CONSTRUCTION & MAINTENANCE OF UNSEALED ROADS

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AN IMPORTANT NOTE FOR THE READER

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EXECUTIVE SUMMARY

1. Introduction

"Construction and Maintenance of Unsealed Roads" investigates the cost effectiveness of conventional and alternative construction and maintenance procedures for unsealed roadways. The study was undertaken during 1987, 1988 and 1989.

Test sections of unsealed pavement were constructed on two unsealed roads within the Rodney District, North Island, New Zealand, that had been monitored previously for roughness. Comparisons were also made between the historical and current procedures and specifications.

A material testing programme was carried out to evaluate the characteristics of the local aggregates, a selection of which were then used for the five test sections of unsealed roadway.

2. Recommendations for Alternative Procedures

Alternative construction and maintenance procedures included the use of clay as a binder within the aggregate, increased pavement crossfall, and mechanical compaction of aggregates before trafficking. The recommendations for these procedures are as follows:

- Adopt a uniform crossfall of 6% - 8% and ensure that the roadside drainage is adequate.
- Test pavements on unsealed roads should be located on sections of roadway with a relatively constant microclimate.
- Test pavements on unsealed roads should be formed approximately 100 m longer than the test section length to be studied. The additional length should provide a 50-m "buffer-zone" between the different types of pavement.
- The engineering properties of local aggregates should be established to determine their suitability for use in the construction and maintenance of unsealed roads.
- Should the gradation of the local aggregate necessitate blending, the engineering properties of the clay should be determined. Also the clay should be in a sufficiently dry state to readily crumble during blending.
- The aggregate blending procedure using rotary hoeing is recommended.
- Sampling of aggregates should be done with care to ensure that the sample taken is typical of the material stockpiled.
- The actual particle size distribution for a particular aggregate must be established, especially for those that appear densely graded.

- The suitability of a material which has a lineal shrinkage value level as high as 10%, when measured using the NZS 4402:1986 procedure, should be verified again using the 1938 MHB Specification method.

- Aggregates reputed to be of low durability should be tested using the LAA test to ensure that the 1938 MHB Specification is met.

- The shape of a prepared sub-grade should be verified as correct before aggregate is placed and compacted.

- The grader should not straddle and cut the crown of the pavement during either construction or maintenance as this will flatten the desired inverted "V" profile of the pavement.

- Unsealed pavements should be constructed according to the following details:
  1. Aggregates conforming to the 1938 MHB Specification should be used.
  2. Adequate pavement crossfall, i.e. 6% - 8%, should be provided.
  3. Adequate drainage should be provided.
  4. Sufficient carriageway width, preferably two lanes, to prevent wear of the carriageway crown should be allowed.
  5. Areas of pavement with limited crossfall (in the vicinity of tangent points on corners) should be minimised.
  6. Thickness of running course replenishment should be reduced, particularly on grades, to prevent the formation of corrugations.

- During the construction of unsealed pavements using an aggregate which requires the addition of clay, care should be taken to ensure that:
  1. Pockets of weak rock are not inadvertently included during the quarrying process.
  2. An angular running course is used.
  3. The clay is well blended.

3. Cost Effectiveness of Alternative Procedures

The performance and maintenance requirements of these test sections of the two roads on which the recommended alternative procedures were used, and of the conventionally constructed and maintained portions of unsealed road, were monitored for roughness and maintenance costs.

From analyses of these data the cost effectiveness was evaluated of alternative materials and of construction and maintenance procedures. Application of loose aggregates on unsealed pavements, although cost effective in the short term, is not cost effective in the long term because of roughness and maintenance requirements.

The most cost-effective procedures were ascertained to be:

- use of "secondary" aggregates,
- increased crossfalls (to 6 - 8%), and
- use of up to 10% clay as a binder.

ABSTRACT

"Construction and Maintenance of Unsealed Roads" investigates the cost effectiveness of conventional and alternative construction and maintenance procedures for unsealed roadways. The study was undertaken during 1987, 1988 and 1989.

Test sections of unsealed pavement were constructed on two unsealed roads within Rodney District, North Island, New Zealand. A material testing programme was carried out to evaluate the characteristics of the local aggregates, as well as testing alternative construction and maintenance procedures. The performance and maintenance requirements of the roads were monitored for roughness and maintenance costs.

The cost effectiveness of alternative materials, construction and maintenance procedures was evaluated from analyses of the roughness and maintenance cost records. The most cost-effective procedures were ascertained to be:

- use of "secondary" aggregates,
- increased crossfalls (to 6 - 8%), and
- use of up to 10% clay as a binder.

1. INTRODUCTION

The cost effectiveness of constructing unsealed roads using clay-bound aggregate and relatively steep surface crossfalls is investigated in this project (originally designated RM21).

The project was carried out during 1987, 1988 and 1889 on selected lengths of Haruru Road and Old North Road, in Rodney District, North Island, New Zealand, and was under the control of the Rodney District Council. The roads are located north-west of Auckland.

Both these roads had been the subject of a Road Roughness Measurement Study (RM12) made by Bartley et al. (1988) and carried out for the National Roads Board (NRB, now Transit New Zealand). This earlier study, *"Roughness of Unsealed Roads"*, involved the regular measurement of surface roughness using a NAASRA Roughness Meter installed in a Toyota Corona station wagon. The RM12 study also provided a history of the surface condition of these roads over a period of fifteen months, commencing January 1985.

Haruru Road provides access to Flat Top Quarry operated by Winstone Aggregates Ltd. It is used for cartage of all material produced at this major quarry for use within the Rodney District. The road has some steep and soft unstable areas, and a relatively rough surface even though a considerable sum of money has been spent on maintenance.

Old North Road skirts the west and south sides of Riverhead State Forest between Ararimu Valley Road and Riverhead Road. The road carries mainly light vehicular traffic owned by people commuting between Ararimu Valley and Kumeu, and other villages to the south. The road crosses mainly rolling terrain and becomes relatively rough at times, particularly in the summer months. The road also provides access to the shooting range operated by the Waitemata Gun Club which was the site of the Trap Shooting event at the 1990 Commonwealth Games.

2. PROJECT OBJECTIVES

The objectives of this present study were to:

1. Construct, maintain and monitor lengths of unsealed pavement.

2. Collect all data relevant to the construction and maintenance of selected unsealed pavements.

3. Analyse the cost and performance data, to determine the cost effectiveness of the construction and maintenance procedures studied.

In particular the project was required to consider the effects of:

1. Use of clay as a binder in the aggregate layer.
2. Increased crossfall.
3. Mechanical compaction of the aggregate before trafficking.
4. Alternative maintenance techniques.

Roughness monitoring of the original roads was to be continued so that the structural performance and cost effectiveness of the new pavement test sections could be compared with the properties of the original roads.

3. UNSEALED ROADS

3.1 Background

Rodney District Council is responsible for the operation of approximately 1500 km of formed road of which over 70% are unsealed. The typical unsealed rural road pavement (Figure 3.1) within the District carries approximately 200 vehicles per day (vpd).

Most unsealed pavements have two or three relatively bare wheel tracks bounded by a thin cover of loose aggregate which is redistributed when the road is regraded. Very few of these unsealed pavements would have retained their original condition as normally the typical pavement has been improved from a dry weather track to its present profile over a long period of time (between 25 to 100 years). These unsealed pavements are considered by the public to be rough and often dusty and generally to be avoided unless no other option exists.

Before the Second World War (1939-1945), considerable engineering effort was employed to optimise the construction and maintenance of unsealed pavements. With the more widespread development of sealed pavements, much of the old technology has been abandoned as it is not considered to be appropriate to the new form of construction.

However, as unsealed pavements will be part of our national roading system for many years to come, improvements to the construction and maintenance techniques are required to provide smoother, more permanent and less dusty roads. It is now possible to quantify these improvements in economic terms by regular measurement of the surface roughness and by reference to criteria relating roughness to vehicle-operating costs.

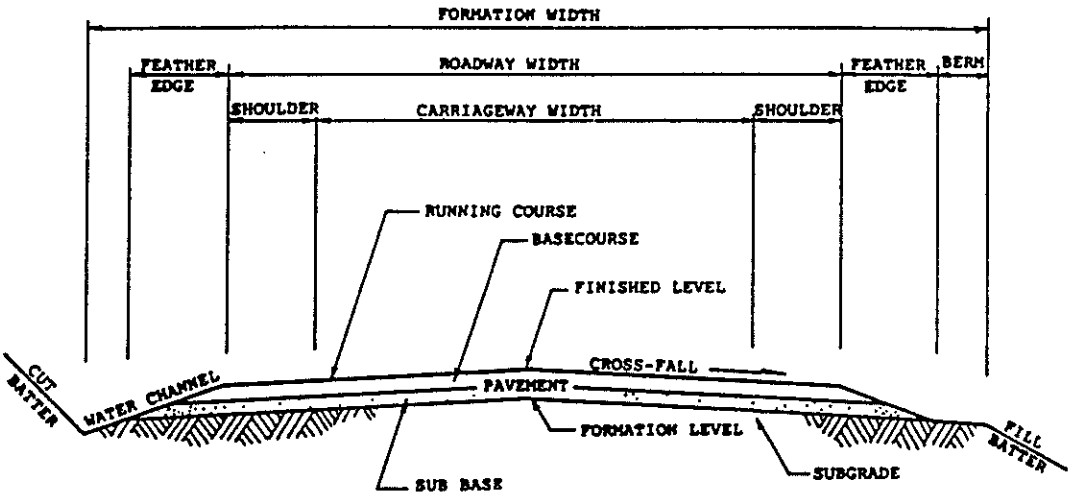

Figure 3.1 Typical unsealed pavement profile (Ferry 1986b).

3.2 Clay Content

The 1938 edition of the (New Zealand) Main Highways Board (MHB 43) *"Specification for Construction of Base-course"* encouraged the use of clay as a binder within the basecourse aggregate mixture. The use of aggregate which complies with the 1938 MHB Specification is considered to be an essential ingredient in unsealed road construction.

This specification differs from the current Transit New Zealand (TNZ) 1985 M/4 *"Specification for Crushed Basecourse Aggregate"* particularly with respect to the quantity of clay-sized fines (material passing the 75 micron sieve). The 1938 specification nominates 8-15% while the 1985 specification limits the quantity to a maximum of 7%.

The original concept (1938) was for the basecourse to be a *"densely graded mineral aggregate mix including cohesive clay"*. It was intended that the clay material would bind the aggregate layer, reduce the loss of moisture and therefore reduce the volume of dust in dry weather. The quantity of clay material was specified as part of a mix ratio, such as

- six parts of coarse aggregate,
- two parts of sand,
- one part of clay

The MHB Specification requires the tensile breaking strength of the clay to be not less than 10 pounds per square inch (approximately 70 kPa) using a briquette test (used to test cement mortar), and the lineal shrinkage was to be less than 5%. Resistance to abrasion, measured by the Los Angeles Abrasion (LAA) Loss test, was to be not greater than 65%. Details of testing for this Specification are provided in Section 6 of this report.

3.3 Pavement Crossfall

The accumulation of water on the surface of an unsealed pavement results in a reduction in the forces binding the particles together. The passage of a vehicle through surface water on a wet area which is holding surface water loosens the fine particles. These particles are then washed out with each subsequent passage of a wheel. In this way a pothole is formed.

Hence the efficient removal of surface water is essential to the preservation of a relatively smooth surface. This can be achieved using steeper, uniform crossfalls and avoiding a flat crown in the centre of the road.

3.4 Compaction Before Trafficking

The pavement of an unsealed rural road has usually been developed over a period of many years. As weaknesses in the pavement develop, aggregate is added to provide a layer on which the traffic can move. The traffic is normally expected to provide all the compaction that is required.

Compaction with steel-wheeled rollers is commonly considered an unwarranted expense. However the placement and immediate compaction of a layer of clay-bound aggregate does offer some economic benefits. A uniform aggregate grading will be maintained and the layer can be stabilised to its maximum load carrying capacity before the traffic disturbs it. The surface can also be brought to a condition of minimal roughness.

3.5 Maintenance Procedures

Unsealed roads have been traditionally maintained using a long wheel-base motor grader. The grading process has three objectives:

1. To clean out water tables on each side of road to promote good drainage.
2. To redistribute the aggregate that has been swept to the side by the traffic.
3. To generally smooth out the surface of the road.

Only the first two of these objectives are usually achieved. The third is not often achieved as the pavement may be rougher after it has been graded than it was previously. Also grading seldom fills potholes permanently.

Another reason for roughness, particularly after grading, is the preponderance of large stone on the surface. Traffic soon sweeps this aside but at some risk to other traffic. Large stone, if in a sufficiently thick layer, may cause some drivers to lose control of their vehicle. Roughness could be reduced and safety improved if smaller stone was used.

Another problem arises when grader drivers cut the "crown" off the centre of the road to create a more rounded cross section. This often provides an area where water can accumulate. The preferred practice is to leave a narrow peak along the crown at the intersection of the crossfall from each side.

3.6 Procedures Adopted for this Project

The procedures adopted for this project involved:

1. Manufacturing aggregates which complied with the 1938 MHB Specification.
2. Preparing the sub-grade so that correct crossfalls were established and good drainage was provided.
3. Laying the aggregate carefully to the correct thickness before it was compacted with a roller.
4. Controlling the maintenance procedures to observe the performance of the test pavements compared to that of the remainder of the road.
5. Instituting a quality control programme to control construction and to record start data.

4. TEST ROAD SELECTION

4.1 Background

4.1.1 Road Research Unit Project RM12 (1988)

Project RM12 (Bartley et al. 1988) was the initial study in the suite of projects mounted by the Pavements Committee of the Road Research Unit (RRU) of the National Roads Board (NRB, now Transit New Zealand) to evaluate the NAASRA roughness meter and to gain experience with its use on unsealed roads. The project involved monitoring the roughness of four typical unsealed roads within Rodney District. Conventional maintenance procedures continued while the roughness data were being collected.

Pavement performance data had been collected from four roads (Durey-Awanohi, Weranui, Haruru, Old North roads). Pavements of two of these roads, Haruru and Old North Roads, were included in the "Smoothing Unsealed Roads" section of the Rodney District Council budget for the 1986/87 financial year. Such funding is directed at unsealed pavements that require specific attention but are not expected to be sealed within the foreseeable future. These two roads were selected for this present project (RM21).

4.1.2 Preliminary Investigations

Before any reconstruction on the test pavement commenced, vehicle counts, existing construction and maintenance procedures, roughness and pavement performance data were investigated for the two selected roads.

The two pavements had different performance requirements. Haruru Road provides access to Flat Top quarry and is subject to severe heavy commercial vehicle loadings while Old North Road supports mostly light traffic with only occasional heavy traffic from the adjacent Riverhead Forest.

4.2 Haruru Road

4.2.1 Description

Haruru Road is located 10 km west of Silverdale on a route between Silverdale and Makarau. The longitudinal profile of the first 4 km of Haruru Road from the eastern end is rolling to hilly. The first 0.5 km of Haruru Road had been upgraded in 1985 when minor widening, realignment, and lime stabilisation were carried out.

Haruru Road is the only access to Flat Top Quarry which is leased to Winstone Quarries Ltd by the Rodney District Council. Because of the quarry location, the vehicle loadings on Haruru Road are severe when compared to most of the other unsealed roads in the district. The average daily total of vehicles in April 1986 was approximately 340 vpd with a weekday average of approximately 440 vpd. Haruru Road has a very high heavy commercial vehicle (HCV) ratio during the weekdays with approximately 60% HCV.

The soils in the area are derived from the Onerahi Formation comprising sheared soft mudstone with serpentine lenses.

4.2.2 Proposed Test Section

One 500 m section commencing at the end of the existing seal was to be constructed to the following criteria:

Crossfall:	6%
Aggregate:	Pebblebrook AP40 (described in Section 5.2.3)
Clay Content:	10%
Aggregate Depth:	100 mm compacted

4.3 Old North Road

4.3.1 Description

Old North Road begins 600 m west of the intersection of State Highways 16 and 18, near Kumeu. The section selected for the test programme extended 1.2 kilometres to the north-west from the intersection with Deacon Road. Deacon Road is 1.35 km along Old North Road from the intersection with State Highway 16. This section, which skirts one side of Riverhead State Forest, was one of the roughest monitored during the initial project RM12.

Approximately 230 vpd, most of which were light vehicles, used the road. However, this figure does vary significantly during periods of logging when the road is used as access to the Riverhead sawmill, located one kilometre west of Old North Road. In addition, logging trucks from the Woodhill State Forest pass over the first 100 m of the proposed test section to gain access to the sawmill.

Weekend traffic increased significantly just before the start of the project when a "War Games" amusement venue was opened at a site near the end of the test section.

Soils in the area are derived from siltstone and sandstone of the Waitemata Series.

4.3.2 Proposed Test Sections

The 1.2 km long test section on Old North Road was divided into four 300-m sections so that comparisons between different construction and maintenance procedures could be made. The four sections were to be constructed as follows:

Test Section	Crossfall (%)	Additional Clay Content (%)	Aggregate Depth (mm)	Length (m)
TS1	6	-	100 compacted	300
TS2	6	10	100 compacted	300
TS3	6	-	100 uncompacted	300
TS4	3	-	100 uncompacted	300

The aggregate used for the reconstruction on all four sections was Coatesville AP40 (described in Section 5 of this report). It was decided to use only one source for aggregate for all four sections so that any variation in the performance of the pavements was not the result of differences in aggregate type. Test Sections TS1 and TS2 were constructed to compare the effect of the addition of 10% clay, Section TS3 provided a comparison with the compacted aggregates while retaining the steeper than normal crossfall, and Section TS4 acted as a control.

The control section represented the traditional construction technique in which aggregate is spread over the sub-grade and left to be compacted by the traffic. A crossfall of approximately 3% was normal.

5. AGGREGATES

5.1 Economic Factors

A large proportion of the roads in Rodney District are unsealed. The economics of maintenance are dependent on the traffic, the frequency of reshaping (grading), the quantity of aggregate used and the cost of plant and materials. One significant cost is that of aggregate and in particular the cost of transporting it to a road. Research was therefore carried out to identify local sources of aggregates suitable for the test pavements.

5.2 Sources of Aggregates

Five quarries (Figure 5.1) supplying aggregate to the Rodney District Council were selected as possible aggregate sources for this project. Preliminary discussions indicated that the initial quarry selections were also representative of most aggregate suppliers within the District.

The quarries selected for initial investigations were:

1. Omaha
2. Flat Top
3. Pebblebrook (Kings)
4. Coatesville
5. Waitakere

Aggregate for roading is commonly identified in terms of quality and maximum particle size. Hence AP40 (All Passing 40) is a relatively good quality, well graded aggregate with all particles passing the 40mm sieve. GAP65 (General All Passing 65) is generally an "all-in" aggregate with a maximum particle size of 65mm.

5.2.1 Omaha

Approximately 50,000 cubic metres of rock is quarried annually from the Omaha quarry, north-east of Warkworth. The major proportion of this aggregate is high quality, clean, crushed greywacke.

From the wide range of aggregates that were stockpiled only one, a brown AP80 (All Passing 80mm sieve) aggregate, appeared to be densely graded. It was selected for preliminary sieve testing.

Although it was not economical to transport such an aggregate over the 100 km to either of the proposed test section locations, the initial sieve analysis would reveal any variations between this aggregate and others from more local sources. This could also be useful in selecting aggregate for use in road maintenance in the Omaha region.

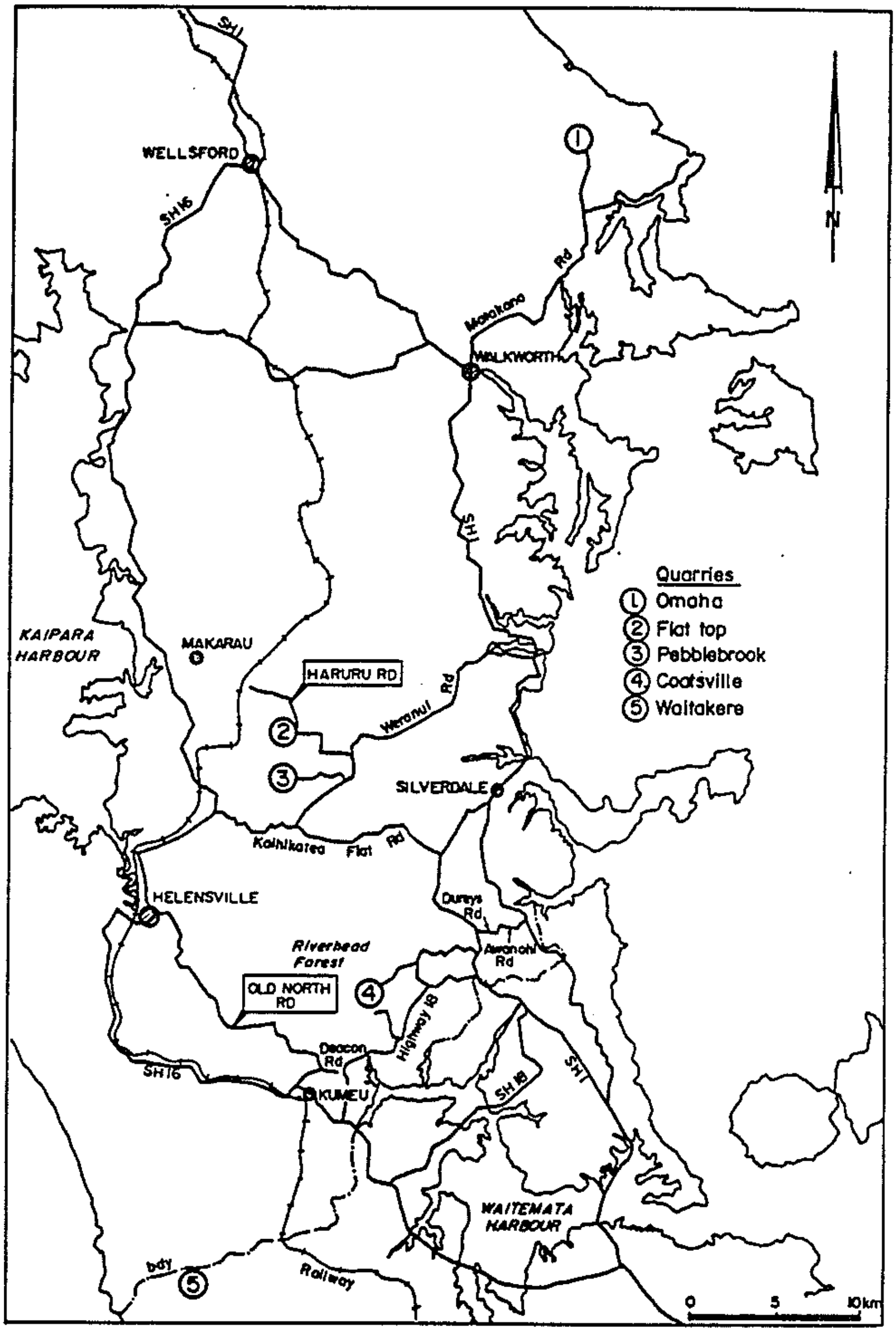

Figure 5.1 Locations of test roads and quarries supplying aggregate used in the project, in Rodney District, Auckland, New Zealand.

5.2.2 Flat Top

This quarry is located approximately four kilometres from the eastern end of Haruru Road. The aggregate source is similar in appearance to a huge boulder (approximately 500 m diameter) with a segment quarried from its apex, hence its name "Flat Top". This andesitic rock is isolated in terms of its position and composition from any other aggregate sources about it.

Weathered rock was initially quarried from the "outer skin" of the boulder. As the source was quarried further, the fresh rock was found to be hard and blue in colour. The fresh rock has been used to produce large quantities of screened aggregates.

The GAP40 aggregate produced from the weathered rock stripped from the "outer skin" (quarry strippings) was the only material available that had a suitable particle size distribution, particularly of the fines content, for the project. Aggregates from Flat Top were considered to have an advantage for use on steeper road profiles because of their angular nature, but they also had a reputation for breaking down relatively easily when used as maintenance metal on unsealed roads. Particle Size Distribution (psd) and LAA tests were required to establish if the GAP40 aggregate could meet the requirements of the 1938 MHB Specification.

5.2.3 Pebblebrook

The Pebblebrook Quarry at Wainui, approximately five kilometres from Haruru Road, is located in a seam of conglomerate. Material blasted from the 30 m-high vertical faces of the quarry wall requires little further processing apart from screening. The fresh stone appeared clean and dense in situ so initially the top quarry levels had to be to investigated for material that was more weathered.

The AP65 aggregate and quarry strippings were the only stockpiled materials that had been taken from the top levels. They contained clay and also appeared to be well graded. For these reasons the AP65 aggregate was sampled for particle size analysis. A sample of GAP70 was also taken for analysis.

5.2.4 Coatesville

This quarry is located on the southern border of the Riverhead State Forest, approximately 8 km from Old North Road. The conglomerate source is ripped from the quarry wall by a digger and crushed in a two jaw crusher at a rate of approximately 2000 cubic metres per month. The quarry is a small operation with most of the aggregate crushed to either GAP65 or AP40 gradings.

Initial visual inspection indicated that the AP40 contained a quantity of fines sufficient to ensure that it would produce a densely bound pavement. Lime, silica and sandstone were evident in this aggregate but the individual stones were expected to have sufficient hardness to be suitable for unsealed pavement construction. The fine particles should not only increase the final in situ density of the aggregate but the silica and lime content could provide some cementing action between the larger particles. The AP40 material was therefore selected for further investigation.

5.2.5 Waitakere

A sample of AP65 maintenance metal was obtained from the Waitakere quarry, west of Auckland City, for particle size analysis because it contained sufficient fines and appeared to be densely graded. Owing to the distance of the test roads from this quarry, this source was to be investigated further only if the local Coatesville aggregate did not prove suitable.

5.2.6 Summary

All quarries visited during the initial investigations had "clean aggregate" that could have been blended to produce the desired grading curve, although some would have required the addition of both sand and clay. The cost of the "clean aggregate" would have also been higher than that of the "secondary quality aggregate".

Although it was initially recognised that the GAP materials did not contain sufficient fines, one sample of GAP70 was taken from Pebblebrook to provide a comparison with the AP65 material.

The larger size gradings, e.g. AP65, if selected, would require further crushing in order to provide a material suitable for use in a layer of 100 mm maximum thickness.

5.3 Aggregate Selection

The initial investigations involved visiting the quarries and establishing if they produced, or were able to produce, densely graded secondary quality aggregate. This visual survey indicated that they all could produce a "brown rock" which was well graded and had suitable clay content (10-15%).

Following the initial survey, testing was carried out to establish if the aggregates met the particle size requirements of the 1938 MHB Specification. In addition Atterberg Limits and shrinkage characteristics were determined for selected samples. Tensile strength and LAA tests were carried out on material considered to be most suitable for use in the test sections. The test programme is summarised in Table 6.1.

As most of the aggregates tested produced similar grading curves, the aggregates selected for use were those from the quarries closest to the proposed test sites.

Although Flat Top quarry was closest to the Haruru Road test section, this quarry was considered unable to produce a suitable aggregate. The next closest quarry was Pebblebrook. Initial test results on the Pebblebrook AP65 indicated that the aggregate could be blended to meet the grading requirements of the 1938 MHB Specification.

Coatesville was the closest quarry to the Old North Road site. Initial test results indicated that their AP40 aggregate would be simple to blend to obtain the desired grading specification. For this reason, Coatesville AP40 was tested further to establish if it met the other requirements of the 1938 MHB Specification.

6. TESTING AGGREGATES

6.1 1938 Main Highways Board Basecourse Specification

The 1938 MHB Specification, which was used as a guide for this project, details the following requirements for testing.

6.1.1 Particle Size Distribution

The distribution specified is in terms of imperial sieve sizes. The Specification has been converted to the following requirements based on the nearest appropriate metric sieve size.

• **40 mm Grading Envelope** (Figure 6.1)

Passing	1.5 inch	(30 mm) (circular)	100%
Passing	0.75 inch	(15 mm) "	65-75%
Passing	0.25 inch	(5 mm) "	40-55%
Passing	10 mesh	(2 mm) (US series)	25-40%
Passing	50 mesh	(297 microns)(")	15-25%
Passing	200 mesh	(74 microns)(")	8-15%

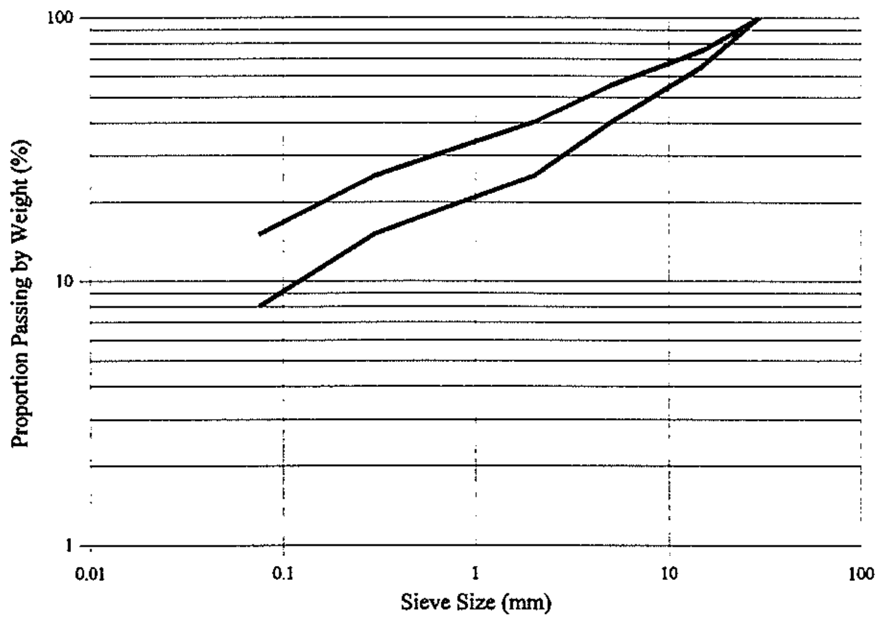

Figure 6.1 40 mm grading envelope for particle size distribution, according to the 1938 MHB Specification.

• **20 mm Grading Envelope** (Figure 6.2)

Passing	0.75 inch	(15 mm) (circular)	100%
Passing	0.25 inch	(5 mm) "	60-80%
Passing	10 mesh	(2 mm) (US Series)	40-60%
Passing	50 mesh	(297 microns)(")	25-35%
Passing	200 mesh	(74 microns)(")	10-20%

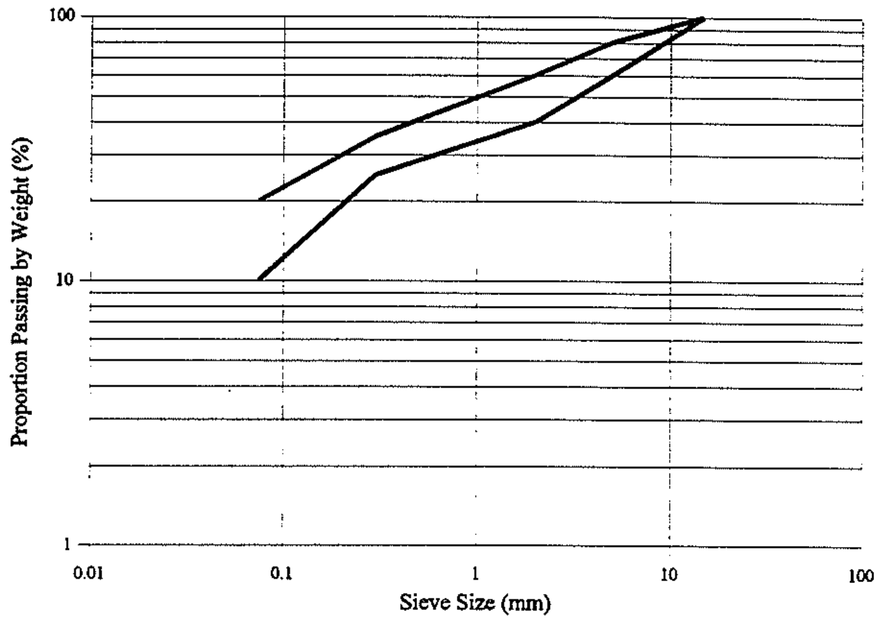

Figure 6.2 20 mm grading envelope for particle size distribution, according to the 1938 MHB Specification.

6.1.2 Tensile Strength

The tensile strength of the binder fraction passing the 50 mesh sieve shall be not less than 10 pounds per square inch (70 kPa), using the method described in the Specification.

6.1.3 Lineal Shrinkage

The lineal shrinkage shall be less than 5%.

6.1.4 Los Angeles Abrasion Loss test

The material retained on the 10 mesh sieve shall have a LAA loss of not more than 65%.

6.2 Correlation of 1938 MHB Specification Tests and 1986 SANZ Tests

Lineal shrinkage was tested in 1938 using the method described in Section 6.7 of this report. The test done today uses NZS 4402:1986, Test 2.6 (SANZ 1986). Because lineal shrinkage could be tested by the two methods, both were carried out to compare results and to establish if any correlations could be made.

6.3 Sampling Aggregates

Samples were initially obtained from stockpiles within each quarry. Some problems were experienced initially in obtaining representative samples, but this was overcome to a large degree by sampling after the stockpiles were mixed with a loader.

The aggregate sample size was approximately 25 kg and sample bags were sealed so that the moisture content could be measured later in the laboratory. The size of the sample was reduced in the laboratory by passing the aggregate through a riffle box as many times as necessary to achieve the required quantity for sieve analysis.

Samples were also obtained at the end of construction from the Haruru Road Test Section and Test Section TS2 on Old North Road, to check that the desired in situ aggregate/clay blend had been achieved.

6.4 Aggregate Testing

Most of the tests were carried out in the Geotechnical Laboratory of the School of Engineering, University of Auckland. However, tests on sample numbers 1121, 1124 and 1125 were carried out at the Ministry of Works and Development, Engineering Laboratory, Auckland. The other tests carried out on the aggregates are listed in Table 6.1.

6.5 Particle Size Analysis

6.5.1 Dry Sieve Analysis

The selection of aggregates for the basecourse was based on the 40 mm maximum size aggregate grading curve from the 1938 MHB Specification. Coatesville quarry was the only source of a 40 mm aggregate. However all the other aggregates tested had only a very small proportion of aggregate, if any, retained on the 38 mm sieve. The sieve analyses were carried out using dry aggregate as this was the method used in the original 1938 MHB Specification. The testing procedure used was that listed in NZS 4402:1986 Test 2.8.2 and the sieve sizes used were as follows:

38.00 mm	19.00 mm	9.50 mm	4.75 mm	2.36 mm
1.18 mm	600 μm	300 μm	150 μm	75 μm

The aggregates were oven-dried for approximately 24 hours at 110°C before the dry sieve analyses were carried out. The results of the analyses of only Pebblebrook AP65 and Coatesville AP40 are summarised in Tables 6.2 and 6.3 and discussed in sections 6.5.3 and 6.5.4 respectively.

Table 6.1 Aggregate testing schedule, in order of sample number.

Sample No.	Date	Aggregate	Test Types*
1100	09/12/86	Pebblebrook AP65	Dry Sieve, LL, PL, CPL
1101	10/12/86	Pebblebrook GAP70	Dry Sieve
1102	11/12/86	Pebblebrook Strippings	Dry Sieve
1103	11/12/86	Coatesville AP40	Dry Sieve
1104	12/12/86	Omaha AP80	Dry Sieve, LL, PL, CPL
1105	15/12/86	Flat Top Strippings	Dry Sieve, LL, PL, CPL
1106	19/12/86	Coatesville AP40	Dry Sieve
1107	19/12/86	Pebblebrook AP65	Dry Sieve
1108	20/12/86	Pebblebrook AP65	Dry Sieve
1109	19/12/86	Waitakere AP65	Dry Sieve
1110	11/01/87	Pebblebrook AP65	Wet Sieve
1111	15/01/87	Pebblebrook AP65	Dry Sieve
1112	15/01/87	Pebblebrook Strippings	Dry Sieve
1113	15/01/87	Coatesville AP40	Dry Sieve
1114	18/01/87	Coatesville AP7	Dry Sieve
1115	16/01/87	Coatesville AP40	Wet Sieve, LL, PL, CPL
1116	19/01/87	Pebblebrook Strippings	Dry Sieve
1117	18/01/87	Pebblebrook AP65	Tensile Test
1118	18/01/87	Pebblebrook AP65	Lineal Shrinkage
1119	19/01/87	Coatesville AP40	Tensile Test
1120	19/01/87	Coatesville AP40	Lineal Shrinkage
1121	06/07/87	Pebblebrook AP40	Dry Sieve, LAA
1122	06/07/87	Pebblebrook	Dry Sieve, LL, PL
1123	06/07/87	Coatesville AP40/Clay Blend	Dry Sieve, LL, PL
1124	24/07/87	Flat Top AP40	LAA
1125	24/07/87	Coatesville AP40	LAA

* **Key**

LL	Liquid Limit
PL	Plastic Limit
CPL	Cone Penetrometer Limit
LAA	Los Angeles Abrasion

6.5.2 Wet Sieve Analysis

A wet sieve analysis was carried out to check the proportion of fine silt and clay-size material present in samples of Pebblebrook AP65 and Coatesville AP40.

The testing procedure used was that described in NZS 4402:1986 Test 2.8.1. The sample was washed over a BS75 micron sieve, the aggregate retained on the screen was oven-dried, then tested as for the dry sieve analysis.

The grading curves for these wet-sieved aggregates were similar to those determined using the dry sieving technique and no further use was made of the wet method.

6.5.3 Pebblebrook AP65 Aggregate

All the particle size sieve analyses carried out on this aggregate produced similar grading curves except for sample no. 1100. It was believed that this sample was not collected correctly and the results have not been included in the analysis.

Pebblebrook AP65 was deficient in fines less than 75 microns size so it was necessary to add 10% clay. While clay particles are smaller than 75 micron particles (fine sand), the addition of 10% clay improved the distribution of particles so that the whole curve fitted within the 1938 MHB Specification grading envelope (Figure 6.3).

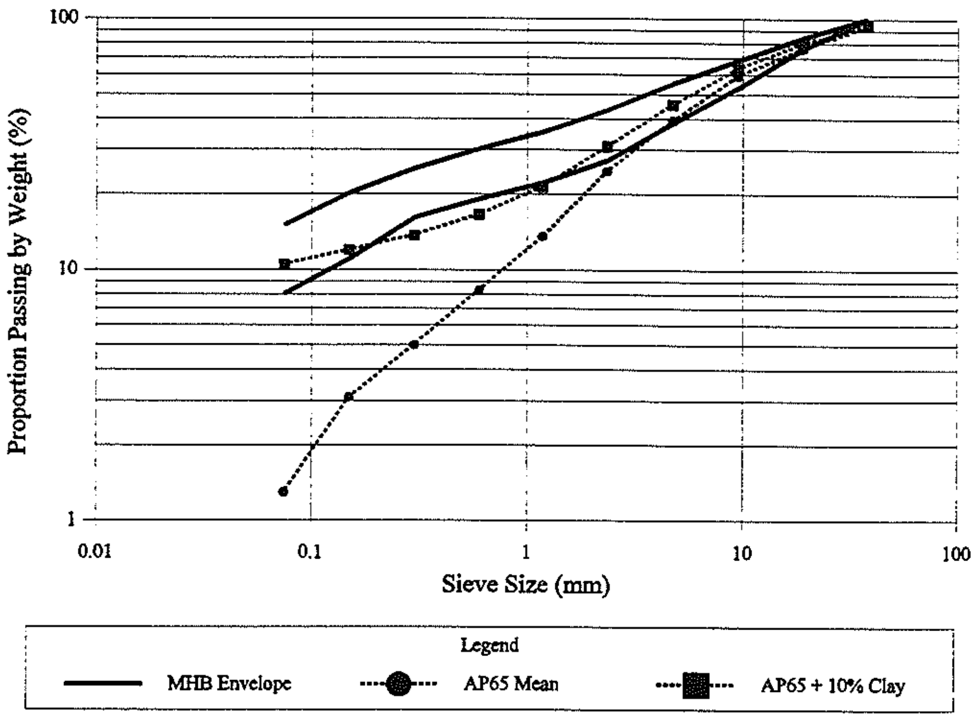

Figure 6.3 Particle size distribution of Pebblebrook AP65 aggregate with and without 10% clay, related to 1938 MHB Specification grading envelope.

Table 6.2 Particle size analysis of samples of Pebblebrook AP65 aggregate.

BS Sieve Sizes	Percent Passing (%) for Samples			Average % Passing
	1107	1108	1111	
38 mm	96.2	95.8	90.0	94.0
19 mm	80.2	77.0	76.3	77.8
9.5 mm	60.4	59.6	59.2	59.7
4.75 mm	41.4	39.1	39.2	39.9
2.36 mm	26.3	21.2	24.7	24.1
1.18 mm	15.4	11.6	13.6	13.5
600 microns	9.4	7.3	8.3	8.3
300 microns	5.7	4.6	5.0	5.1
150 microns	3.6	2.9	3.1	3.2
75 microns	2.0	1.6	1.3	1.6
<75 microns	—	—	—	—

6.5.4 Coatesville AP40 Aggregate

Coatesville AP40 aggregate was similar to the Pebblebrook AP65 in that it was deficient in fines less than 75 microns size. The addition of 10% clay to the AP40 also produced a reasonable fit within the desired 1938 MHB Specification grading envelope (Figure 6.4).

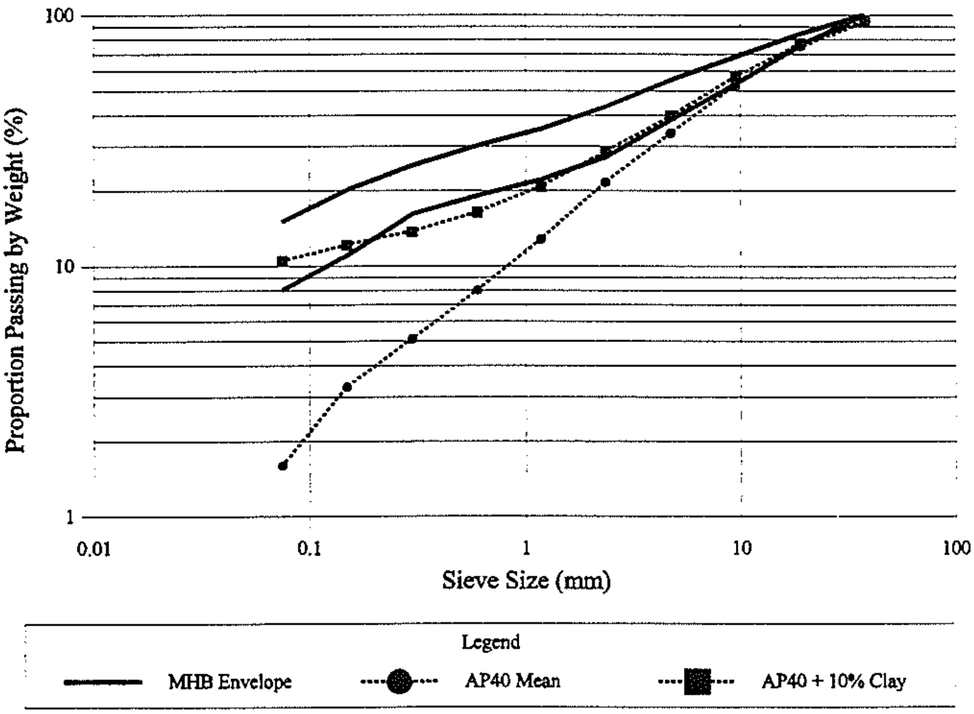

Figure 6.4 Particle size distribution of Coatesville AP40 aggregate with and without 10% clay, related to 1938 MHB Specification grading envelope.

Table 6.3 Particle size analysis of samples of Coatesville AP40 aggregate.

BS Sieve Sizes	Percent Passing (%) for Samples			Average % Passing
	1103	1106	1113	
38 mm	100.0	84.2	97.9	94.0
19 mm	78.0	64.3	82.1	74.8
9.5 mm	54.5	47.5	56.0	52.6
4.75 mm	33.8	34.4	33.2	33.8
2.36 mm	19.6	26.1	19.1	20.9
1.18 mm	10.7	16.1	11.5	12.8
600 microns	5.4	11.1	7.5	8.0
300 microns	2.7	7.7	5.0	5.1
150 microns	1.5	4.8	3.5	3.2
75 microns	0.7	2.4	1.6	1.6
<75 microns	—	—	—	—

6.6 Tensile Strength

6.6.1 Procedure for 1938 MHB Specification

Since no relevant test procedure is given in NZS 4402:1986 for obtaining the tensile strength of the binder fraction of an aggregate, the method outlined in the 1938 MHB Specification was used. This Specification requires that the tensile strength of the binder fraction passing the 50 mesh sieve shall exceed 10 pounds per square inch (70 kPa), while being loaded at a rate of 5 pounds per second (23 N/s).

The 1938 MHB Specification also stipulated that the tensile strength "*of the total material passing the 50-mesh sieve shall be determined by mixing the material with water to the field-moisture equivalent as defined by the Bureau of Public Roads (USA)*". This moisture content is achieved when a drop of water placed on the smoothed off material is not readily absorbed.

Material at this moisture content then has to be evenly packed into tensile strength cement/sand moulds as defined in the 1931 British Standards Specification for Portland Cement (BS12:1931)[1]. These briquette moulds are 3 inches (75 mm) long, with a 1 inch (25 mm) square middle section, and enlarged at each end. The jaws of the tensile test machine are attached to the enlargement at each end of the specimen.

The briquettes were to be air dried before being removed from the moulds and oven dried at 110°C until a constant weight was achieved at which stage tensile testing could be carried out.

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1 Note that BS12:1931 referred to in the 1938 MHB Specification has been superseded by BS12:1991 (BSI 1991).

6.6.2 Adapted Procedure

The actual laboratory procedure adopted was slightly different to the requirements of the 1938 MHB Specification. An Avery manual tensile test machine was available in the laboratory but it required calibration before testing could proceed. This was carried out by the Laboratory staff after the machine had been put in working order and checked.

The briquettes were made from material with a moisture content equal to that described in *"Determining the field moisture equivalent of soils"* (AASHO Designation: T93-49, 1949)[2]. The procedure for making the briquettes was that described in *"Tensile strength of hydraulic cement mortars"* (AASHO Designation: T132-49, 1949, "Moulding Test Specimens")[2].

Once formed in a briquette gang mould, the specimens were left to cure for 24 hours. Following air drying the specimens were oven-dried for a further 24 hours. Finally each briquette was labelled, removed from the mould, inspected for defects, and then loaded into the test machine.

The machine was originally designed to use lead shot for the load. After the tensile sample briquette had been placed between the jaws of the machine, a trap was opened allowing the lead shot to fall from an upper hopper into a lower hopper which was connected to the main lever arm of the machine. A constant loading rate was applied to the test piece until the sample failed, when an automatic cut-off lever was activated. At this stage the lead shot could be weighed and the tensile capacity of the sample established.

Owing to the lack of lead shot and some damage to the mechanism, sand was used as the load instead. When failure occurred, the amount of sand in the lower hopper was weighed and the tensile strength was obtained. The sand had been poured into the hopper at a rate of approximately 100g/second, which was equivalent to a loading rate of 4 kg/s (40N/s). This loading rate compares with 2.27 kg/s (23N/s) as given in the 1938 MHB Specification.

The mean values of the tensile strength of the two aggregates tested are as follows:

Pebblebrook	AP65	497 kPa
Coatesville	AP40	277 kPa

It was evident from these tests that the fine fractions within the aggregates had sufficient tensile strength even without the addition of clay.

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2 Note that AASHO Designations T93-49 and T132-49 (AASHO 1949) have been superseded by AASHTO T93-86 and T132-87 (AASHTO 1990).

6.7 Lineal Shrinkage

Aggregates for use in pavements should not shrink or swell as the moisture content changes. Continual shrinking and swelling from varying moisture contents could cause the pavement surface to crack and it could promote ravelling. The 1938 MHB Specification requires that the shrinkage should be less than 5%.

Two test procedures were used to determine lineal shrinkage. One was in accordance with the 1938 MHB Specification while the other complied with NZS 4402:1986 Test 2.6.

In the first procedure, the length of each oven-dried briquette was measured before it was placed in the loading frame and the reduction in length was expressed as a percentage of the original length (75 mm). In the second procedure the dried length of a semi-circular (25 mm wide) sample was compared to its original length of 150 mm. The results are summarised in Table 6.5.

The lineal shrinkage of Coatesville AP40 aggregate determined using the MHB procedure was well within the 5% limit specified while the Pebblebrook AP65 was slightly above. The second test method was used to determine if it could be used instead of the MHB test. However the results the tests are significantly different and no correlation has been established.

Table 6.5 Lineal shrinkage of Pebblebrook and Coatesville aggregates.

Aggregate	Original Length		Final Length		Shrinkage	
	mm[a]	in.[b]	mm[a]	in.[b]	%[a]	%[b]
Pebblebrook AP65	150	3	135.5	2.81	9.7	6.2
Coatesville AP40	150	3	134.1	2.89	10.6	3.8

[a] Lineal shrinkage as derived using NZS 4402:1986
[b] Lineal shrinkage as derived using 1938 MHB Specification
1 inch = 25.4 mm

6.8 Atterberg Limits

The following tests were carried out on four of the aggregates to establish their liquid limits, plastic limits, and plasticity indices. The NZS 4402:1986 test procedures (SANZ 1986) used are as follows:

NZS 4402 Test 2.2 Determination of the Liquid Limit (LL)
NZS 4402 Test 2.3 Determination of the Plastic Limit (PL)
NZS 4402 Test 2.4 Determination of the Plasticity Index (PI)
NZS 4402 Test 2.5 Determination of the Cone Penetrometer Limit (CPL)

Table 6.6 Atterberg Limits of aggregates.

Sample No.	Aggregate	Test LL		Test PL	Test PI
		(a)	(b)		
1100	Pebblebrook AP65	41	43	25	16
1104	Omaha AP80	38	38	23	15
1105	Flat Top strippings	42	43	27	15
1115	Coatesville AP40	55	56	25	30

LL = Liquid Limit PL = Plastic Limit PI = Plasticity Index
(a) Liquid Limit derived using Casagrande Apparatus
(b) Limit derived using Cone Penetrometer (should coincide with LL for values<50)

6.9 Los Angeles Abrasion Loss for Resistance to Abrasion

LAA Loss tests were carried out on the following aggregates in accordance with ASTM C131-89 (ASTM 1989).

Table 6.7 Los Angeles Abrasion Loss for samples of Pebblebrook AP40, Flat Top AP40 and Coatesville AP40 aggregates.

Sample No.	Aggregate	LA Abrasion Loss (%)
1121	Pebblebrook AP40	35
1124	Flat Top AP40	30
1125	Coatesville AP40	44

The results for these aggregates are well within the LAA loss of not more than 65%, specified in the 1938 MHB Specification.

6.10 Conclusion

The test results confirmed that Pebblebrook AP40 was suitable for use on the Haruru Road test section and that Coatesville AP40 was suitable for use on the Old North Road test sections provided the clay content was increased to improve the particle size distribution.

Both aggregates met the requirements of the 1938 MHB Specification following the addition of approximately 10% clay.

7. CONSTRUCTION

7.1 Introduction

The unsealed pavement construction methods promoted in this study were designed to produce a structurally competent, dense pavement with improved wear characteristics. Improved wear was to be achieved by:

- increasing the pavement crossfall to promote surface water shedding,
- incorporating a small quantity of clay binder in the basecourse aggregate,
- compacting the basecourse with steel-wheel rollers.

Because a range of test pavements were constructed, construction procedures needed to be closely monitored to ensure that the objectives of the study for each test section were achieved.

7.2 Sub-grade

The 1938 MHB Specification requires that the sub-grade be constructed with care to ensure that a firm, uniform and smooth surface is produced at the formation level. To control this section of the construction operation, off-set pegs were set at 25 m intervals along each side of the proposed test sections and used to level the sub-grade. The existing metal courses on the road were then windrowed to one side so that the exposed sub-grade could be excavated to the required longitudinal and transverse profiles.

A water-table drain was cut on each side and fill was placed in low areas of the alignment. The sub-grade was then compacted and given a final trim before the previously salvaged metal was respread.

7.3 Basecourse

7.3.1 Haruru Road

Pebblebrook AP40 aggregate was spread, shaped and compacted until an even 100 mm thickness had been achieved over the sub-grade. Clay had to be blended with the aggregate but, because of poor weather, this blending had to be postponed approximately one week. Because the clays near Haruru Road did not have the required engineering properties, 40 cubic metres of cohesive clay from another construction site were transported to the test section.

The 1938 MHB Specification recommends that when clay is to be mixed with an aggregate, the clay should be either peeled in thin layers from a dry surface with a power grader or excavated from a well drained vertical face. However, in this instance the clay would be almost impossible to handle unless the excavation process was carried out carefully. So, following a drying period, the borrow area was rotary hoed before the clay was loaded and transported, in a relatively loose form, to the test section.

The clay was then spread evenly on the basecourse and mixed to a depth of 100 mm, with a soil-stabilising rotary hoe. Care was taken not to disturb the compacted sub-grade. Although the hoe blended the clay evenly throughout the 100 mm layer, most of the clay lumps exceeded the 12-mm maximum particle size specified in the 1938 MHB Specification.

The moisture content of the imported clay was too high and the clay should have been left to dry further and been re-hoed before transporting onto the site. However as little could be done to reduce the size of the lumps once the clay had been mixed with the aggregate, the blended basecourse was compacted and shaped to the required pavement profile. The final appearance of the pavement was dense and very smooth.

7.3.2 Old North Road

Coatesville AP40 aggregate was spread, shaped and compacted over the sub-grade of Test Sections TS1 and TS2 until an even 100-mm thickness had been achieved. Similar AP40 material was spread and shaped on Test Sections TS3 and TS4 to an even depth of 100 mm. It was then necessary to blend clay into the compacted 100 mm depth of Test Section TS2.

Although the sub-grade material had satisfactory engineering properties, 24 cubic metres of dry clay were transported from a nearby site and stockpiled at Test Section TS2. Rain then delayed the blending of the clay with the basecourse and an alternative blending procedure was attempted rather than risk the problems experienced on Haruru Road.

A rotary hoe was used to cut through the basecourse layer and to a depth of approximately 10 mm into the clay sub-grade. After a series of short trials, this method was adopted as it resulted in a very well blended basecourse with no large clay lumps. Although the 10 mm layer removed from the sub-grade was expected to leave an uneven surface, it was unlikely to have a significant effect on the overall performance of the pavement.

7.4 Running Course

On completion of construction of each test section of pavement on Old North Road, a layer of Pebblebrook 20/7 running course was applied. Experience in the Rodney District showed that this material, which is a rounded aggregate, provides a good cushion between vehicles and the pavement. It also reduced evaporation of moisture from the basecourse and was easily re-distributed by a grader or a drag. The rounded stone was less likely than the alternative, a crushed chip, to fly out from under vehicle tyres.

7.5 Construction Period

Initial clearing works were completed on Haruru Road during November and December 1986 and the pavement reconstruction works were completed during February and March 1987. The pavements on Old North Road were constructed during March 1987.

8. MONITORING PAVEMENT PERFORMANCE

8.1 Pavement Roughness

The condition of the surfaces of the pavements on Haruru and Old North Roads was monitored on a monthly basis for 31 months, using a NAASRA roughness meter operated by Works Consultancy Services, Auckland. The roughness of the test sections was recorded at 100 m intervals while that of the surface of the entire road was recorded at 500 m intervals.

The roughness meter was mounted for this trial in a Holden Barina station wagon. The vehicle was driven at a uniform speed of 50 km/h, in the predominant wheel tracks in the direction of increasing distance from the eastern-most direction of each road to the end of the surveyed section. It was then turned around and driven in the predominant wheel tracks on the other side of the road, in the direction of decreasing distance. This process was repeated until relatively consistent results were obtained in each direction.

The test sections were located part way along the survey section in each road. Provision was made on the record sheet to note the roughness reading at 100 m intervals over the test section while maintaining the record for all the road at 500 m intervals. All roughness measurements were converted to NAASRA counts per kilometre.

The results of the roughness surveys are summarised in Table 8.1. Plots of the mean NAASRA roughness counts for each test section and the remaining portions of monitored unsealed roadway are shown on Figures 8.1 and 8.2.

8.2 Pavement Performance

8.2.1 Introduction

No formal record of the condition of the road was kept, apart from comments recorded during monthly roughness monitoring of the roadways. These comments were usually of a general nature about the overall road surface and the weather. However on occasion, particular note was made of a local feature, e.g. corrugations, etc.

A summary of the observations recorded during the initial months of operation is given in Sections 8.2.2 and 8.2.3.

Table 8.1 Mean NAASRA roughness in counts/km for test sections on Haruru and Old North Roads and for remaining length of each road.

Date	Haruru Road		Old North Road				
	TS	Road	TS1*	TS2	TS3	TS4	Road
24/03/87	141	222	116	95	249	232	263
24/04/87	166	226	129	104	259	324	255
19/05/87	188	233	140	118	218	259	279
30/06/87	189	212	135	120	209	256	264
30/07/87	200	241	169	158	355	225	263
02/09/87	220	266	146	110	185	235	261
02/10/87	194	243	174	127	205	215	244
05/11/87	232	300	252	171	246	242	229
30/11/87	170	251	195	190	276	247	216
29/01/88	259	349	327	269	384	360	308
07/03/88	246	302	263	241	241	382	304
07/04/88	265	363	238	254	266	292	324
06/05/88	246	296	275	281	297	349	316
03/06/88	248	277	195	175	186	187	251
06/07/88	219	270	203	189	180	199	247
10/08/88	211	278	212	191	186	224	251
05/09/88	211	284	—	198	222	211	196
10/10/88	195	287	—	206	240	247	222
18/11/88	234	299	—	227	238	268	285
12/12/88	270	324	—	271	273	312	350
10/01/89	228	308	—	155	225	207	195
20/02/89	302	315	—	333	287	310	257
06/05/89	221	317	—	222	218	284	279
10/06/89	276	287	—	210	207	271	265
28/08/89	274	281	—	190	151	200	228
01/09/89	231	283	—	190	149	175	296
09/09/89	237	296	—	200	153	184	273
16/09/89	226	303	—	264	282	352	274
23/09/89	244	306	—	244	265	317	252
30/09/89	257	308	—	356	370	412	370
Average	**227**	**284**	**198**	**202**	**241**	**263**	**267**

* Test Section TS1 of Old North Road was sealed in August 1988
TS Test section

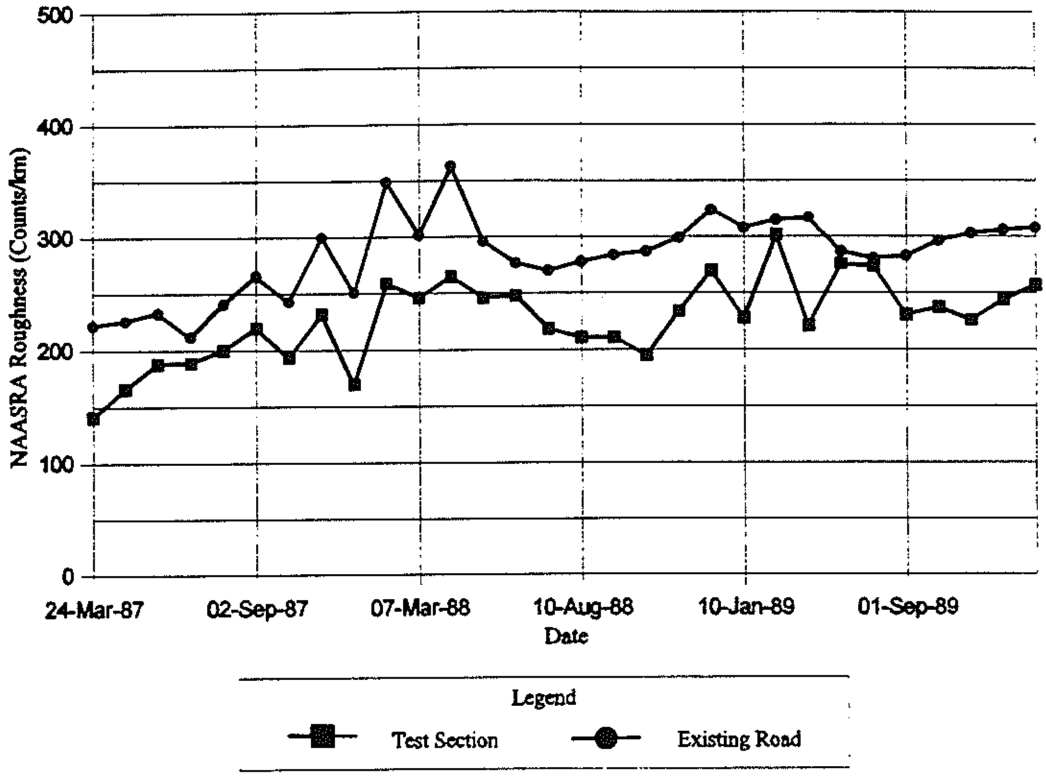

Figure 8.1 NAASRA roughness (counts/km) for Haruru Road.

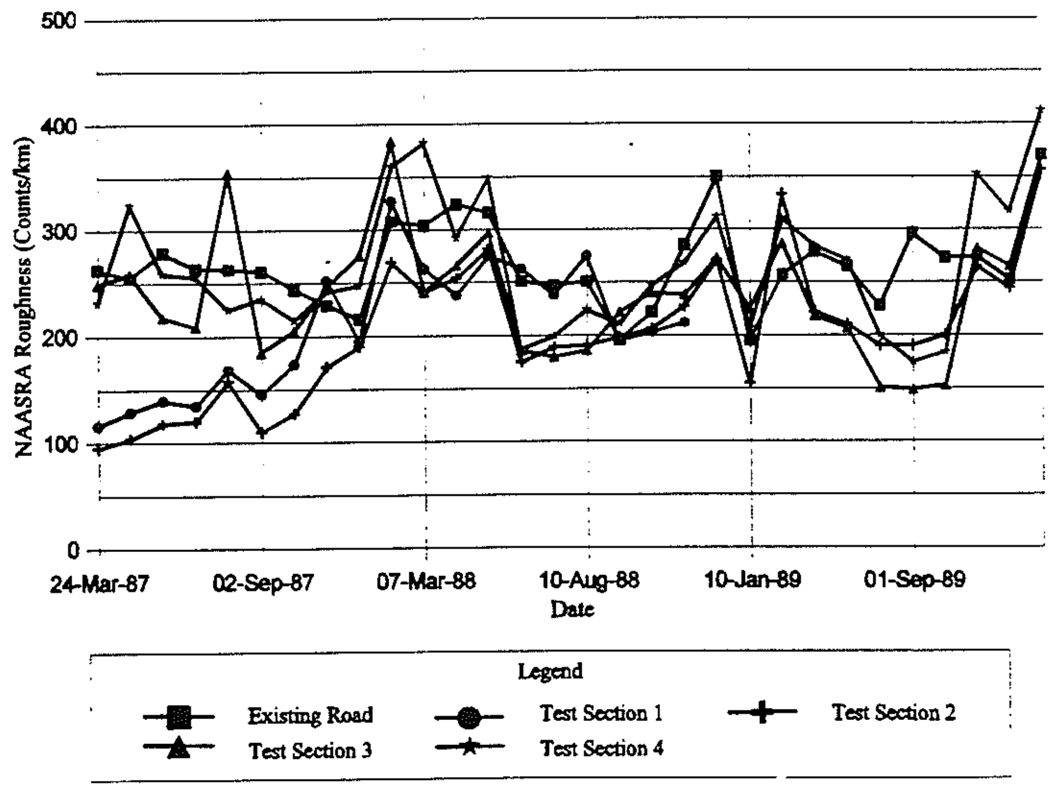

Figure 8.2 NAASRA roughness (counts/km) for Old North Road. Note that Test Section TS1 was sealed in August 1988.

8.2.2 Haruru Road

Test Section (crossfall 6%, compacted, 10% clay)

The shape of the test pavement deteriorated during the first two months of trafficking. The crossfall became reduced due to consolidation of the pavement foundation and the movement of surface water over the steep sections of the pavement resulted in the formation of longitudinal gouges. After two months the pavement was re-constructed to an 8% crossfall.

An elevated level of ground water, not detected during the construction period, resulted in springs appearing at six locations along the test section. These caused localised failures and an increase in the roughness during July and August 1987. The affected areas were dug out and a layer of drainage aggregate was laid to re-direct the seepage horizontally to the side drains.

An in situ sieve analysis of an aggregate sample, taken after initial construction had been completed, revealed that the aggregate had an excessively high clay content which exacerbated the problems with the ground water.

The test section incorporated two sharp bends and was on a continuous rising grade of 3 to 14%. The surface of the pavement on the two bends tended to ravel during the initial period of trafficking. However this ravelling eventually settled down and was considered to be less apparent than on similar sections of the existing road. The surface of the test section did not corrugate after construction although this was a major problem on the remainder of the road.

Trucks using the road repeatedly cut one of the corners to the extent that the pavement required continual attention. The affected area was subsequently undercut and the pavement rebuilt in mid-1989.

8.2.3 Old North Road

Test Section TS1 (crossfall 6%, compacted, 10% clay added)

The pavement in Test Section TS1 performed to design predictions through the first seven months (Mar - Oct 1987) after construction. However it deteriorated during December 1987 and January 1988 but returned to a smoother condition in March 1988. It improved during the winter (June, July, August), not long before it was overlaid and sealed in August 1988 in preparation for the 1990 Commonwealth Games.

In the initial period the surface remained tight and smooth with a riding quality similar to that of a sealed pavement. The only problem experienced was the formation of potholes as a result of scuffing by trucks entering the Riverhead Sawmill weighbridge. These potholes were repaired by hand, using Coatesville AP40 with 10% clay added.

Test Section TS2 (crossfall 6%, compacted, 10% clay)
This pavement performed slightly better than that in Test Section TS1, for example no potholes formed. However the surface was adversely affected in July 1987 by a carry-over of slurry and aggregate from the adjoining Test Section TS3. It also became quite rough during the following summer (Dec, Jan, Feb 1987/88). It returned to a relatively smooth condition in the winter of 1988, deteriorated during the next summer and recovered again during the winter of 1989. No corrugations formed even though they had been a major problem on this part of the original road.

Test Section TS3 (crossfall 6%, uncompacted, no added clay)
This section contained basecourse which had been laid but not compacted. The density of the layer was improved by the traffic, although mainly in the predominant wheel tracks. Water tended to collect in these tracks and potholes formed. In July 1987 additional aggregate was brought in and the surface was reshaped to shed the surface water. This reduced the roughness significantly. Other than this problem area, which extended over approximately 100 m, the pavement performed relatively well.

The test section was located alongside the forest and received little sunlight, so that the surface remained damp for most of the year.

Test Section TS4 (crossfall 3%, uncompacted, no added clay)
This section was constructed in a similar manner to Test Section TS3 except that the crossfall was less. Visually there was a significant difference between the performance of the two because the crossfall was not enough to allow water to flow freely from the pavement and potholes formed in the wheel tracks.

9. COST EFFECTIVENESS

9.1 Introduction

The cost effectiveness of each of the techniques tested was ranked according to the evaluation of the benefits and costs of each option. This involved the analysis of the costs of the construction and maintenance of the pavements and the cost of vehicle operation to enable the merits of each option to be compared.

A system for the collection of cost data was established at the start of the project. Contractor's invoices and the time sheets from the Rodney District Council staff were assembled for all the construction work. The quantity of maintenance work was reported by the District Overseer at the end of each month for costing by the Researcher.

Traffic surveys were carried out to identify the type and frequency of traffic movements. Vehicle-operating costs were estimated utilising the data provided in Road Research Unit (RRU) Technical Recommendation TR9 (Bone 1986).

It should be noted that the analysis discussed in this Section 9 does not purport to be an Economic Analysis as defined in the current Project Evaluation Manual published by Transit New Zealand (1991). The terms "benefit" and "cost" as used in this project are defined in Section 9.5.1. The results of the analysis should be interpreted in terms of these definitions and should not be used in an economic analysis of a project to be funded by Transfund New Zealand unless they are converted into data consistent with, and applied in accordance with, the Project Evaluation Manual. All costs are in New Zealand dollars as at 1986.

9.2 Construction Costs

9.2.1 Haruru Road

The costs to construct the 500 m-long test section on Haruru Road are summarised in Table 9.1.

Table 9.1 Construction costs for Haruru Road Test Section.

Description of Work	Cost	
	Total	per lineal metre
Berm clearing and formation widening	16,483.00	32.97
Lime stabilisation of sub-grade	18,018.00	36.04
Sub-grade preparation and pavement construction	14,630.00	29.26
Supply of basecourse	8,595.00	17.19
Supply of running course	719.00	1.44
Total	**$58,445.00**	**$116.89/m**

The additional costs, over and above those which would have been incurred had traditional methods of construction been applied, are summarised in Table 9.2. These costs are approximately 8% more than the traditional construction cost.

Table 9.2 Additional costs for constructing Haruru Road Test Section.

Item	**Cost ($)**
Roller hire	1,687.50
Transporting roller	680.00
Watercart	720.00
Loader	300.00
Transport of clay	237.50
Rotary hoe clay at stockpile	375.00
Rotary hoe basecourse on site	525.00
Total	**$4,525.00**

9.2.2 Old North Road

The overall costs of constructing the test sections on the road are summarised in Table 9.3. However it was difficult to separate some of the costs to relate them to each of the four test sections because the work was often proceeding on all of them more or less at the same time. An allocation of costs has been made by the Researcher and this is considered to be the most accurate possible.

Table 9.3 Construction costs for the four Old North Road Test Sections.

Description of Work	**Construction Cost ($)**			
	TS1	**TS2**	**TS3**	**TS4**
Berm clearing and formation widening	5,911	5,911	5,911	5,911
Subgrade preparation and pavement construction	3,162	4,037	2,204	2,204
Supply of basecourse	4,848	4,847	3,232	3,232
Supply of running course	662	662	—	—
Total	$14,583	$15,457	$11,347	$11,347
Cost per lineal metre ($/m)	**$48.61**	**$51.52**	**$37.82**	**$37.82**

Note: each test section was 300 m in length.

The additional costs, over and above those which would have been incurred if traditional methods of construction had been used, are summarised in Table 9.4.

Table 9.4 Additional costs for constructing Test Sections TS1 and TS2 on Old North Road.

Item	Cost ($)	
	TS1	TS2
Roller hire	858	858
Transporting roller	100	-
Rotary hoe basecourse/clay on site	-	875
Additional aggregate	1616	1616
Totals	**$2574**	**$3449**

TS1 = Test Section TS1 TS2 = Test Section TS2

These additional costs increased the total reconstruction cost by 21% for Test Section TS1 and by 29% for Test Section TS2.

Test Sections TS3 and TS4 were constructed in the traditional manner and no additional costs were involved.

9.3 Maintenance Costs

At the start of this project, the Council Overseers were instructed not to carry out any maintenance on the test sections unless specifically instructed by the Researcher. They were, however, to continue to maintain the rest of the road in the traditional manner.

The costs of maintaining the test sections and the rest of each road was assessed by the Researcher on the basis of the monthly returns from the Overseers. The assessment involved allocating costs to the quantities of material, labour and plant used. Unfortunately the records, including those for maintenance, were not complete and it has been necessary, in a number of instances, to estimate the likely maintenance costs.

The costs of maintenance are summarised on a monthly basis, from March 1987 to September 1989, in Table 9.5.

9.4 Vehicle-Operating Costs

This study used the vehicle-operating cost data provided in RRU TR9 (Bone 1986) which relates vehicle-operating costs to surface roughness. In order to calculate the performance ratio for a particular construction or maintenance procedure, the costs or benefits at various roughness levels were established. Traffic count and vehicle class data for a particular road vehicle were used to calculate operating costs.

Table 9.5 Maintenance expenditure ($/m/month) for unsealed pavements.

Month	Haruru Road		Old North Road				
	Existing	TS	Existing	TS1	TS2	TS3	TS4
1987							
March	0.24	0.00	0.23	0.00	0.00	0.00	0.00
April	0.22	0.00	0.00	0.00	0.00	0.50	0.50
May	0.05	7.73	0.00	0.05	0.05	0.32	0.32
June	0.05	2.82	0.06	0.00	0.00	0.00	0.00
July	0.36	0.13	0.57	0.21	0.25	3.13	3.13
August	0.52	3.52	0.51	1.46	1.46	4.41	4.41
September	0.15	0.13	0.14*	0.10*	0.10*	0.39*	0.47*
October	0.19	0.00	0.14*	0.10*	0.10*	0.39*	0.47*
November	0.21	0.06	0.14*	0.10*	0.10*	0.39*	0.47*
December	0.22*	0.82*	0.14*	0.10*	0.10*	0.39*	0.47*
1988							
January	0.22*	0.82*	0.14*	0.10*	0.10*	0.39*	0.47*
February	0.22*	0.82*	0.14*	0.10*	0.10*	0.39*	0.47*
March	0.22*	0.82*	0.14*	0.10*	0.10*	0.39*	0.47*
April	0.22*	0.82*	0.14	0.13	0.13	0.28	0.58
May	0.22*	0.82*	0.11	0.00	0.00	0.00	0.00
June	0.22*	0.82*	0.17	0.13	0.13	0.26	0.52
July	0.22*	0.82*	0.11	0.11	0.11	0.11	0.11
August	0.22*	0.82*	0.12	0.13	0.13	0.13	0.13
September	0.22*	0.61	0.00	0.00	0.00	0.00	0.00
October	0.22*	0.00	0.05	0.00	0.00	0.00	0.00
November	0.22*	0.00	0.00	0.00	0.00	0.00	0.00
December	0.22*	0.25	0.00	0.00	0.00	0.00	0.00
1989							
January	0.22*	0.00	0.12	0.00	0.00	0.00	0.00
February	0.22*	0.13	0.12	0.00	0.00	0.00	0.00
March	0.22*	0.13	0.11	0.00	0.00	0.00	0.00
April	0.22*	0.32	0.00	0.00	0.00	0.00	0.00
May	0.22*	0.38	0.13	0.00	0.00	0.00	0.00
June	0.22*	0.19	0.14	0.03	0.04	0.08	0.13
July	0.22*	0.40	0.30	0.04	0.03	0.08	0.13
August	0.22*	1.09	0.08	0.00	0.00	0.00	0.00
September	0.22*	0.19	0.34	0.07	0.00	0.00	0.00
Mean($/m)	**0.22**	**0.82**	**0.14**	**0.10**	**0.10**	**0.39**	**0.43**

* These figures are estimated because maintenance records were incomplete

TS Test section

9.4.1 Haruru Road

From a visual traffic count carried out on Haruru Road in October 1986, the following proportions of vehicle classes were obtained (Table 9.6).

Table 9.6 Distribution of classes of vehicles using Haruru Road.

Vehicle Class	Proportion of total vehicle count
Car	35.0%
Light Commercial (LCV)	10.5%
Medium Commercial (MCV)	3.5%
Heavy Commercial I (HV-I)	17.5%
Heavy Commercial II (HV-II)	33.5%
Bus	0.0%

The ADT (Average Daily Traffic) count for Haruru Road during April 1986, as recorded by a pneumatic tube counter and after correction for multi-axle vehicles, was 342. The average roughness of Haruru Road and its associated test section recorded over the monitoring period, was 284 and 227 NAASRA counts respectively (Table 8.1). Table A2.14 (Other Rural Road Running Costs) of RRU TR9 was used to evaluate the additional running costs caused by roughness for each vehicle class.

Table 9.7 Additional vehicle-operating costs for Haruru Road related to pavement roughness.

Vehicle Class	Vehicle Numbers (ADT)	Additional Vehicle-Operating Costs*			
		227 NAASRA/km**		284 NAASRA/km***	
		Unit Cost* (cents/km)	Total Costs ($/km/day)	Unit Cost* (cents/km)	Total Costs ($/km/day)
Car	120	8.12	9.74	11.85	14.22
LCV	36	8.93	3.21	13.04	4.69
MCV	12	18.04	2.17	22.60	2.71
HCV-I	60	54.20	32.52	67.87	40.72
HCV-II	114	72.86	83.06	91.23	104.03
Totals	**342**		**$130.70**		**$166.37**

* Additional vehicle-operating costs (cents/km) as at 1st April 1986

** Haruru Road Test Section

*** Haruru Road

NAASRA NAASRA roughness counts /kilometre

Using the operating costs in Table 9.7 the additional costs per kilometre are as follows:

342 vehicles at a roughness of 227 NAASRA counts/km = $130.70/km/day
342 vehicles at a roughness of 284 NAASRA counts/km = $166.37/km/day

These values indicate that the 500 m test section on Haruru Road provides a vehicle-operating cost benefit of $35.67 per kilometre length of pavement per day. The benefit of operating a vehicle over the test section is shown in Table 9.8.

Table 9.8 Costs and benefits for Haruru Road (1986 NZ$).

Pavement	Additional Vehicle-Operating Costs ($/m/month)	Benefits ($/m/month)
Haruru Road	5.06	0.00
Test Section	3.98	1.08

9.4.2 Old North Road

A visual traffic classification survey was not carried out on Old North Road but traffic count data were available from a survey done during November/December 1985. The average daily traffic count recorded during this study was 227 vpd. The average pavement roughness and additional vehicle-operating costs over the 31 month monitoring period for Old North Road and its associated test sections are summarised in Table 9.9.

Table A2.13 (Rural Industrial Road Running Costs) of RRU TR9 was used to evaluate the additional running costs caused by pavement roughness. The Old North Road was classified as an RI road (using TR9 classification) because it provides access for rural industry and other rural land uses. As for Haruru Road, the additional units of vehicle-operating cost were converted to $/m/month.

Table 9.9 Additional vehicle-operating costs for Old North Road.

Pavement	Average NAASRA counts/km	Additional Vehicle-Operating Costs	
		cents/km	dollars/km/day
Old North Road	267	18.68	42.40
Test Section TS1	198	12.74	28.92
Test Section TS2	205	13.30	30.19
Test Section TS3	241	16.32	37.05
Test Section TS4	263	18.32	41.59

Table 9.10 Costs and benefits for Old North Road.

Pavement	Additional Vehicle-Operating Costs ($/m/month)	Benefits ($/m/month)
Old North Road	1.28	0.00
Test Section TS1	0.89	0.39
Test Section TS2	0.89	0.39
Test Section TS3	1.14	0.14
Test Section TS4	1.26	0.02

9.4.3 Summary

The additional vehicle-operating costs for both the roads resulting from pavement roughness were calculated as recorded in Tables 9.7 and 9.9. These additional vehicle-operating costs were also evaluated on a monthly basis. This enabled the benefit/cost (B/C) ratios to be calculated on a similar time scale. A summary of the additional vehicle-operating costs are listed in Table 9.11.

9.5 Benefits and Costs

The benefits realised and costs incurred on each of the test sections, on both Haruru and Old North Roads, were compared with similar criteria for the existing pavements that were maintained in a traditional manner. It was necessary to express the performance of each test section as a ratio of benefits to costs in order to compare the various construction options. At Old North Road the opportunity also existed to compare the performance of the first three test sections with the fourth which was constructed in the traditional way.

9.5.1 Performance Ratios

The ratio of benefits to costs was calculated by combining all financial benefits and costs including initial construction, pavement maintenance and vehicle operation expenses. During this analysis, account was taken of any additional construction costs incurred as a result of adopting new construction techniques.

Performance Ratio (PR) = Benefits /Costs

The benefits and costs are defined as follows:

Benefit: All cost savings realised from the operation of a pavement test section as compared with the conventionally maintained pavement. For example, the saving made by operating vehicles on smoother pavements; or reduced pavement maintenance requirements.

Cost: Any expense incurred on a pavement test section above the level of expenditure for the traditional unsealed pavement. For example, the expense resulting from operating vehicles on rougher pavements; increased road maintenance requirements; or initial additional construction expenses.

Table 9.11 Additional vehicle-operating costs relating to unsealed roads and test sections ($/m/month).

Month	Haruru Road		Old North Road				
	Existing	TS	Existing	TS1	TS2	TS3	TS4
1987							
March	3.89	2.42	1.27	0.47	0.38	1.18	1.07
April	3.96	2.87	1.21	0.53	0.42	1.24	1.68
May	4.09	3.26	1.37	0.59	0.48	0.99	1.24
June	3.70	3.28	1.27	0.56	0.49	0.94	1.22
July	4.24	3.48	1.27	0.73	0.67	1.90	1.03
August	4.72	3.85	1.25	0.61	0.45	0.81	1.09
September	4.28	3.37	1.15*	0.75	0.53	0.92	0.97
October	5.38	4.07	1.06*	1.20	0.74	1.16	1.13
November	4.43	2.94	0.98*	0.86	0.84	1.35	1.16
December	4.76*	3.98*	1.29*	0.88*	0.90*	1.13*	1.27*
1988							
January	6.33	4.58	1.57	1.70	1.30	2.10	1.93
February	5.41	4.34	1.54	1.27	1.13	1.13	1.39
March	6.61	4.70	1.68	1.11	1.21	1.29	1.46
April	5.30	4.34	1.63	1.34	1.39	1.50	1.85
May	4.93	4.37	1.19	0.86	0.76	0.82	0.82
June	4.79	3.38	1.16	0.91	0.83	0.78	0.89
July	4.95	3.68	1.19	0.96	0.84	0.82	1.03
August	4.76	3.68	0.87	0.88*	0.88	1.01	0.95
September	5.12	3.39	1.01	0.88*	0.92	1.12	1.16
October	5.36	4.11	1.41	0.88*	1.04	1.11	1.30
November	5.84	4.79	1.86	0.88*	1.32	1.33	1.60
December	5.53	4.00	0.86	0.88*	0.66	1.03	0.93
1989							
January	5.67	5.41	1.23	0.88*	1.74	1.43	1.59
February	4.76*	3.98*	1.29*	0.88*	0.90*	1.13*	1.27*
March	4.76*	3.98*	1.29*	0.88*	0.90*	1.13*	1.27*
April	5.71	3.87	1.37	0.88*	1.01	0.99	1.41
May	5.12	4.91	1.28	0.88*	0.95	0.93	1.32
June	4.76*	3.98*	1.29*	0.88*	0.90*	1.13*	1.27*
July	4.76*	3.98*	1.29*	0.88*	0.90*	1.13*	1.27*
August	5.01	4.87	1.05	0.88*	0.84	0.64	0.89
September	5.29	4.20	1.47	0.88*	1.21	1.19	1.51
Mean ($/m)	4.97	3.94	1.28	0.89	0.89	1.14	1.26

* These figures are estimated because roughness monitoring records were incomplete and Test Section TS1 was sealed in August 1988.

TS Test section

For an adopted construction procedure to be favourable the ratio of benefits to costs should be greater than one. The break-even point (when the performance ratio becomes greater than one) is time dependent. The value of the performance ratio changed during the progression of this project as benefits were realised and the impact of the initial construction costs was reduced.

It was thought that a structurally competent unsealed pavement would become financially attractive after a short period of time. Benefits from reduced maintenance requirements and roughness should accumulate in the months following reconstruction until the sum of the benefits surpassed the original additional expenditure.

The following analysis is included to demonstrate the procedure that was adopted to calculate the ratios.

9.5.2 Performance Analysis

Analysis: To evaluate the ratio of benefits and costs for the Haruru Road Test Section two months after reconstruction.

Benefits:

Vehicle-operating costs from Table 9.11:

Month 1	3.89 - 2.42	=	\$1.47/m
Month 2	3.96 - 2.87	=	\$1.09/m
			\$2.56/m

Maintenance costs from Table 9.5:

Month 1	0.24 - 0.00	=	\$0.24/m
Month 2	0.22 - 0.00	=	\$0.22/m
			\$0.46/m

Total benefits = (2.56 + 0.46) x 500 metres = **\$1,510.00**

Costs:

Initial additional construction cost = \$4,525

Total costs = **\$4,525**

Performance Ratio:

Performance Ratio (PR) = Benefits/Costs = 1,510/4,525 = **0.33**

The performance ratio for the Haruru Road Test Section two months after construction was therefore 0.33.

Similar ratios have been calculated for all five test sections on a monthly basis (Table 9.12).

Table 9.12 Performance ratios for each test section with respect to the existing road.

Months since Reconstruction	Haruru Road TS	Old North Road			
		TS1	TS2	TS3	TS4
1	0.19	0.12	0.10	infinite	infinite
2	0.33	0.20	0.17	infinite	0.44
3	0.19	0.29	0.24	infinite	0.37
4	0.17	0.38	0.31	infinite	0.47
5	0.22	0.48	0.39	infinite	0.16
6	0.22	0.47	0.39	13.26	0.07
7	0.27	0.52	0.44	14.68	0.07
8	0.35	0.51	0.47	11.10	0.07
9	0.44	0.53	0.49	11.49	0.07
10	0.45	0.58	0.53	12.59	0.06
11	0.52	0.57	0.55	10.32	0.06
12	0.54	0.61	0.59	10.94	0.06
13	0.61	0.68	0.64	12.16	0.06
14	0.63	0.71	0.66	12.76	0.05
15	0.63	0.76	0.70	13.64	0.10
16	0.68	0.79	0.74	14.22	0.13
17	0.71	0.82	0.77	14.68	0.15
18	0.74	0.81	0.76	14.12	0.15
19	0.81	0.83	0.77	14.37	0.15
20	0.89	0.89	0.81	15.48	0.16
21	0.96	1.00	0.85	17.37	0.19
22	1.04	1.00	0.87	16.72	0.19
23	1.07	1.05	0.84	17.59	0.18
24	1.12	1.11	0.89	18.57	0.20
25	1.17	1.17	0.93	19.54	0.21
26	1.26	1.22	0.96	20.44	0.21
27	1.26	1.28	1.00	21.43	0.22
28	1.31	1.34	1.04	22.39	0.22
29	1.34	1.41	1.09	23.63	0.24
30	1.29	1.44	1.11	24.09	0.26
31	1.35	1.53	1.16	25.69	0.29

TS = Test section

The comparison between the newly constructed test section and a mature pavement is, in retrospect, invalid because the mature pavement should require less maintenance. This is highlighted in Table 9.12 where the performance ratio for Test Section TS4 decreases because the cost of maintenance was greater than that for the existing road.

In Table 9.13, the performance ratio of the first three test sections (TS1 - TS3) on Old North Road are compared with those on TS4.

Table 9.13 Performance ratios for the Old North Road test sections (TS1 - TS3) with respect to TS4.

Months since Reconstruction	TS 1	TS 2	TS 3
1	0.07	0.06	infinite
2	0.27	0.21	infinite
3	0.37	0.30	infinite
4	0.45	0.37	infinite
5	0.83	0.65	infinite
6	1.23	0.96	infinite
7	1.30	1.03	infinite
8	1.34	1.10	infinite
9	1.42	1.16	infinite
10	1.51	1.22	infinite
11	1.58	1.31	infinite
12	1.64	1.36	infinite
13	1.72	1.42	infinite
14	1.83	1.50	infinite
15	1.83	1.50	389.25
16	1.82	1.50	194.62
17	1.83	1.52	195.75
18	1.81	1.52	111.86
19	1.85	1.54	113.86
20	1.90	1.56	116.86
21	1.98	1.58	122.00
22	1.98	1.61	122.36
23	2.07	1.59	127.43
24	2.11	1.62	130.21
25	2.16	1.65	133.00
26	2.22	1.68	136.79
27	2.27	1.71	139.93
28	2.33	1.75	143.43
29	2.38	1.79	146.86
30	2.38	1.80	146.93
31	2.45	1.82	150.93

9.5.3 Evaluation of Performance

Wide variations in the performance ratios were experienced during the monitoring period. These are illustrated in Figures 9.1 - 9.5 and discussed in the following sections of this report. Only one basis for comparison is available for Haruru Road while two can be used for Old North Road.

It is unfortunate that the data are incomplete, particularly with respect to maintenance costs since this aspect has a significant effect on the analysis. Also it is apparent that a project period, significantly greater than that available for this project, may have provided more conclusive results.

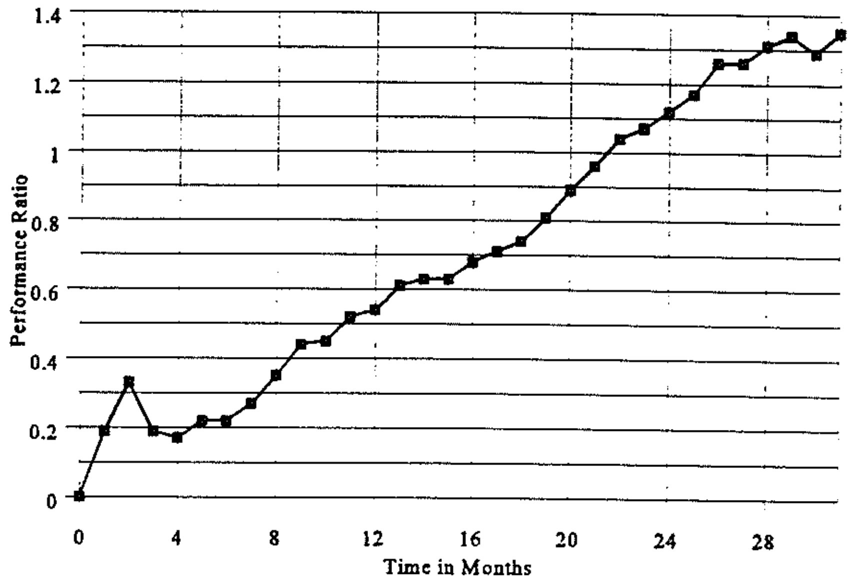

Figure 9.1 Performance ratio for Haruru Road. The performance of the Test Section compared with that of the existing road (see Table 9.12).

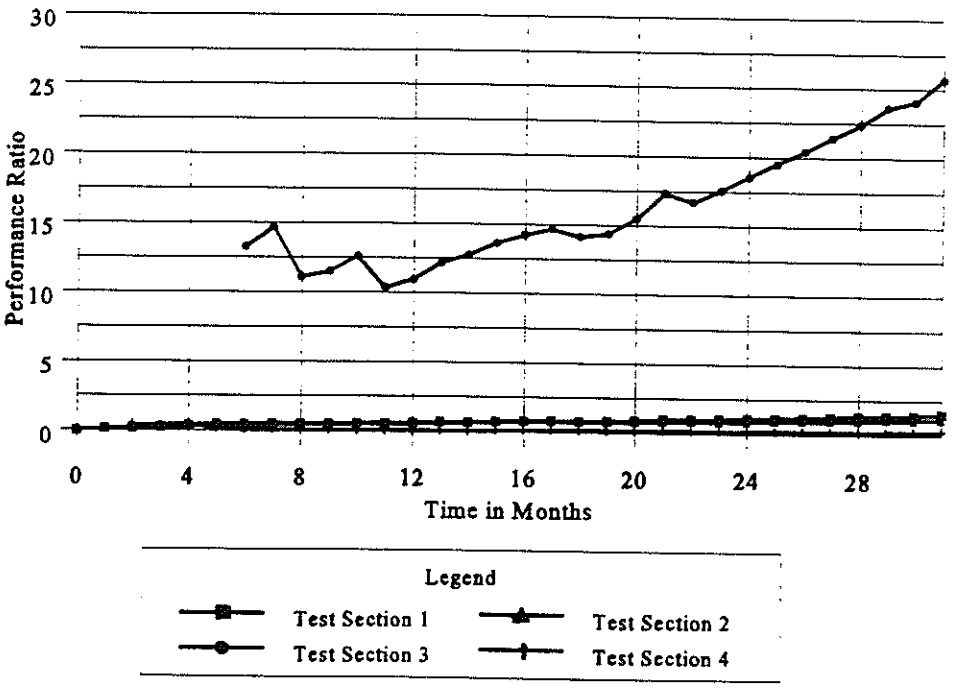

Figure 9.2 Performance ratios for Old North Road. The performance of the Test Sections compared with that of the existing road (see Table 9.12).

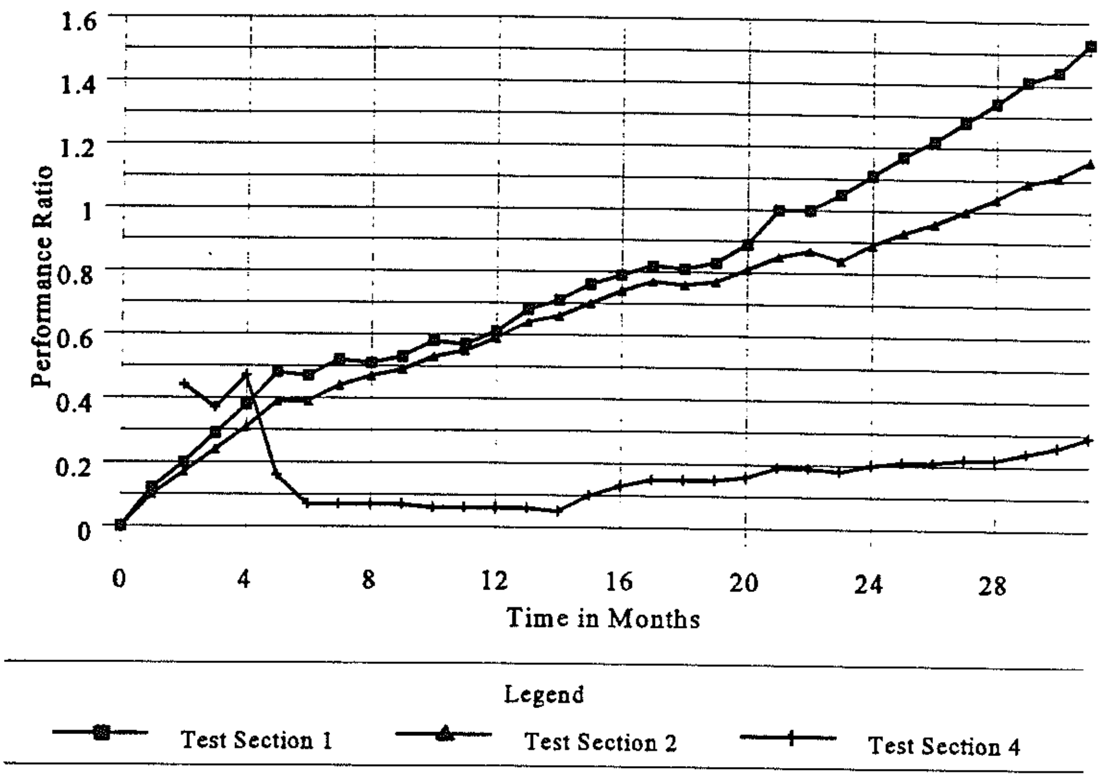

Figure 9.3 Performance ratios for Old North Road. The performance of Test Sections TS1, TS2 and TS4 compared with that of the existing road (see Table 9.12).

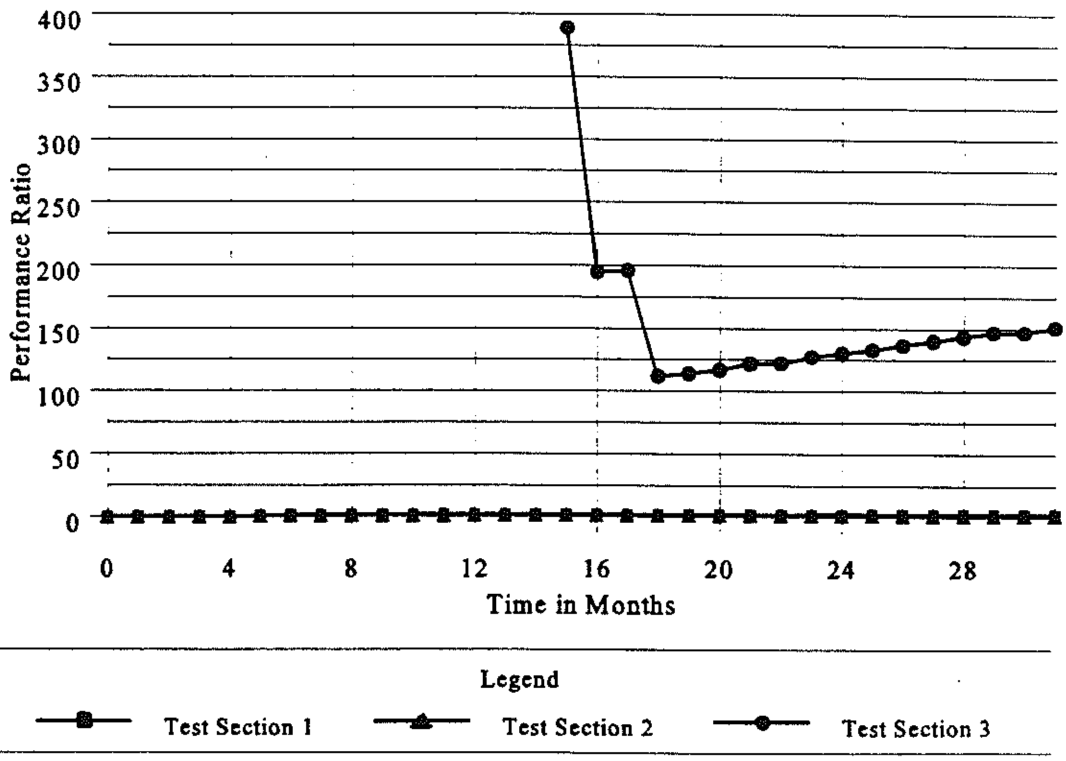

Figure 9.4 Performance ratios for Old North Road. The performance of Test Sections TS1, TS2 and TS3 compared with that of Test Section TS4 (see Table 9.13).

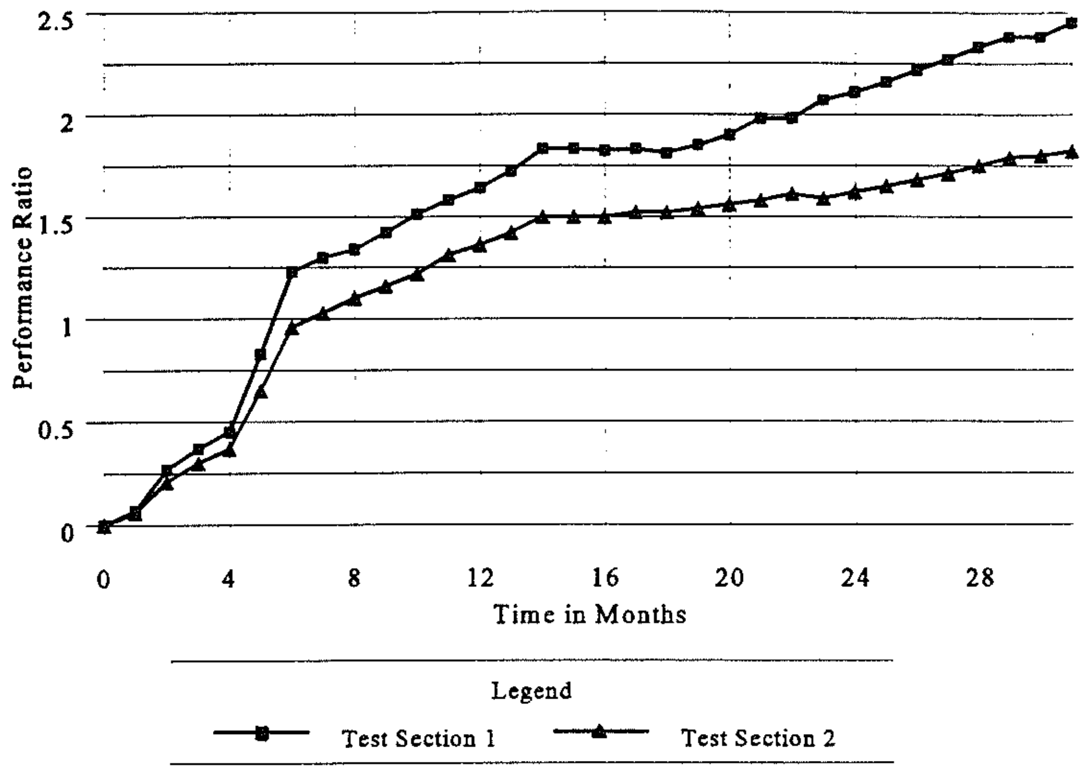

Figure 9.5 Performance ratios for Old North Road. The performance of Test Sections TS1and TS2 compared with that of Test Section TS4 (see Table 9.13).

9.5.4 Haruru Road Test Section

Construction and performance problems meant that this test section had to be reconstructed after three and again after six months, from commencement of the project. The failures that occurred were primarily caused by the introduction of too much clay into the basecourse. In addition the pieces of clay were too large.

The additional expenditure incurred in the initial stages adversely affected the performance ratio for the duration of the project. If these initial construction problems had not occurred the average month's maintenance expenditure ($0.82/metre) would probably have been closer to that of the existing unsealed pavement ($0.22/metre).

The Haruru Road Test Section was consistently smoother (by approximately 60 NAASRA units) than the rest of the unsealed pavement that was monitored. This resulted in a vehicle-operating benefit of $1.08/metre/month (Table 9.8). However the difference between the vehicle-operating benefit and the average monthly maintenance cost was not sufficient to cause a significant increase in the performance ratio. This would have occurred if the maintenance expenditure had been less. Although smoother, the test section of pavement was more costly to construct and maintain than the rest of Haruru Road.

9.5.5 Old North Road

9.5.5.1 Comparison with existing road

The advantage of applying uncompacted aggregate to a pavement is clearly illustrated by the plot for Test Section TS3 in Figure 9.2. The ratio was infinite for the first 5 months.

The steeper crossfall (6%) used on Test Section TS3 was an advantage as it led to less basecourse replenishment and maintenance than that required for Test Section TS4. This crossfall allowed surface run-off to be shed more efficiently particularly during the initial pavement settling period. The maintenance and operating costs were similar to those for the first two sections. In addition, the passing vehicular traffic compacted and stabilised the originally uncompacted basecourse layer (even if this effect was mainly confined to the wheel tracks). As a result the performance ratio is strongly influenced by the lack of expenditure on construction.

The performance ratio for Test Section TS1 shown on Figure 9.3 increased at a more uniform rate and reach a slightly larger value than that for Haruru Road.

The performance ratio disadvantage for Test Section TS2 was caused initially by the additional expenditure ($875, Table 9.4) required to blend the aggregate with clay and by a higher roughness value in January 1989.

Test Section TS1 became less costly to use and maintain than the existing unsealed roadway within 21 months from its reconstruction, while Test Section TS2 achieved a benefit/cost ratio greater than 1 after 27 months. While the ratios were not as high as had been expected, the values for both test sections were continuing to improve at a constant rate at the time monitoring ceased.

The results for Test Section TS4 show a interesting comparison. In this case the performance ratio was high for one month and then maintained a very low value, i.e. less than 0.5 from then on. This was mainly related to a greater expenditure on maintenance and the cost of operating vehicles over the rougher surface.

9.5.5.2 Comparison within test sections

In this case the benefits and costs associated with the construction, maintenance and operation of vehicles for Test Sections TS1, TS2, TS3 have been compared with those for Test Section TS4 which modelled the traditional methods adopted for construction and maintenance. The results of the performance analysis are illustrated in Figures 9.4 and 9.5.

Figure 9.4 shows a comparison involving the first three sections and illustrates that Test Section TS3 maintained a large economic advantage over the other two. This was a consequence of the difference in the cost of construction (TS3-TS4) being zero, and the relative smoothness and minimal cost of maintenance for Test Section TS3. The major difference between Test Section TS3 and Test Section TS4 was in the crossfall.

Figure 9.5 provides a comparison between Test Section TS1 and Test Section TS2. While the performance ratio values are higher than those in Figure 9.3, clearly it would take a long time for these sections to reach the economic value of Test Section TS3.

10. CONCLUSIONS AND RECOMMENDATIONS

10.1 Introduction

A large proportion of the procedures adopted during this project were based on previously documented works and the 1938 MHB Specification. It was beneficial to revive these "historical" methods so that they could be compared with the construction and maintenance procedures currently (1980s) used by most local authorities throughout New Zealand.

10.2 Unsealed Roads

Original unsealed pavement basecourse depths recorded on both Haruru and Old North Roads indicated that those depths were directly related to formation profile and pavement roughness. For example, the roughest sections of pavement contained the greatest aggregate depth and poorest pavement profile.

Sections of pavement that had minimal aggregate depths (20 mm) were generally areas of well-shaped pavement with sufficient crossfall and drainage. Conversely, sections of pavement with high basecourse depths (200 mm) had incorrect pavement profile and/or poor drainage. This ten-fold variation in aggregate depth on the same roadway, with similar sub-grade properties, carrying the same vehicle classes and numbers, emphasises the principle deficiencies in traditional unsealed pavement construction and maintenance procedures.

Recommendation: Adopt a uniform crossfall of 6% - 8% and ensure that the roadside drainage is adequate.

10.3 Road Selection

Haruru Road carries a very heavy traffic loading by national standards. The construction, maintenance and monitoring of an unsealed test pavement subjected to such a traffic loading revealed some interesting results. For example the problems associated with the use of a clay-bound basecourse.

The test sections on Old North Road carried a steady count and class of vehicle during the project. Although the average traffic count (230 vpd) would be higher than the national average for unsealed rural roads, it is normal for unsealed roads within the Rodney District. The use of this road as the site for test pavements was considered appropriate. The following points however should be noted:

- *Effect of Shade*

The effect of the continual shading of Test Section TS3 had two consequences. In the winter months it was detrimental to the pavement's performance because the pavement became saturated. Conversely, during the summer months, the shading allowed the pavement to remain damp which promoted a smoother, more stable, pavement surface.

Recommendation:
Test pavements on unsealed roads should be located on sections of roadway with a relatively constant microclimate.

- *Use of Buffer Zone*

The test sections did not have a "buffer zone" between them. In some instances "carry-over" of one construction material (e.g. silt) onto the adjoining test section occurred.

Recommendation:
Test pavements on unsealed roads should be formed approximately 100 m longer than the test section length to be studied. The additional length should provide a 50 m "buffer-zone" between the different types of pavement.

10.4 Aggregates

For an aggregate to be suitable for unsealed pavement construction, it must be densely graded, durable, and have some cohesive strength. Although the aggregate testing carried out for this project was more comprehensive than would normally be done for a construction project of this size, testing of local aggregates is recommended.

Recommendation:
The engineering properties of local aggregates should be established to determine their suitability for use in the construction and maintenance of unsealed roads.

Experienced selection of secondary aggregates from the quarry source may produce a suitable aggregate requiring no further processing. The blending of clay with the aggregate should not be necessary where the proportion of clay-sized particles satisfies the requirements of the 1938 MHB Specification.

Experience gained during this project indicated that the selection of the clay and the method of blending were critical operations.

Recommendation:
Should the gradation of the local aggregate necessitate blending, the engineering properties of the clay should be determined. Also the clay should be in a sufficiently dry state to readily crumble during blending.

Recommendation:
The successful aggregate blending procedure using rotary hoeing, adopted for Test Section TS2 in Old North Road (Section 7.3.2), is recommended.

10.5 Testing Aggregates

Quarries with a uniform source of rock could be tested on a routine basis following an initial testing programme. Once the tensile strength, lineal shrinkage, and resistance to abrasion of an aggregate have been established, infrequent particle size analysis should be all that is necessary, unless the nature of the source rock at the quarry face alters significantly.

Experience during this project showed that sampling of aggregate must be carried out with care.

Recommendation:
Sampling of aggregates should be done with care to ensure that the sample taken is typical of the material stockpiled.

It was found that the visual appearance of an aggregate was indicative of its size grade properties. However aggregates that appeared densely graded could sometimes lack the necessary clay-sized particles.

Recommendation:
It is important to establish the actual particle size distribution for a particular aggregate, especially those that appear densely graded.

The lineal shrinkage of the fines proportion of an aggregate is important to ascertain if pavement stability can be maintained during summer months (Dec, Jan, Feb). Aggregates with high lineal shrinkage properties will tend to ravel following the loss of moisture. The 1938 MHB Specification states that the lineal shrinkage should be less than 5%. The NZS 4402:1986 lineal shrinkage test procedure gave results that were 3.5 - 7.2 percentage points higher than those recorded using the 1938 MHB method.

Recommendation:
The suitability of a material which has a lineal shrinkage value level as high as 10%, when measured using the NZS 4402:1986 procedure, should be verified using the 1938 MHB Specification method.

The durability of aggregates can be determined using the LAA test. The LAA values of the aggregates tested for durability in this project fell well within the 1938 MHB Specification requirements. Less durable local aggregates (e.g. lime rock) should be evaluated before being considered for use. However their acceptance should be linked to both their cost of production and consequent performance.

Recommendation:
Aggregates reputed to be of low durability should be tested using the LAA test to ensure that the 1938 MHB Specification is met.

10.6 Construction

Unsealed pavement construction in New Zealand over recent years seems to have had little survey control during reconstruction and/or maintenance. On this project the short time taken to set out off-set pegs before reconstruction was worthwhile, as the pegs had three major advantages:

1. The longitudinal and transverse profiles of the completed pavement were geometrically correct.

2. The construction team had reference marks to work to and could efficiently produce the required shape and thickness of pavement.

3. The pavement could be formed to an adequate geometric standard and profile, so that little further upgrading should be required if the pavement is to be sealed in the future.

Unless the correct profile is obtained at this stage, it is likely that the completed pavement will also have an incorrect profile.

Recommendation:
The shape of a prepared sub-grade should be verified as correct before aggregate is placed and compacted.

It was possible to accurately produce and maintain the required surface profile with a grader by constructing a uniform crossfall from each side of the centreline. Cutting the crown resulted in the spontaneous formation of potholes.

Recommendation:
The grader should not straddle and cut the crown of the pavement during either construction or maintenance as this will flatten the desired inverted "V" profile of the pavement.

10.7 Monitoring Pavement Performance

10.7.1 Pavement Roughness

Monitoring the roughness of the pavements has provided an efficient and quantitative method for ranking the different techniques adopted. In fact, it would be difficult to accurately assess the condition of pavements without such a procedure. The results obtained in this project closely modelled the ride quality perceived when travelling over the pavements.

10.7.2 Pavement Performance

The data collected during the 31-month long monitoring period showed that variations in construction significantly affected the performance of unsealed pavements.

- *Aggregates*

The aggregate used should have engineering properties similar to those described in the 1938 MHB Specification. By adopting the guidelines in this Specification the following features may be realised:

1. The aggregate will bind together to create a dense, smooth, water-resistant pavement.

2. Aggregate loss and maintenance requirements will be reduced significantly on unsealed pavements.

3. The stability will be maintained and the surface will be significantly smoother than conventionally constructed uncompacted pavements.

4. The application of an aggregate with these properties during patching provides a stable pavement repair.

Recommendation:
Unsealed pavements should be constructed according to the following details:

1. Aggregates conforming to the 1938 MHB Specification should be utilised.
2. Adequate pavement crossfall, i.e. 6% - 8%, should be provided.
3. Adequate drainage should be provided.
4. Sufficient carriageway width, preferably two lanes, to prevent wear of the carriageway crown should be allowed.

5. Areas of pavement with limited crossfall (in the vicinity of tangent points on corners) should be minimised.

6. Thickness of running course replenishment should be reduced, particularly on grades, to prevent the formation of corrugations.

- *Clay Content*

During the course of this project a number of common problems associated with unsealed pavement design and construction were encountered:

1. Close monitoring of the quarry production was required to ensure that pockets of weak rock were not processed for supply as basecourse aggregate.

2. Angular running course had to be applied to improve the friction between the pavement surface and vehicle tyres.

3. It was difficult to blend the clay into the basecourse. Care was necessary to ensure that the correct quantity of clay was added and that it was in a finely divided state.

Recommendation:
During the construction of unsealed pavements using an aggregate which requires the addition of clay, care should be taken to ensure that:

1. Pockets of weak rock are not inadvertently included during the quarrying process.

2. An angular running course is used.

3. The clay is well blended.

10.8 Evaluation of Performance

At the commencement of this project reshaping and compacting unsealed pavements was believed to ultimately result in economic advantage. The problems encountered, particularly with respect to differentiating the construction and maintenance costs, have unfortunately provided conflicting results. The theory is supported in some instances, e.g. Haruru Road and Test Sections TS1 and TS2 on Old North Road, while Test Section TS3 on Old North Road provides evidence of a strongly conflicting nature.

The compaction of secondary quality aggregates on unsealed pavements that have sufficient crossfall can be more cost effective than conventionally constructed and/or maintained pavements. The savings realised in this project however were considered less than could be realised during well controlled maintenance of unsealed pavements.

The lack of uniformity of an "uncompacted" pavement and the consequences of it were not measured in this project. However, it was obvious that the pavement outside the wheel tracks was much looser and rougher than that within.

In this project, which was of limited magnitude, the establishment costs influenced the performance. On larger projects of this type the proportion of establishment cost to total cost would diminish.

The performance analysis carried out on all five test sections of the unsealed pavements has revealed the following results:

1. The use of secondary aggregates on unsealed roads is cost effective.

2. Increased crossfalls (6% - 8%) enhance the economic performance of pavements. Crossfalls <5% require more maintenance.

3. The addition of up to 10% clay as a binder, as recommended in 1938 MHB Specification, is cost effective.

4. Application of loose aggregate on unsealed pavements appears to be cost effective although roughness and maintenance requirements may adversely effect the long-term financial performance.

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APPENDIX

MAIN HIGHWAYS BOARD

SPECIFICATION FOR CONSTRUCTION OF BASE-COURSE

Facsimile of MHB 43, September 1938

MAIN HIGHWAYS BOARD.

SPECIFICATION FOR CONSTRUCTION OF BASE-COURSE.

September, 1938.

1. BASE-COURSE.—The base-course shall consist of a densely graded mineral aggregate mix including cohesive clay. It shall be laid on the subgrade, bladed, and sprinkled with water as three-wheeled rollers, or pneumatic-tired rollers, and vehicles effect compaction and a true finish.

2. PLANT AND ORGANIZATION.—The Contractor shall at his own cost provide all labour, material, and plant necessary for the complete construction and maintenance of the said works, and shall have a competent person in charge at all times during the period of the contract. All plant and tools necessary to carry out the work shall be in first-class working-condition and shall have been approved by the Engineer before the Contractor will be permitted to commence work. All workmen shall have sufficient skill and experience to the satisfaction of the Engineer to properly perform the work assigned to them.

Special attention is called to the requirement that, for the trimming of the subgrade, and the construction and maintenance of the base-course, the Contractor shall employ and utilize, as directed by the Engineer, a long base self-propelled single-unit power-grader with a wheel-base of not less than 16 ft., fitted with pneumatic tires, and operated by a skilled driver. On no account will the use of a separate-unit pull-type light maintenance grader be permitted for the construction or maintenance of the base-course. The grader is a most important item of plant for this type of work and must be specially approved by the Engineer.

3. SUPERVISION. — The Engineer may appoint an accredited Clerk of Works to supervise the work on his behalf. The Engineer, the Clerk of Works, or the representative of the

Main Highways Board shall each have power to stop the work at any time if, in his opinion, it is not being carried out in accordance with the specification.

All important instructions will, as far as possible, be given to the Contractor in writing, and similarly any complaints or requests by the Contractor, except those of a minor nature, shall be made in writing.

4. SURVEYING AND SETTING OUT.—The Contractor shall be responsible for all setting out of the work in accordance with instructions from the Engineer, or from the survey pegs and the information supplied on the drawings attached hereto, or from such further pegs or drawings as may be found necessary by the Engineer as the work proceeds.

5. PREPARATION OF SUBGRADE.—Full use shall be made of the power-grader in the trimming and shaping of the subgrade. When the subgrade has been properly shaped it shall be brought to a firm, uniform, and smooth surface by rolling the entire area, in conjunction with grading and blading to fill any depressions which develop. The roller shall be a three-wheeled roller weighing not less than eight (8) tons, or, alternatively, a pneumatic-tired roller or vehicle may be used to effect compaction to the approval of the Engineer.

Sand subgrade shall be sprinkled and maintained in a sufficiently moist condition at all times for maximum compaction under rolling. Other subgrade materials shall be watered during compaction only if ordered by the Engineer.

The subgrade shall be maintained so that metal is always laid on a firm and properly shaped foundation, and no metal shall be applied unless the subgrade is dry to the extent that it contains no more moisture than is necessary for maximum stability, and is approved by the Engineer. On no account shall metal be placed on a clay-soil subgrade while it is in a wet plastic state. If the Contractor spreads metal on wet plastic clay material, for his own convenience or for the temporary passage of construction vehicles or traffic, the cost of such metalling shall be entirely at his own expense.

Immediately prior to the application of base-course metal the subgrade shall conform to grades and typical cross-sections, and there shall be no area in the general surface which varies more than $\frac{3}{4}$ in. from a camber board laid at right angles to or a 10 ft. straight-edge laid parallel to the centre-line of the road.

6. METAL PREVIOUSLY MOVED FROM ROAD.—All metal previously scarified and moved from the road surface during "formation," whether under a different contract or not, shall be evenly distributed over the prepared subgrade as directed by the Engineer, and shall be considered as part of the base-course. Any oversize stones which will not pass a two and a half ($2\frac{1}{2}$) inch ring shall be raked or forked from the surface, and disposed of or stacked as directed by the Engineer.

This existing metal moved from the road surface during "formation" will not be paid for as new base-course, but the handling and working of any existing metal will be paid for under item 2 of the Schedule for "Spreading of Existing Metal."

7. DEPTH OF BASE-COURSE.—The Engineer will direct as to the depth of base-course to be constructed on any section of the road, but in general base-course aggregate shall be applied at an average rate of* cubic yards, loose measurement, per chain of road. Where the base-course is to be constructed on existing metal or natural gravel subgrade, the quantity or depth of base-course shall be reduced as instructed by the Engineer.

8. WIDTH OF BASE-COURSE.—The width of the base-course shall be generally * feet on straight sections of road, but shall be wider on curves so that the base-course always extends from shoulder to shoulder.

9. BASE-COURSE AGGREGATE.—The base-course mineral aggregate shall be either a natural pit gravel or an artificial mixture of any two or more of the following—viz., pit gravel, river shingle, crushed stone, sand and an approved clay binder. The base-course aggregate, whether a natural or an artificial mixture, shall be well graded from coarse to fine, and when tested by laboratory screens shall meet the following requirements:—

(A) When the loose depth of base-course is five (5) inches or more, and if initial compaction is obtained by means of an iron-wheeled roller—

	Per Cent.
Passing $2\frac{1}{2}$ in. (circular screen)	100
„ $1\frac{1}{2}$ „	75–85
„ $\frac{3}{4}$ „	55–65
„ $\frac{1}{4}$ „	30–40
„ 10 mesh (U.S. series)	20–30
„ 50 „	10–20
„ 200 „	5–10

* Figures to be inserted.

(B) When the loose depth of base-course is three (3) inches or more—

		Per Cent.
Passing	$1\frac{1}{2}$ in. (circular screen)	100
,,	$\frac{3}{4}$,, ...	65–75
,,	$\frac{1}{4}$,, ...	40–55
,,	10 mesh (U.S. series)	25–40
,,	50 ,, ...	15–25
,,	200 ,, ...	8–15

(C) When the loose depth of base-course is one and one half ($1\frac{1}{2}$) inches or more—

		Per Cent.
Passing	$\frac{3}{4}$ in. (circular screen)	100
,,	$\frac{1}{4}$,, ...	60–80
,,	10 mesh (U.S. series)	40–60
,,	50 ,, ...	25–35
,,	200 ,, ...	10–20

That portion of the aggregate retained on the 10-mesh sieve shall be from stone with a French coefficient of wear of not less than three and one-half or, if tested in a Los Angeles abrasion machine in accordance with the methods laid down by the American Society for Testing Materials, the percentage of wear shall be not greater than sixty-five.

When mixing has been completed the aggregate shall contain no lumps of clay which will not pass a $\frac{1}{2}$ in. circular screen, and shall be free from organic, vegetable, or other deleterious substances. The tension of the binder fraction passing the 50-mesh sieve shall be not less than 10 lb. per square inch, and the lineal shrinkage shall be not more than 5 per cent.

10. TEST FOR LINEAL SHRINKAGE AND TENSION.—The lineal shrinkage and tension of the total material passing the 50-mesh sieve shall be determined by mixing the material with water to the field-moisture equivalent as defined by the Bureau of Public Roads (U.S.A.), or, in other words, the moisture content shall be such that, if a drop of water is placed on the smoothed-off material, the water will remain on the surface and will not be readily absorbed. When at this consistency the wet mixture shall be evenly packed, without air bubbles, into tensile strength cement/sand moulds of the form and shape shown in Fig. 1, Plate 1, of the British Standard Specification for Portland Cement No. 12, 1931. These moulds are 3 in. in length, enlarged at the ends, and with the middle section exactly 1 in. square.

When the briquettes have sufficiently dried out in air, they shall be removed from the moulds and dried to constant weight in an oven at a temperature of 110° C. The briquettes shall then be tested for tensile breaking strength by holding in metal jaws of the shape shown in Figs. 2 and 3, Plate 1, British Standard Specification for Portland Cement No. 12, 1931, and uniformly applying a load at the rate of 5 lb. per second.

The tensile breaking strength shall be not less than ten (10) pounds per square inch.

The lineal shrinkage shall be taken as the decrease in length of the briquettes from the wet moulded state (field-moisture equivalent) to the length at the dried constant weight, and the decrease in length shall be expressed as a percentage of the wet moulded length.

The lineal shrinkage shall not be greater than five (5) per cent.

11. APPROXIMATE BASE-COURSE MIXTURE. — The following information as to aggregate mixtures is given as a general guide to the Contractor: Stabilized gravel course mixtures may be considered in the same terms as are commonly employed in regard to concrete work. For instance, in concrete work it is common practice to designate a mix as 1 : 2 : 4, and so on. The same terms may be used for stabilized gravel work, with the exception, of course, that clay is to be understood instead of cement.

(A) With the maximum size of stone fragments at 2½ in. (circular) the mixture of stone screenings, sand, and clay should be approximately :—

> *Eight* parts of metal or stone graded from 2½ in. (circular) down to 10 mesh—*i.e.*, graded metal without sand—as is often the practice in producing screenings or gravel for concrete,
>
> *plus*
>
> *two* parts of graded sand—*i.e.*, coarse sand from 10 mesh down to fine sand of wind-blown size
>
> *plus*
>
> *one* part of clay—*i.e.*, plastic material mostly passing the 200-mesh sieve.

In short, the above stabilized gravel mixture may be considered as a

1 : 2 : 8 mix (2½ in. stone).

(B) When the maximum size of stone fragments is 1½ in. (circular) the proportion of clay and sand should remain as above, but the metal or stone screenings should be reduced to six parts, or, in short, a

1 : 2 : 6 mix (1½ in. stone).

(C) When the maximum size of stone fragments is ¾ in. (circular) the proportion of clay and sand should remain as above, but the metal or stone screenings should be reduced to three parts, or, in short, a

1 : 2 : 3 mix (¾ in. stone).

The above mixtures are approximate and should be taken only as a general guide.

12. BASIS OF PAYMENT FOR BASE-COURSE.—No payment will be made as a separate item for added clay or sand-clay binder. If the Contractor does not supply a natural mineral mixture to comply with the specification, then he shall include the cost of any binder or other void-filling material in the cost of base-course aggregate.

The measurement of base-course for payment purposes will be the loose or lorry volume of coarse aggregate above sand size (10 mesh), unless the coarse aggregate contains fines as delivered on the works, when the volume of the coarse aggregate with whatever fines are incorporated will be the basis of measurement. Any further fines or binder smaller than 10 mesh (U.S. series) to be added, either during mixing or subsequently to adjust the mix, will not be considered for payment purposes as increasing the volume of base-course aggregate.

13. LOCAL MATERIALS.—The Engineer will, whenever possible, supply tenderers with particulars of local rocks, gravels, sands, and clays which, as far as possible, will have been tested beforehand by the Main Highways Board or in the Engineer's laboratory. There will be no restriction on the source from which mineral aggregates may be obtained, always provided that the materials comply, or are prepared to comply, with the specification. The Contractor shall make his own arrangements for access to mineral aggregate deposits, and he shall pay any compensation or royalties.

The attention of the Contractor is called to the position that, whereas in general it has been the practice in the past to require base-course metal with a French coefficient of wear of not less than 7, this specification allows softer material with a French coefficient of wear of not less than 3½ or a Los Angeles abrasion machine loss of not more than 65 per cent.

14. MIXING OF MATERIALS.—If a natural pit gravel complying with the specification is not provided, the clay binder, sand, and coarse aggregate may be mixed either on the road or at the gravel-pit by passing the gravel and the requisite amount of dry clay and/or sand together through a crusher; or by other means approved by the Engineer.

In order to avoid damage to the subgrade, the Contractor will probably find it to his advantage to mix the clay, sand, and gravel through the crusher, or by other means at the gravel pit. However, mixing on the road will be permitted provided that the Contractor takes all precautions to ensure against disturbance of the compacted subgrade during mixing operations.

When the clay binder and sand are to be mixed with the coarse aggregate on the road, this shall be done by spreading the gravel or metal from the tail-board of a lorry, or by other approved means, down the dry road surface in a flattened windrow, and then evenly distributing the necessary amount of dry and pulverized clay binder and/or sand over the coarse aggregate. The clay and/or sand shall then be thoroughly incorporated with the gravel or metal by means of harrowing, disking, blading, and rolling, the latter if required to break dry lumps of clay. A disk attached to the mould-board of a grader is very useful for mixing, and is also effective in breaking lumps of clay. Even an ordinary disk mounted and drawn as for agricultural work is very useful in breaking up clayey material and mixing the aggregate.

Clay should be excavated only under reasonably dry conditions, and not until immediately prior to its addition to the coarse aggregate. If clay or sand-clay material is excavated and loosely stacked in storage heaps in the open, it will absorb large quantities of water during rain, and, no matter how hot and dry later weather conditions may be, the clay will not dry out to any appreciable depth below the surface. It is almost impossible by any ordinary means to satisfactorily handle and mix clay which has become saturated with water.

The pit from which clay is to be obtained should be kept well drained on all occasions, and the clay should be taken only as required.

A satisfactory method of obtaining clay in a suitable condition for incorporation in base-course aggregate is to clear the area until the clay is exposed, and then as the surface dries out strip or remove the clay in thin layers with a power grader. It is advisable to keep the area crowned to rapidly shed surface water into a side drainage system. Clay may also be excavated from a vertical face which is kept well drained, and which is always allowed to dry out after rain before any further material is excavated.

If it is found that the grader is not sufficiently powerful to completely turn and thoroughly mix the full amount of coarse aggregate, sand, and clay in one layer, then the base-course aggregate shall be mixed in two equal layers. Similarly, no matter what the power of the grader may be, if the amount of base-course exceeds 3 in. in loose depth, the work of mixing shall be accomplished in two layers.

When the mixing has been satisfactorily completed to provide a base-course of uniform texture with no segregation of coarse and fine material, the aggregate shall be moved into windrows in suitable positions on the road, but not on to the shoulders, to allow of the treatment of the subgrade as specified below.

15. SUBGRADE DAMAGE.—Any rutting or other disturbance of the subgrade during the mixing and spreading operations shall be immediately remedied by the Contractor. If subgrade soil is brought to the surface, the area so affected shall be excavated and made good with the necessary new materials to the satisfaction of the Engineer.

16. EXTENT OF SCARIFYING AND WATERING SUBGRADE.—As the windrowed base-course is moved about to suitable positions, but on no account on to or beyond the shoulders, undisturbed existing metal or natural compacted gravel subgrade shall be sufficiently scarified or hand-picked to form a key or mechanical bond for the base-course, and then well watered just ahead of the spreading-out of the base-course aggregate.

No scarifying of earth, sand, or clay subgrade will be required unless specially ordered by the Engineer. Watering of any area of earth, sand, or clay subgrade will also not be required unless by special instructions of the Engineer.

17. FINAL SPREADING OF BASE-COURSE.—On the completion of any repair work to the subgrade, and scarifying and/or watering as required, the base-course aggregate shall be continually sprinkled with water, and uniformly spread in successive cuts by the grader over the full width of the subgrade from shoulder to shoulder. Distribution, blading, and watering shall continue until the surface is true and even longitudinally and in cross section.

Only enough water shall be applied to maintain the mixed material in a condition just sufficiently plastic to permit a maximum degree of compaction. The greatest care shall be exercised to ensure that due neither to rain nor excessive sprinkling does the subgrade suffer damage or the base-course aggregate become too wet and sloppy for proper compaction. To minimize the risk of heavy rain soaking through loose base-course to damage the subgrade, the contractor will probably find it to his advantage to undertake initial compaction immediately base-course materials are laid. If, as a result of the presence of too much water from any cause, damage occurs to the subgrade, such damage shall be immediately rectified to the satisfaction of the Engineer. Also, if base-course material becomes too wet, it shall be dried out by continual turning with a power-grader until just sufficiently plastic to allow of proper shaping and compaction, and so that there is no sloppiness or splashing on the passage of vehicles. Any base-course which has become too wet shall be windrowed to leave a clear passage for traffic during hours of darkness, and at all other times when the aggregate is not being turned or manipulated with a grader.

18. CONSOLIDATION OF BASE-COURSE.—Immediately the base-course aggregate has been uniformly spread out with the proper amount of moisture, compaction shall commence. When the base course aggregate contains fragments exceeding one and one-half (1½) inches circular screen dimension initial compaction shall be obtained by rolling with a three-wheeled roller, but final compaction shall be obtained by operating a pneumatic-tired vehicle, with increasing loads, up and down the section in such a manner that the rear wheels make uniform and sufficient contact with every part of the surface; and also by the distribution of traffic and construction vehicles. A specially constructed pneumatic-tired roller may be substituted for the pneumatic-tired vehicle. For base-course aggregates not exceeding one and one-half (1½) inches circular screen dimension, iron-wheeled rollers will be permitted, but will not be insisted upon, for initial compaction. Iron-wheeled rolling shall cease in all cases after initial compaction, at the stage when the surface no longer offers obstruction or discomfort to passing traffic.

To ensure that compaction is uniform over the whole area of metal, particular attention shall be given to the edges of the base-course.

Watering, blading with a power-grader as specified under clause 2 above, and compaction with a pneumatic-tired lorry or other vehicle finally loaded to a gross weight of not less than 6 tons, or with a pneumatic-tired roller, shall continue until there is no movement of the aggregate or tendency to rutting when the surface is thoroughly moistened.

Any weak places or defects that develop during compaction shall be completely excavated and made good with new materials.

The minimum of uncompacted aggregate shall remain on the road overnight, and on no account shall the loose aggregate extend for a distance of more than 20 chains during the hours of darkness. Wherever there is loose aggregate on the road, whether during daylight hours or hours of darkness, ample large warning notices, and red danger lights at night, shall be displayed to the entire approval of the Engineer.

19. DEFECTS TO BE REMEDIED.—Any deficiencies which appear in the grading or stabilization of the base-course aggregate during compaction shall be remedied to the approval of the Engineer, and also all other defects in, or damage to, the subgrade, shoulders, or other roadworks occurring during the construction or maintenance of the base-course shall be immediately made good. Extra labour or materials required to remedy defects, damage, or faulty work will be at the Contractor's expense, and will not be taken into account when determining payments for base-course.

20. MAINTENANCE OF BASE-COURSE.—Maintenance of this type of work is merely a continuance of construction. On the completion of compaction of all base-course aggregate, the surface shall be maintained smooth, compact, and true to grade and cross-section, by watering as required, blading and distribution of traffic by the placing of drums or other barricades during daylight hours. On no account shall the surface at any time be allowed to pot-hole, ravel, rut, or become uneven. This will necessitate daily sprinkling with water during dry periods, and frequent blading at all times. If for any reason the road does ravel or pot-hole, it shall be patched with base-course mixture and completely scarified and recompacted as directed by the Engineer.

If the contract includes the application of the top-course as well as the construction of the base-course, the Contractor shall maintain the surface to the specified standard until the application of the top-course. If, on the other hand, the contract includes the construction of the base-course only, the surface shall be maintained to the specified standard until the end of the maintenance period.

21. SURFACE FINISH.—The standard of smoothness of the surface shall be such that when all free dust, loose stones, and any other floating materials are graded and broomed from the surface every section of the base-course shall register a roughometer reading of not more than * units to the mile when tested with the roughometer attached to the Public Works Department † car under correct tire pressures and mechanical conditions. It is important that the road shall be free of floating material when the roughometer test is made; for loose grit and chips, especially just after blading, have a

* Figure to be inserted. † Make of car to be inserted.

tendency to fill holes and low areas, thus causing a reading better than that obtainable on the surface which is to take the top-course.

In addition to the smooth-riding qualities, the base-course surface shall conform to grades and typical cross-sections, and there shall be no point in the general surface that will vary more than ¾ in. from either a 10 ft. straight-edge laid parallel to the centre-line of the road, or from a cross-section-camber board placed at right angles to the centre-line of the road. Further, there shall be no area of the road surface which will hold water.

22. CROSS-ROADS AND PRIVATE WAYS.—All intersecting roads shall be metalled, compacted, and maintained to the standard of the Main Highway to a point 33 ft. from the centre-line of the new formation, or as directed. Private drives shall be treated similarly for a distance of 20 ft. from the centre-line of the new formation.

23. PASSAGE OF TRAFFIC AND PRECAUTION FOR SAFETY OF PUBLIC.—The Contractor shall carry out his work in such a manner as will permit the safe passage of traffic over the whole length of road included in the contract, and shall keep at least half the width of the roadway open and passable to traffic at all times, with the least possible interference, consistent with the prosecution of the work as directed by the Engineer.

Barricades, warning signs, and, if necessary, watchmen shall be maintained at each end of the section of highway being constructed, and where necessary to safeguard the travelling public, the Contractor shall provide red lights at night on barricades and warning signs, and also on any plant or material offering obstruction to traffic. When the necessity for warning notices no longer exists, all such notices, &c., must be immediately removed.

24. LIABILITY FOR DAMAGE.—The Contractor shall be exclusively liable for any loss, accidents, or injury of any kind, to persons, property, or anything else which may arise in connection with or during the progress of the works, and he shall indemnify the road controlling authorities against liability for any such loss, accident, injury, or damage, and any actions or claims in respect thereof.

25. TENDERERS TO INSPECT SITE.—The Contractor shall be held to have satisfied himself before tendering, by personal inspection of the site, as to the accuracy of the specification, plans, schedules, &c., or any other information of any kind supplied to tenderers. He shall also be held to have satisfied himself as to the feasibility of constructing works of the kind and in the manner specified, and as to all other matters which can in any way influence his tender, as no allowance will be made or compensation allowed on account of any incorrect or insufficient information upon any point, and he is further required to inform himself completely and thoroughly of every circumstance connected with the work, and to provide in his tender for every contingency that may arise.

26. **REMOVAL OF MATERIALS.**—On completion of the contract the Contractor shall remove all surplus material used in connection with the works, and leave the road reserve clean and tidy and free from debris.

27. **TIME FOR COMPLETION.**—The whole of the work included in this contract shall be completed by the

28. **MAINTENANCE OF WORKS.**—All works included within the contract shall be maintained from the date of acceptance of the tender, or from the time of handing over the road, if these dates do not coincide, until the application of the top-course, if the contract includes the construction of both base-course and top-course, or, if not, for a period of twelve weeks from the date that the Engineer certifies the completion of the base-course and incidental works, except that the Engineer may, if he so desires, terminate the maintenance period within any shorter time than twelve weeks. If the maintenance period is reduced, payments for maintenance will be adjusted in accordance with the Schedule unit rate.

The Contractor shall maintain to the entire satisfaction of the Engineer the subgrade and then the base-course, together with all intersections, shoulders, water-tables, side drains, subsoil drains, other drainage channels, and all other works constructed in accordance with the specification. If the contract includes formation as well as base-course, the works to be maintained shall also include all batters and embankments.

29. **GENERAL CONDITIONS.**—The General Conditions of Contract shall be included in and read with this specification.

30. **ALL WORK TO BE CARRIED OUT IN WORKMANLIKE MANNER.**—All construction and maintenance shall be carried out in a workmanlike manner to the entire satisfaction of the Engineer, and any work not specified but necessary to the completion of the contract in accordance with the letter and spirit of the specification shall be carried out by the Contractor as if it had been so included.

31. SAMPLING AND TESTING OF MATERIALS.—The Contractor shall take samples of all road materials in accordance with the directions of the Engineer, and shall have these samples well marked and packed and forwarded with a covering letter to the Chairman, Main Highways Board, Wellington. The covering letter shall state clearly the date of sampling, a description of the material, the place from which the sample was taken, and the name of the contract.

Broken stone, gravel, pit metal, or prepared base-course samples shall weigh at least 30 lb., sand samples 20 lb., and clay binder, mineral filler, or clay subgrade samples 10 lb. The Contractor shall make allowance in his tender for one sample from every place at which broken stone, gravel, pit metal, sand, clay binder, or mineral filler material is obtained, and, in addition, shall supply further samples of prepared base-course as required.

All samples of metal, gravel, sand, mineral filler, clay, or prepared base-course shall be packed in tins with "press-on" or other well-fitting and dust-tight lids, or in closely boarded boxes.

The Contractor shall include the whole cost of sampling under "Unscheduled Items," including preparing and forwarding same, and also the provision of all facilities for further field tests by the Engineer, on the ground.

All materials shall be approved by the Engineer before any particular stage of the work is commenced. In this connection it is pointed out for the guidance of the Contractor, that the testing of materials may occupy at least twenty-eight days.

32. SCHEDULE OF QUANTITIES AND BASIS OF PAYMENT.—As far as practicable the contract shall be a schedule or unit-rate contract, and for tendering purposes a Schedule of quantities has been prepared. Every care has been taken to ensure the correctness of these quantities, but, except for items scheduled for lump-sum payment, all items will be paid for at unit Schedule rates on quantities as directed or approved from time to time by the Engineer, except that, if alterations in Schedule quantities involve an increase or a decrease of more than twenty (20) per cent. of the total cost of the work calculated from the original Schedule quantities and the Schedule unit prices, then equitable adjustment of payment will be arranged between the Engineer and the Contractor. Any variation from the Schedule quantities will in no way void or abate the conditions or provisions of the contract, or relieve the Contractor from the responsibility of constructing the work to the required standard, and carrying out the maintenance as specified.

Any additional labour, transport, mineral aggregate, or other material required to make good faulty work, or used in repairs or maintenance, will be at the expense of the Contractor and will not be taken into account when determining the sum to be paid for any item or section of the work.

The items on which payments will be made are as follows :—

(1) *Preparation of Subgrade.*—Payments will be made on the total length (in lineal chains) of road along which base-course is constructed. There will be no allowance for widening on curves, but the sum of the additional areas treated at intersections and private drives will be converted to equivalent lineal chains of road by dividing by the area of base-course on one chain of straight section of road. The chainage of curved sections of road will be made along the centre-line.

The unit price will be in full compensation for the complete preparation of the subgrade prior to, and until, the application of the base-course, and for all labour, use of equipment, and incidentals necessary for the completion of the work as more particularly specified under clause 5, " Preparation of Subgrade."

(2) *Spreading of Existing Metal.*—Payments will be made at the unit Schedule rate on the total quantity (in cubic yards) of existing metal spread on the subgrade ; existing metal being the road metal or gravel moved from the road during " formation," whether under a different contract or not.

The volume of windrows or storage heaps which must be trimmed to proper shape for measurement to the satisfaction of the Engineer will be the measurement on which payments will be made, except that, if the existing metal is transported from the heaps to the road, vehicular measurements of the metal will be the volume for purposes of payment.

The unit price shall be in full compensation for removing oversize stones and for transporting and spreading the existing metal over the subgrade as directed.

(3) *Base-course Aggregate delivered on the Road.*—Payments will be made at the unit Schedule rate on the total quantity (in cubic yards) by loose measurement of base-course aggregate delivered on the road as set out under clause 12, " Basis of Payment for Base-course." Measurements will be made in every case at the delivery end in the lorry or other delivery vehicle, and the Contractor shall at his own expense do any levelling-off required to facilitate the measurements being made.

The unit price shall be in full compensation for supplying, transporting, and initial spreading of the base-course aggregate along the road surface.

The Contractor shall provide a cartage book with the dockets in duplicate. On the delivery of each load the quantity of base-course aggregate shall be entered in the cartage book. The original docket shall be signed by the Contractor and delivered to the Clerk of Works, while the duplicate will be signed by the Clerk of Works and retained by the Contractor.

(4) *Construction of Base-course.*—Payments will be made on the total length (in lineal chains) of road along which base-course is constructed. There will be no allowance for widening on curves, but the sum of the additional areas treated at intersections and private drives will be converted to equivalent lineal chains of road by dividing by the area of base-course on 1 chain of straight section of road. The chainage of curved sections of road will be made along the centre-line.

The unit price shall be in full compensation for all scarifying, mixing, spreading, watering, compacting, trimming and grading, and for all labour, use of equipment, and incidentals necessary for the construction of the base-course until completion is certified by the Engineer.

(5) *Maintenance.*—Payments will be made on a per-week basis for the total length (in miles) of road along which base-course is constructed, but no extra length will be allowed for intersections or private drives.

Although it is required that all works shall be maintained from the time of acceptance of the tender or from the handing-over of the road, any maintenance preparatory to, or during, base-course construction shall be considered as merely incidental to construction, and construction-unit prices shall cover such work. The period for which maintenance payments are to be made as a separate item will not commence until the Engineer certifies the completion of the base-course and incidental works.

The work to be paid for under item 5, "Maintenance," is more particularly set out under clause 20, "Maintenance of Base-course," and under clause 28, "Maintenance of Works," in so far as this latter clause operates subsequently to the Engineer's certification of the completion of the base-course and incidental works.

The unit for payment purposes will be one mile per week. For example, if ten miles of road are maintained for one week, payment will be made for ten miles/weeks, or, if ten miles of road are maintained for twelve weeks, payment will be made for ten times twelve or one hundred and twenty miles/weeks, and so on.

If the contract includes the construction of top-course in addition to the base-course, no payment as a separate item will be made for maintenance of base-course works, and item 5, "Maintenance," will be ruled out and deleted from the Schedule. The top-course may be laid immediately on the completion of the base-course, so that any maintenance between base-course and top-course construction will be merely incidental to construction.

(6) *Unscheduled Works.*—A lump-sum payment will be made, which will be in full compensation for all items of material, labour, transport, and contingencies for which the Contractor may wish to allow, and incidentals necessary for completion of the works in accordance with the drawings, specification, and general conditions to the satisfaction of the Engineer, but not otherwise covered or allowed for in the Schedule.

(7) *Contingencies.*—A sum as set out in the Schedule under "Contingencies" (which will in general be from $2\frac{1}{2}$ per cent. to 10 per cent. of the total estimated cost, as considered desirable by the Engineer) is intended to cover any extra works which may be authorized from time to time, and which are not included under the specification.

This sum or any part thereof will not be paid to the Contractor unless extra works as authorized and approved by the Engineer are actually carried out. On the other hand, this sum is not necessarily a limit to the value of extra work which the Engineer in his discretion may instruct to be executed.

Place :...

Date :...

....

...., Engineer.

SCHEDULE FOR BASE-COURSE CONSTRUCTION.

Description.	Item.	Quantity.	Unit Rate.	Amount.
				£ s. d.
1. Preparation of subgrade ..	Lineal chains			
2. Spreading of existing metal	Cubic yards			
3. Base-course aggregate delivered on the road	Cubic yards			
4. Construction of base-course	Lineal chains			
5. Maintenance	Miles/weeks			
6. Unscheduled works ..	Lump sum			
7. Contingencies	Sum to be allowed			
Total	..	..	.. £	

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