests that define relevant properties.

To assess the suitability of an aggregate for use in sub-base construction, samples have to be tested but it is extremely difficult to take a truly representative bulk sample of a large batch of material and to prepare that sample for test in a way that entirely excludes errors. These errors arise in taking the bulk sample from the batch (the sampling error) and in reducing the bulk sample to a mass suitable for carrying out the test (the sample reduction error). In addition a test carried out on the same material will be subject to errors because of deficiencies in the test techniques of the operators and of the test equipment (the repeatability and reproducibility of the test).

In those cases where a material just passes or just fails to meet a specification limit arguments can arise then between customer and supplier as to whether acceptance or rejection is really justified; it is therefore important to be able to make reasonable allowance for errors likely to arise from deficiencies in sampling and testing.

This Report describes work done to establish the sampling errors and precision (ie repeatability and reproducibility) of some of the tests used to assess sub-base aggregates. It is divided into three sections, each of which deals with a particular test. Section 2 contains the results of an analysis that has been made of the information that is available about the precision of the particle-size distribution test. Sections 3 and 4 respectively deal with a more limited amount of information that is available about the precision of plasticity and compaction tests.

2. PRECISION OF THE PARTICLE-SIZE DISTRIBUTION TEST

2.1 Introduction

The test most commonly applied to all aggregates is the determination of the particle-size distribution by sieving (see Appendix 1).

Earlier work (Pike 1979) showed that substantial errors could be introduced when bulk samples were reduced during the preparation of test portions. Subsequent investigations have been carried out to assess the errors that are introduced during sampling and testing under conditions that allowed for the assessment of reproducibility, ie during inter-laboratory comparisons.

Some of these investigations have been concerned principally with sieve tests but in other cases this information has been a by-product of studies of other properties. This part of the Report describes the results of these investigations which provide information on the precision of the particle-size test, on the sampling errors likely to occur in obtaining bulk samples from stockpiles and in the sample reduction of the bulk sample to the test sample.

2.2 First experiment

2.2.1 Scope. The main purpose of this experiment was to establish the variations in particle-size test results that arise from real differences between pairs of bulk samples of materials taken from different batches (ie the sampling error). To achieve this a single operator (A) went to a stockpile of about 100 tonnes of hoggin (Aggregate 138) of a kind similar to that often supplied as Type 2 granular sub-base to meet the requirements of Clause 804 of the Specification for Road and Bridge Works (Department of Transport 1976).

To simulate the effects of taking samples from different stockpiles (batches) the operator imagined the stockpile to be composed of nine different segments representing nine separate batches of the material. From each segment he took two duplicate bulk samples each weighing about 60kg. After returning to base (Laboratory A) he took two representative test portions with an approximate mass of 15kg from each bulk sample and determined the particle-size distribution of the 36 resulting test portions by a wet-sieving procedure (see Appendix). The results of these tests are summarised in Table 1.

TABLE 1

Results of particle size determinations on 36 test portions of Aggregate 138

B.S. sieve size	Average of 36 results (percent passing)	Standard Deviation	Sampling Variance (V_S)	Repeatability (r_1)
37.5 mm	99	1.4	0.45	2.6
20	88	5.1	0.38	4.5
10	76	7.9	1.06	7.7
5	64	8.8	1.18	6.9
2.36	55	8.1	0.99	6.9
1.18	48	6.9	0.34	6.8
600 um	35	4.9	0	5.3
300	21	2.4	0	2.7
150	13	1.5	0.01	2.0
75	10	1.2	0	1.8

2.2.2 Discussion of results. The differences between the 36 sets of results summarised in Table 1 arise from the sum of:–

(a) Genuine differences between the nine pairs of bulk samples because of variations in the grading of the material in the stockpile.

(b) Differences between the duplicate bulk samples that cannot be attributed to errors arising in sample reduction and testing – the sampling error.

(c) Differences arising from the sample reduction of the bulk samples – the sample reduction error.

(d) Differences between the results arising from deficiencies in the test method or the manner in which it is carried out – the repeatability (r).

The experiment was planned in such a way that it was possible, to some extent, to separate the influence of these causes of variation. The differences between each of the 18 pairs of duplicate test portions would not include sampling error and from these results it is possible to calculate a value for the repeatability (r_1) of the test results which is defined as "the value below which the absolute difference between two single test results obtained with the same method using different test portions of the same laboratory sample under the same conditions (same operator, same laboratory, same apparatus and a short interval of time) may be expected to lie with a probability of 95 per cent". This definition differs from the classical definition of repeatability (r) because it takes account of error introduced by sample reduction ie the test is repeated using *different* test portion of the same laboratory sample instead of being repeated with identical test material.

The value of the repeatability (r_1) calculated for each sieve fraction is given in Column 5 of Table 1. These values include both the test method variance and sample reduction variance and it is not possible to separate the relative influence of the two effects. The values for repeatability are high and do not compare well with the values for reproducibility (R_1) of the test obtained from the second experiment; this is discussed further in Section 2.4.2.

The sampling variance (V_S) arising from sampling errors in obtaining the nine pairs of bulk samples is given in Column 4 of Table 1. This shows that the sampling error variance (ie the average variation between bulk samples over the nine batches) is small. As might be expected it is larger on those sieves where the bulk of the material is retained.

The variation between the nine pairs of bulk samples is much more than can be attributed to sampling and testing errors. The results therefore represent real differences in the batch to batch variability of the material and indicate that the grading of the material in the stockpile as a whole was very variable.

2.3 Second experiment

2.3.1 Scope. After the first experiment had been completed Operator A put together the residues of all of his bulk samples of the aggregate and mixed them together to provide a laboratory sample with an approximate mass of 560 kg that should have been as representative of the original stockpile as the samples obtained by Operators B to K in the third experiment which is described later.

From this bulk sample he produced eight representative laboratory sub-samples each weighing about 50 kg that were sent to each of eight laboratories (H and L–R). Each laboratory prepared two test portions on which the particle-size test was carried out by the modified BS 812 (British Standards Institution 1975) procedure described in the Appendix. The results of these tests are given in Table 2.

TABLE 2

Results of particle-size analyses and calculations of repeatability and reproducibility from second experiment

B.S. sieve size	Average percentage passing	Repeatability (r_1)	Reproducibility (R_1)
37.5 mm	99	1.2	2.7
20	90	3.6	3.6
10	77	6.4	10
5	66	8.5	12
2.36	58	10	11
1.18	50	10	11
600 um	38	9.1	9.1
300 um	22	5.4	5.4
150 um	14	2.7	3.0
75 um	10	1.6	3.3

2.3.2 Discussion of results. The results of this experiment enabled further estimates to be made of the repeatability (r_1) (which was defined in Section 2.2.2) and also of the reproducibility (R_1) which is defined as "the value below which the absolute difference between two single test results obtained with the same method using different test portions of the same laboratory sample under different conditions (different operators, different apparatus, different laboratories and for different time) may be expected to lie with a probability of 95 per cent". This definition differs from the classical definition of reproducibility R because it takes account of error introduced by sample reduction ie the test is repeated using different test portions of the same laboratory sample instead of being repeated with identical test material.

The results in Table 2 show that there was good agreement between the average grading and the average gradings obtained in the first experiment but the repeatability values (r_1) were somewhat higher than in the previous experiment.

In comparing the individual results to calculate values of repeatability and reproducibility all the results were accepted for calculating the values of repeatability given in Table 2. However, the average of the pairs of results reported by Laboratory N for the percentage of material passing the 20 mm, 150 um and 75 um sieves were 84, 23 and 22 per cent respectively and Laboratory 0 reported results for the percentage of material passing the 300 um, 150 um and 75 um sieves as being 11, 4 and 1 per cent respectively. All of these results were classified as "outliers" or "stragglers" when analysed by the BS 5497 procedure (British Standards Institution 1979) and were excluded from the calculation of reproducibility.

2.4 Third experiment

2.4.1 Scope. This experiment was primarily intended to provide information on the reproducibility (R_2) of the particle-size distribution test but it incidentally also provided further information on the repeatability (r_1) of the test.

The reproducibility (R_2) differs from the reproducibility (R_1) which was determined from the results of the second exercise. R_1 is the reproducibility value obtained when different test portions of the same laboratory sample are used for the test; R_2 is the reproducibility value obtained when different laboratory samples are used for the test. Thus when one operator obtains a bulk sample which he sub-divides and sends to a number of laboratories for testing, the differences between the results are affected by the value of R_1. When each operator visits a stockpile to obtain his own bulk sample the difference between the results depends on the value of R_2.

In the experiment nine operators visited the same stockpile of Aggregate 138 as used in the first experiment and each took a single representative bulk sample of minimum mass of 200 kg from the whole of the stockpile following the procedure given in BS 812. At their own laboratories they each produced by careful sample reduction three separate test portions to enable them to carry out three particle size distribution tests by the procedure described in Test 7(A) of BS 1377 (British Standards Institution 1975) (see Appendix). In addition they also produced further test portions to carry out plasticity tests and compactability tests by B.S. procedure (see Sections 3 and 4).

The results of the particle-size analyses are given in Table 3 and compared with the results from the previous experiments in Table 4.

2.4.2 Discussion of results. The values of repeatability (r_1) obtained from this experiment are of the same order as those obtained in the first and second experiments. The values for reproducibility (R_2) were also not significantly different from the values of R_1 obtained in the second experiment. This was unexpected because if each laboratory takes responsibility for obtaining its own samples from the stockpile this might be considered to produce more variable results than one laboratory taking a large bulk sample for sharing out by careful sample reduction among the participating laboratories.

The fact that the values of R_1 and R_2 are so close together and that the values of r_1 are high in relation to the values of R suggested that the sample reduction error, ie the error involved in sub-dividing the bulk sample down to the test portion was playing a large part in affecting the results thus confirming the results of previous investigation (Pike 1979). The work described in Sections 2.6 and 2.7 provides some further evidence for this and the contributions of the various factors that affect the precision of the particle-size distribution test are discussed in Section 2.8.

2.5 Fourth experiment

2.5.1 Scope. In this experiment one operator (from Laboratory E) visited the stockpile of Aggregate 138 and carefully obtained a number of representative bulk samples by B.S. procedure which were taken back to his laboratory. These samples were sent to a number of different laboratories which carried out a particle-size distribution test by Test 7(A) of BS 1377 (British Standards Institution 1975). In addition they also produced further test portions on which to carry out plasticity tests and compactability tests by B.S. procedure (see Parts 2 and 3). A total of 32 laboratories reported results for the particle-size test and these are summarised in Table 5.

2.5.2 Discussion of results. There was good agreement between the average gradings obtained in this experiment and those obtained in the previous two experiments. In this experiment only one result was reported by each of the laboratories taking part so it was not possible to assess the repeatability (r_1) of the results. However, an estimate can be made of reproducibility R_1. A comparison with values of R_1 and R_2 in Table 4 shows that the values of R_1 in the fourth experiment are of the same order as those in the earlier experiment.

TABLE 3

Results of particle-size determinations reported by nine laboratories each of which collected their own bulk sample of Aggregate 138

Laboratory No.	Mean (of 3) percentage passing sieve size:–							
	37.5 mm	20 mm	10 mm	5 mm	2.36 mm	600 um	300 um	150 um
B	99	85	73	62	53	33	19	11
C	99	90	76	66	57	36	19	12
D	100	89	74	62	54	33	19	12
F	100	89	76	64	55	33	18	12
G	99	86	73	59	49	31	18	11
H	99	90	79	68	59	37	21	13
I	100	89	76	63	54	33	18	13
J	100	92	80	67	57	36	21	16
K	99	85	67	57	50	30	18	11
Mean	99	88	75	63	54	34	19	12
Repeatability (r_1)	1.6	7.3	7.5	6.2	5.3	2.8	2.4	2.0
Reproducibility (R_2)	2.0	9.4	12	11	10	6.5	4.3.	4.2

TABLE 4

Comparison of the results obtained in three experiments on Aggregate 138

Sieve Size	Overall Average passing (%)	Values of repeatability (r_1)			Values of reproducibility	
		1st exp.	2nd exp.	3rd exp.	2nd exp. (R_1)	3rd exp. (R_2)
37.5 mm	99	2.6	1.2	1.6	2.7	2.0
20	88	4.5	3.6	7.3	3.6	9.4
10	75	7.7	6.4	7.5	10	12.1
5	63	6.9	8.5	6.2	12	11
2.36	54	6.9	10	5.3	11	10
1.18	48	6.8	10	–	11	–
600 um	36	5.3	9.1	2.8	9.1	6.5
300	21	2.7	5.4	2.4	5.4	4.3
150	12	2.0	2.7	2.0	3.0	4.2
75(63)	9	1.8	1.6	1.7	3.3	2.7

TABLE 5

B.S. sieve size	Mean (% passing sieve)	Standard Deviation	Reproducibility R_1
37.5 mm	98	1.5	4.2
20	88	2.9	8.1
10	76	3.5	9.8
5	65	3.4	9.5
600 um	36	2.2	5.9
75	10	1.2	3.1

2.6 Fifth experiment

2.6.1 Scope. Two additional aggregates (Nos. 103 and 105) were used for this experiment. Aggregate 103 was another hoggin which met the requirements for Type 2 granular sub-bases. Aggregate 105 was a well-graded crushed rock which was suitable for use as a Type 1 granular sub-base (Department of Transport 1976). Operator A carefully prepared sixteen test portions, each weighing about 18 kg of both of these aggregates, in such a way as to reduce differences in grading between the samples that might arise from sample reduction errors. This was done by splitting the bulk sample into three nominal size fractions (retained 40 mm, 40 mm – 5 mm passing 5 mm).

Material retained on the 40 mm sieve was discarded and the two remaining fractions were weighed to determine the proportions of each in the bulk sample. The sixteen test portions were then prepared from these fractions combined together to give representative portions with the same proportions of these fractions as were present in the bulk sample.

One pair of the sixteen test portions was sent to each of the eight participating laboratories where they were carefully mixed together before being split once more by riffling. Particle-size tests were then made on each test portion; the results of these tests are given in Table 6.

TABLE 6

Results of particle-size analyses from fifth experiment

B.S. sieve size	Average percentage passing		Repeatability r_1		Reproducibility R_1	
	103	105	103	105	103	105
37.5 mm	99	98	1.7	3.6	1.7	4.7
20	82	82	4.1	5.6	5.2	6.3
10	62	52	4.2	8.6	7.8	8.6
5	50	34	3.4	7.0	6.3	7.0
2.36	44	14	3.5	3.3	5.2	3.3
1.18	40	9.2	3.4	2.2	4.9	1.6
600 um	35	6.6*	3.2	1.6	4.5	1.6
300	24	4.8	3.0	1.3	4.9	1.3
150	13	3.6	1.1	0.3	2.9	1.0
75	7.8	2.6	0.9	0.5	1.2	1.1

* Aggregate 105 was 1.4 per cent too coarse at 600 um to meet the requirements of a Type 1 sub-base.

2.6.2 Discussion of results. The method of sample preparation might have been expected to reduce the sample reduction error but in fact the estimates of precision given in Table 6 are at levels comparable with those found in the previous experiments. The clear implication of this experiment is that splitting into two fractions has little effect on the sample reduction error. It is probable that splitting into more fractions would reduce this error and evidence that this is indeed the case is provided by the results of the sixth experiment which is described in Section 2.7.

2.7 Sixth experiment

2.7.1 Scope. This experiment was carried out as part of a precision exercise to estimate the reproducibility of the TRRL Frost Heave test. This test requires a trial frost-heave specimen to be prepared to ensure that stable specimens can be made without causing undue degradation of the particles. The degree of degradation can be assessed by carrying out a particle-size distribution test on the stable specimen. The aggregate used for this exercise was a hoggin (Aggregate 114) that conformed to the grading requirements for Type 2 granular sub-bases.

The bulk sample of this material was wet-sieved mechanically into six nominal size fractions 37.5–20 mm; 20–10 mm; 10–5 mm; 5 mm – 600 um; 600–300 um and 300–75 um. The material retained in the 37.5 mm sieve was discarded and the passing 75 um sieve fraction was allowed to run to waste during the sieving. The material was oven-dried and then reconstituted to provide test portions with the target grading given in Table 7. The procedure was thus similar to that used in the fifth experiment except that the material was sieved into three times as many sieve sizes before reconstituting.

The test portions were sent to 14 laboratories (12 of which had taken part in some of the previous exercises) each of which, after compacting the material in a frost-heave test mould to its maximum dry density at its optimum moisture content, carried out a particle-size distribution test on the whole specimen (mass 2600g) by BS 1377 procedure. The results of these tests are given in Table 7.

2.7.2 Discussion of results. The mean results from the laboratories listed in Table 7 agree well with the target grading. There are small differences in the values for the percentage of material passing the 10 mm and 5 mm sieves. These were caused probably by some slight degradation and an error in sampling of the mixed material that occurred during the preparation of the trial specimen. The agreement between laboratories as indicated by the estimate of reproducibility for each sieve size was better than had been obtained in any of the previous experiments described.

The method of sample preparation minimised errors due to sample reduction and the values found for reproducibility (R_1) should therefore be close to the value of the "true" reproducibility (R) of the test ie in the hypothetical case that applies when tests are made on identical samples rather than different test portions of the same laboratory sample.

2.8 General discussion of results

The results of the experiments described in the previous sections makes it possible to draw some conclusions about the contributions of the various factors that affect the precision of the particle-size distribution test. These factors are:

(a) The sampling error

This is the error involved in obtaining bulk samples from the batch; experiments 1–4 show that the effect of this is small if sampling is done in accordance with the recommended procedure and there is good agreement between the average grading of Aggregate 138 as determined by the four experiments.

(b) The within-laboratory error including sample reduction error

This is the error caused by the sub-division of the bulk sample down to the test portion. Normally this cannot be separated from the other errors involved in carrying out the test (ie different operator techniques and the effect of the apparatus used). However, evidence that it plays a major part in influencing the results is provided by the fact that the value of the reproducibility is greatly reduced when rigorous steps are taken to reduce the sample reduction error to negligible proportions as in the sixth experiment. Previous work (Pike 1979) has also shown the importance of sample reduction error which had not hitherto been regarded as a major source of error.

(c) Between-laboratory testing errors

These are errors which arise from differences in the people and equipment used to carry out the test in different laboratories. In the case of the particle size distribution test this appears to be quite small and as a consequence the reproducibility of the test is only marginally greater than its repeatability.

TABLE 7

Results of particle-size distribution tests carried out in connection with frost-heave precision trials

Lab. No.	Percentage by mass passing sieve size:—						
	37.5 mm	20 mm	10 mm	5 mm	600 um	300 um	63 um
Target Grading	100	86	69	44	22	16	0
B	100	86	69	48	23	18	1
C	100	85	66	46	24	17	1
D	100	87	71	49	23	17	1
E	100	86	68	48	23	17	2
G	100	84	66	47	22	16	0
H	100	88	71	50	24	17	2
I	100	84	67	46	23	15	2
K	100	84	65	47	23	16	0
O	100	84	65	46	22	16	1
P	100	83	66	48	25	18	3
Q	100	88	68	47	21	12	0
R	100	84	66	46	23	16	1
S	100	88	70	48	24	17	2
T	100	85	66	47	23	15	2
Mean	100	85.4	67.4	47.4	23.1	16.2	1.3
S.D.	0	1.7	2.1	1.2	1.0	1.5	0.9
R	0	4.8	5.9	3.4	2.8	4.2	2.4

2.9 Summary of results of repeatability and reproducibility

An examination was made of all the results obtained to ascertain whether any relation existed between the values of repeatability and reproducibility and the magnitude of the value recorded for the amount of material passing a sieve. For those sieve sizes where little material was retained ie at the coarse and fine ends of the range of sieves the values of r_1, R_1 and R_2 were significantly lower. In the middle of the range because all the materials were reasonably well-graded a roughly equivalent amount of material was retained on each sieve and the values of r_1, R_1 and R_2 were not greatly influenced by sieve size. The mean values obtained for r_1, R, R_1 and R_2 are summarised in Table 8.

TABLE 8

Summary of the values for repeatability and reproducibility of the particle-size test carried out on Type 2 granular sub-base materials

Sieve Size	Repeatability value r_1	Reproducibility values R	R_1	R_2
37.5 mm	2	–	3	2
20	5	5	6	9
10	7	6	9	12
5	6	3	9	11
2.36	6	–	7	10
1.18	6	–	6	–
600 um	4	3	5	7
300	3	4	4	4
150	2	–	3	4
75	1	2	2	3

The results obtained in Table 8 relate only to aggregate that conforms to the grading requirements for Type 2 granular sub-bases. For aggregates having different gradings it is therefore desirable that the work described in this Report is extended to provide information in these instances. However, it is probable that similar values of repeatability and reproducibility would apply in those cases where aggregates are supplied in a range of sizes eg Type 1 granular sub-bases.

3. REPRODUCIBILITY OF PLASTICITY TEST RESULTS

3.1 Introduction

The plasticity tests (liquid limit, plastic limit and plasticity index) are primarily soil classification tests (British Standards Institution 1975) but they are used to specify the properties of the fines fraction of granular materials. Thus the Specification for Road and Bridge Works (Department of Transport 1976) requires that the fraction passing the 425 um sieve shall be non-plastic in the case of Type 1 granular sub-base materials (ie PI=0) and in the case of Type 2 granular sub-base materials the requirement is that the PI should not exceed 6 per cent.

In the course of the work described in Part 1 of this Report plasticity measurements were made on the fines fraction (passing 425 um sieve) of one of the aggregates used. The results of these tests provide information about the precision of the plasticity tests and this part of the Report summarises that information.

3.2 Scope of the investigation

All the plasticity measurements discussed were carried out on the fines fraction of Aggregate 138 in the course of the third and fourth experiments described in Section 2. A total of 29 laboratories reported results for the plasticity tests and these are summarised in Table 9.

Similarly in the fourth experiment the laboratories taking part were asked to report results for plasticity tests made on the samples that were collected. The results of these tests are summarised in Table 10.

TABLE 9

Results of plasticity tests on the fines fraction of Aggregate 138 reported by 29 laboratories (third experiment)

Laboratory	Liquid Limit	Plastic Limit	Plasticity Index
1	36	18	18*
2	26	15	11
3	24	14	10
4	24	16	8
5	23	NP (12)	NP (11)
6	25	16	9
7	31	15	16
8	29	13	16
9	25	12	13
10	27	18	9
12	25	17	8
13	26	14	12
14	25	NP (12)	NP (13)
15	28	14	14
16	24	15	9
17	27	16	11
18	25	15	10
19	20	NP (12)	NP (8)
20	27	15	12
21	24	14	10
23	24	16	8
25	23	12	11
26	26	15	11
27	46*	21	25*
28	31	16	15
29	31	17	14
31	24	16	8
32	27	14	13
Mean	26	15	11
Standard Deviation	2.6	2.1	2.8
Range	20–46	NP–21	NP–25
Reproducibility (R_1)	7	6	8

* These values omitted in calculating mean, standard deviations and R_1.
Values of PL and PI in brackets are estimated.

In calculating the standard deviation and the values of reproducibility a problem arose in the case of those instances where a plastic limit result was not obtainable. In such cases the plastic limit could not have been zero but must have been just below the values recorded by the operators. Therefore, in Tables 9 and 10 the standard deviation and reproducibility of the plastic limit and plasticity index results have been calculated on the basis that, in those cases, where the material was recorded as non-plastic (NP) a value of 12 per cent has been used. The reason for this choice was that 12 per cent was the lowest value recorded by any of the laboratories that were able to report a result for the plastic limit.

TABLE 10

Results of plasticity tests on the fines fraction of Aggregate 138 (fourth experiment)

Laboratory	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
B	25	NP (12)	NP (13)
C	29	NP (12)	NP (17)
D	25	17	8
E	27	15	12
F	25	18	7
G	23	16	7
H	24	NP (12)	NP (12)
I	28	15	13
J	–	NP (12)	NP
K	29	16	13
U	21	NP (12)	NP (9)
Mean	26	14	11
Standard Deviation	2.6	2.3	3.2
Reproducibility (R_2)	7	6	9

* Values of PL and PI in brackets are estimated.

3.3 Discussion of results

The results in Table 9 give an indication of the values of R_1 for the three plasticity tests and the results in Table 10 for the values of R_2. They are not significantly different and confirm previous work (Sherwood 1970) that the precision of these tests is poor although the degree of precision may be acceptable for the original purpose of soil classification.

4. REPRODUCIBILITY OF COMPACTION TEST RESULTS

4.1 Introduction

BS 1377 (British Standards Institution 1975) contains three tests for determining the dry density/moisture content relation of materials. For granular materials the most appropriate test is Test 14 the Vibrating Hammer Method. Type 2 granular sub-base materials are required to be laid at a moisture content within the range of 1 per cent above to 2 per cent below the optimum moisture content determined by this method. An improved version of the vibrating hammer method has been developed (Pike and Acott 1975) which is now British Standard BS 5835 (British Standards Institution 1980). This test is of recent origin and is not yet included in any specifications but it is possible that it may largely replace the vibrating hammer method of BS 1377.

In the course of the work described in Section 2 of this Report compaction tests by both methods were made on one of the aggregates used. The results of these tests provide information about the precision of the compaction tests and this part of the Report summarises that information.

4.2 Scope of the investigation

All the compaction bests discussed were carried out on Aggregate 138 in the course of the third and fourth experiments described in Section 2.

In the third experiment Laboratory E in addition to other tests also asked for compaction test to be carried out by Test 14 or BS 1377 and if possible also by BS 5835. A total of 25 laboratories reported results of the BS 1377 test and four by the BS 5835 test, the results are summarised in Table 11.

TABLE 11

Results of maximum dry density and optimum moisture content determined by test 14 of BS 1377 and BS 5835 (third experiment)

Lab. No.	Test 14 BS 1377		BS 5835	
	Maximum Dry Density (Mg/m^3)	Optimum Moisture Content (%)	Maximum Dry Density (Mg/m^3)	Optimum Moisture Content (%)
6	–	–	2.27	6.3
7	–	–	2.23	7.0
29	–	–	2.24	6.2
32	2.21	7.0	2.25	6.5
1	2.24	6.3		
2	2.26	7.0		
4	2.23	6.3		
5	2.27	6.4		
8	2.22	7.0		
9	2.30	5.9		
10	2.23	5.5		
11	2.23	7.5		
12	2.27	7.7		
13	2.22	6.5		
14	2.30	6.5		
15	2.27	6.0		
16	2.29	6.5		
17	2.20	8.0		
18	2.26	6.5		
19	2.21	7.0		
20	2.20	7.0		
22	2.26	6.1		
25	2.28	6.5		
26	2.22	7.0		
27	2.17	6.5		
28	2.21	7.4		
30	2.36	6.1		
31	2.21	6.6		
Mean	2.24	6.7	2.25	6.5
Standard Deviation	0.04	0.59	0.04	0.36
R_1	0.1	1.7	Too few results for estimate to be made	

Similarly in the fourth experiment the laboratories taking part were asked to report results for compaction tests made on the samples that were collected. The results of these tests are summarised in Table 12.

TABLE 12

Results of maximum dry density and optimum moisture content determined by Test 14 of BS 1377 and BS 5835 (fourth experiment)

Lab. No.	Test 14 BS 1377		BS 5835	
	Maximum Dry Density (Mg/m^3)	Optimum Moisture Content (%)	Maximum Dry Density (Mg/m^3)	Optimum Moisture Content (%)
D	2.31	6.5	2.26	5.9
J	–	–	2.25	5.7
B	2.28	7.2		
C	2.19	7.4		
E	2.19	7.5		
F	2.06	6.0		
G	2.27	7.5		
H	2.22	5.5		
I	2.24	6.0		
K	2.25	7.2		
U	2.14	7.5		
Mean	2.22	6.8	2.26	5.8
Standard Deviation	0.07	0.76	Too few results for estimates to be made	
R_2	0.02	2		

4.3 Discussion of results

There were too few results in Tables 11 and 12 available from the BS 5835 compaction test to permit values to be calculated for the repeatability and reproducibility of the optimum moisture content and maximum dry density but the mean of the values from this test and of Test 14 of BS 1377 agree quite well.

5. GENERAL CONCLUSIONS

It is now the policy of the British Standards Institution that in future all tests on aggregates must include reliable information on the precision of the methods.

Most of the experiments described in this report were not planned strictly in the manner required by BS 5497 (British Standards Institution 1979) and thus some of the data obtained should be used only as background information. The Report does contain valid data on the precision of the particle-size distribution for several aggregates used as unbound road sub-bases but further work is needed to extend this to other types of aggregate. In the case of the plasticity and compactability tests more work is needed to establish the precision because the results in the Report only give an indication of what the reproducibility of these tests is likely to be.

6. ACKNOWLEDGEMENTS

The work described in this Report was carried out in the Pavement Materials and Construction Division (Division Head: Mr G F Salt) of the Highways and Structures Department of TRRL. The assistance of all those organisations that took part in providing results is gratefully acknowledged.

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8. APPENDIX

METHODS FOR DETERMINING THE PARTICLE SIZE DISTRIBUTION OF AGGREGATES

The particle-size distribution of aggregates used in road construction can be determined by the methods given in BS 1377 or BS 812. These methods are basically similar but there are important differences of emphasis and detail.

BS 1377 gives two methods; Test 7 (A) the standard method by wet-sieving and Test 7 (B) a subsidiary method by dry sieving. The standard makes clear that the subsidiary method by dry sieving is acceptable only if it can be shown that it gives the same results as wet-sieving for the material under test.

BS 812 also gives two methods but reverses the emphasis. Test 7.1.4 is the normal test procedure by dry sieving, Test 7.1.6 is a washing and decantation procedure which must be used where aggregates contain materials which cause aggregation of particles.

Test 7 (B) of BS 1377 and Test 7.1.4 of BS 812 are both based on dry sieving and the two methods do not differ in essential detail. Neither method is suitable for the type of aggregates considered in this Report.

Despite its name, Test 7 (A) of BS 1377 is not strictly a wet-sieving method; it requires that the material should be soaked in water prior to its being washed through a 2 mm sieve resting on top of a 63 um sieve. The material retained in these sieves is then dried and sieved in a dry condition through appropriate sieves.

Test 7.1.6 of BS 812 requires that the material shall be soaked in water and agitated to remove the fine material, which is then decanted through a 75 um sieve. The operation is repeated until all the wash water is clear. It is similar in principle to Test 7 (A) of BS 1377 but the test description lacks the detail given in BS 1377 and is therefore less satisfactory.

In this report the particle-size distribution tests described in the first, second and fifth experiments were done by a modification of Test 7.1.6 or BS 812 that brought it close to Test 7 (A) of BS 1377 used for the other three experiments. The difference between the two methods is not therefore likely to have affected the results obtained.

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ABSTRACT

Errors in the sampling and testing of sub-base aggregates: P T SHERWOOD and D C PIKE: Department of the Environment Department of Transport, TRRL Supplementary Report 831: Crowthorne, 1984 (Transport and Road Research Laboratory). Specifications for sub-bases are based on knowledge that has been gained from past performance of a wide range of aggregates in conjunction with results of tests that define relevant properties.

To assess the suitability of an aggregate samples have to be tested but it is extremely difficult to take a truly representative bulk sample of a large batch of material and to prepare that sample for test in a way that entirely excludes errors. This means that in those cases where a material just passes or just fails to meet a specification limit doubts can exist between customers and suppliers as to whether acceptance or rejection is really justified; it is therefore important to be able to make reasonable allowance for the errors likely to arise from deficiencies in sampling and testing.

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ISSN 0305–1315

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