Forest Road Pavement Design in New Zealand

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Abstract

The New Zealand forest industry currently has an annual cut of 19 million m^3 that is expected to increase over the next decade to 30 million m^3 per year. Much of the new production is situated in first-rotation forests that are located on steep terrain and have minimal existing forest road networks. A survey conducted as part of this study identified that current road engineering practices vary widely between forest owners and that forest road construction owes more to the experience of roading supervisors than to formal design methods, qualifications and training. While the economical design of forest roads is affected by many factors, including: road location and surveying, geometric design, and construction and maintenance, the acquisition and placement of aggregates for pavement can contribute 60-70% of forest road cost.

The majority of forest owners use a single 'improved' aggregate layer to complete their forest road, as opposed to a multi-layered approach used for most public roads. This paper focuses on reviewing the aggregate grading standards available for forest road design, and notes there is considerable variation between standards. A series of eight aggregates actually used for East Cape forest road construction were analysed by sieve test and compared to the standards. It found that the aggregates had widely varied gradation and were dissimilar to the gradation envelopes of the reviewed standards. Further research is required to determine an aggregate grading standard that will best suit East Cape aggregate sources and conditions.

Background

The New Zealand commercial forest estate is currently estimated at 1.8 million hectares, with an annual cut of 19 million m^3 (MAF 2008). The annual harvest is predicted to increase by 50% over the next decade (MAF 2000). Much of this new harvest area is situated in first-rotation forests that are located on steep terrain and have minimal existing forest road networks. A significant investment in forest road design and construction is required in order to provide access for harvesting in these new areas. This investment will call for the application of sound technical engineering knowledge and capability. Anecdotal evidence obtained through discussions with forest managers has identified that forest road engineering practices vary widely across the industry, and that many forestry regions struggle with developing and maintaining a cost-effective forest road network. The current level of forest road engineering capability in New Zealand, and the specific nature of deficiencies, is not well understood.

Figure 1 – Examples of forest roads in the East Cape region of New Zealand. The left picture shows a prepared subgrade awaiting placement of aggregate. The right picture shows a road constructed with log corduroy after failure of the original road pavement.

The purpose of this paper is to outline the forest road engineering research programme being implemented at the School of Forestry. Specifically, we review forest road pavement design considerations and aggregate grading standards, before presenting gradation curves for a selection of East Cape aggregates that have been tested.

Road Engineering Research Programme

The School of Forestry has committed to a programme of forest road engineering research. The objective of the research is to examine current New Zealand forest road engineering practices and identify opportunities to improve the design and construction of economical forest road pavements. To achieve this objective, the research programme will:

- Formally evaluate current forest road engineering practices in New Zealand in order to define current industry capability,

- Identify opportunities for improvement in pavement design that could be applied to New Zealand forest roads, and

- Test alternative pavement design methods to determine the applicability, and potential economic benefits, of these opportunities.

The research commenced at the end of 2008 and is in its early stages. The formal survey of industry capability is underway. While conducting the survey, the author has had the opportunity to observe many forest roads and to collect soil and aggregate samples for lab testing to determine material engineering properties. It was during these visits that forest owners expressed conflicting views of what aggregate grading should be used for surfacing unsealed forest roads.

Gradation of Forest Road Aggregates

<u>Forest Road Pavement Design Considerations</u>

In New Zealand, and in many other parts of the world, public low-volume roads are constructed using unbound flexible pavements – an arrangement that uses layers of unbound granular material that may be unsealed, or capped by a thin asphalt or chip-sealed layer. The typical structure of flexible pavement for a low-volume road is illustrated in Figure 2.

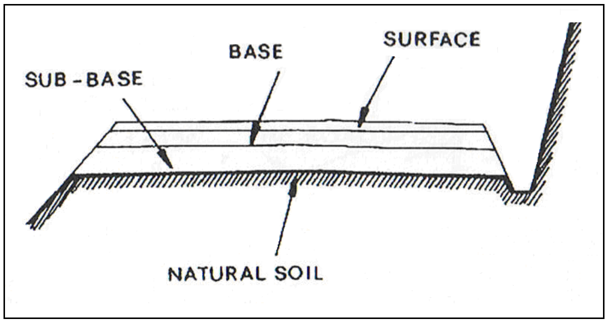

Figure 2 – Typical design of a public low-volume road (Sessions, 2007)

Pavements for forest roads often differ from public low-volume roads in that they commonly will not have multiple pavement layers or a sealed running course, but will consist of a single improved layer placed over the compacted natural soil, as illustrated in Figure 3. These two different design approaches have a significant impact on the gradation of aggregate required for the road pavement.

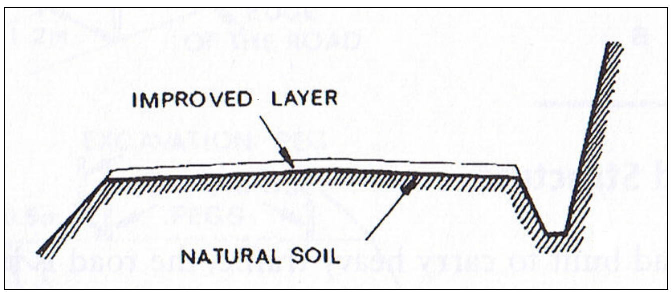

Figure 3 – Typical design of a forest road (Sessions, 2007)

<u>Aggregate Gradation Standards</u>

The difficulty faced by forest road engineers is that most aggregate gradation standards have been designed for the multi-layered pavement approach. A multi-layer pavement incorporates a surface layer that uses smaller aggregate and increased fines content to provide a smooth running surface that is water and abrasion resistant. By comparison, the base layer uses larger aggregates and reduced fines content to maximise structural strength and to provide resistance against capillary action. The improved layer approach is more problematic, as the single layer needs to have a gradation that concurrently satisfies the requirements of both the base and surface layers.

A review of a selection of existing aggregate gradation standards identified two broad categories of grading envelopes, namely: base course specifications and surface course specifications. These specifications relate to the base layer and the surface layer respectively. In all cases, aggregate gradation was specified via a gradation envelope in order to allow for variability of aggregate size, shape, texture and mechanical properties.

The base course specifications that were reviewed and compared in more detail are listed below in Table 1 and the surface course specifications in Table 2. Note that a number of entities and texts, including the USDA (1979), the FHWA (1996), and Giummarra (2000) list multiple gradation standards – but only one has been selected from each for the purpose of this comparison. These tables describe the maximum permitted aggregate size, the range for percentage of fines (fines are particles passing the 0.075mm sieve) and the coefficient of uniformity at the mid-range of each gradation envelope. The coefficient of uniformity (C_U) describes the uniformity of the aggregate. A higher C_U value indicates that the aggregate is less porous and is consequently less permeable (Forrester 2001). Low permeability is desirable for a surface course to provide water-resistance, but is less desirable for a base course, as the smaller pore spaces encourage water entry to the pavement by capillary action.

$$C_U = \frac{D_{60}}{D_{10}} \quad \text{Eqn. 1}$$

Where: *D_{10} is the particle diameter corresponding to 10% passing*
D_{60} is the particle diameter corresponding to 60% passing

Table 1 – Aggregate gradation characteristics for base course specifications

Gradation type	**Source**	**Max. particle size**	**Percent fines**	**C_U**
Base course	Keller and Sherar 2003	37.5 mm	2 – 9%	75
Base course AP40	TransitNZ 2006a	37.5 mm	0 – 7%	35
Base course H	USDA 1979	38 mm	0 – 15%	43
Base course D	FHWA 1996	50 mm	4 – 8%	65
Base course 40a	Giummarra 2000	53 mm	4 – 10%	50
Base course No.1	Ryan *et al.* 2004	75 mm	0 – 10%	60

Table 2 – Aggregate gradation characteristics for surface course specifications

Gradation type	**Source**	**Max. particle size**	**Percent fines**	**C_U**
Surface course AP20	Main Highways Board 1938	19 mm	10 – 20%	240
Surface course	FHWA 1996	25 mm	9 – 16%	110
Surface course	Keller and Sherar 2003	25 mm	9 – 17%	80
Surface course D	USDA 1979	25 mm	3 – 15%	107
Surface course DSA	PSU 2006	37.5 mm	10 – 15%	160
Surface course 2	TransitNZ 2006b	37.5 mm	0 – 8%	67

The base course gradation specifications produce an average maximum particle size of 49mm, an average fines content of 2–10% and an average coefficient of uniformity of 55. By comparison, the surface course specifications produce an average maximum particle size of 28mm, an average fines content of 7–15% and an average coefficient of uniformity of 127. These results fit with the expectation that a base course should have larger aggregates and less fines, thus producing a layer that has high structural strength and resistance to capillary action. Similarly, the surface course specifications support the need for smaller particles and increased fines to help develop the required water and abrasion resistance.

The average characteristics from Tables 1 and 2 highlight the expected differences between base and surface course aggregate specifications. However, examining each specification in isolation shows a picture that is much less clear. Regardless of the parameters that are compared within the different gradation standards, we can see quite a range a values – indicating that even across the different standards, both between countries and within a country, there is very little consistency. Comparing these standards side-by-side produces a much wider 'combined' gradation envelope. This combined envelope is demonstrated below for both the base course aggregates and the surface course aggregates in Figures 4 and 5 respectively. For emphasis, the combined envelope is outlined in bold.

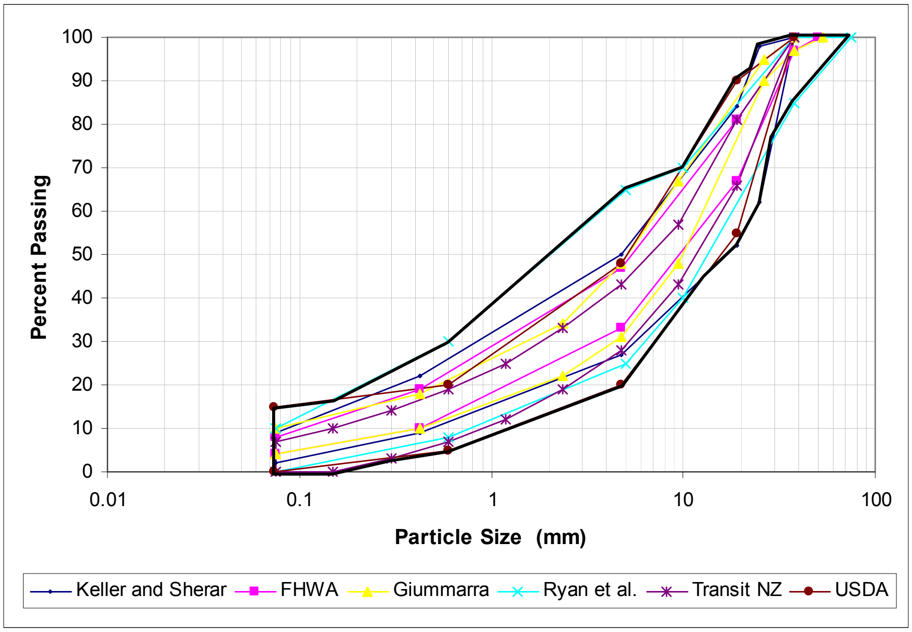

Figure 4 – Aggregate grading envelopes for selected base course standards

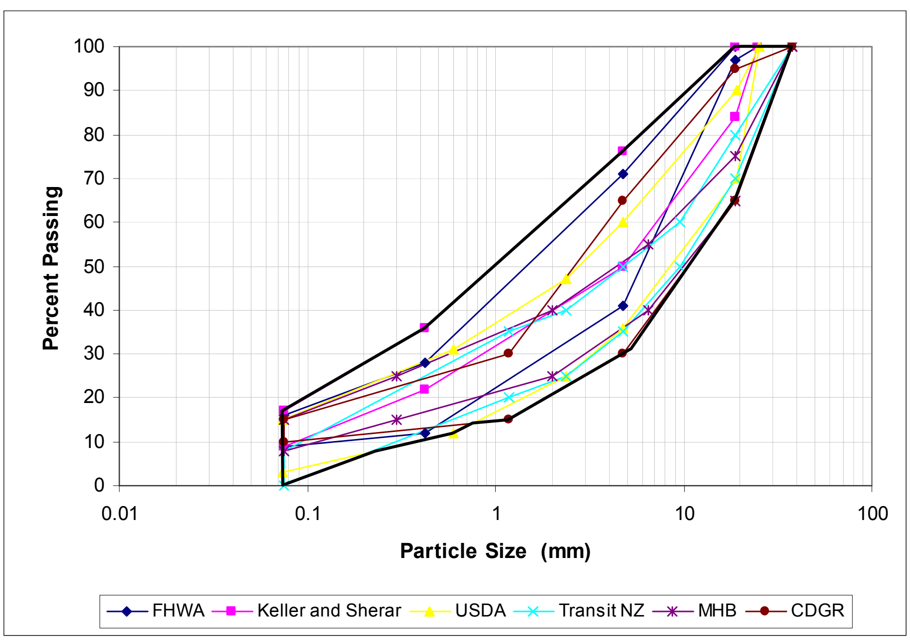

Figure 5 – Aggregate grading envelopes for selected surface course standards

The combined grading envelopes in Figures 4 and 5 appear, at first glance, to not be appreciably different to each other. Comparison of these two combined envelops, as shown in Figure 6, reinforces that the difference between surface course and base course grading specifications is not as apparent as the average characteristics extracted from Table 1 and 2 might suggest.

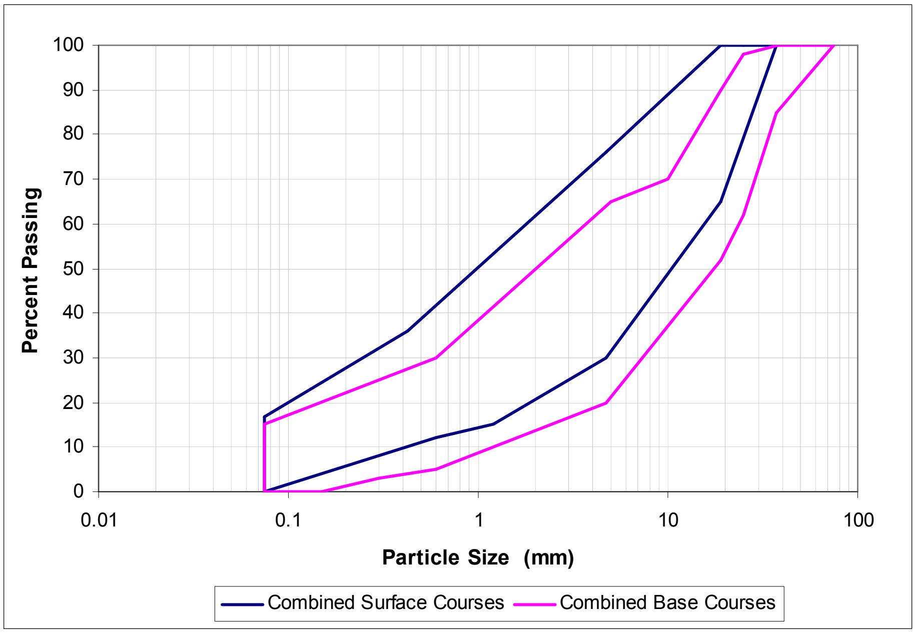

Figure 6 –Combined grading envelopes for surface course and base course aggregates

The considerable overlap between surface course and base course grading specifications highlights the difficulty facing forest managers when attempting to determine the most appropriate aggregate grading standard for their unique aggregate sources and forest road conditions.

Results from Testing of Aggregate Samples

Testing of eight forest road aggregates sourced from in-forest quarries and in-forest stockpiles in the East Cape region has been completed. The sampled aggregates were representative of materials being used during summer 2008/09 by three different forest managers as a combined base and surface course on East Cape forest roads (i.e. the East Cape forest managers were foregoing the traditional multi-layered pavement approach and had adopted the single improved layer approach). Minimum sample sizes of 25kg were collected for each aggregate and then reduced to sieving samples of not less than 5kg. Samples were wet sieved in accordance with NZS 4407 Test 3.8.1:1991 (Standards New Zealand 1991). The results from these tests are presented below as Figure 7. The combined envelope for surface course aggregates has been added as a grey shaded outline to provide reference to the reviewed standards.

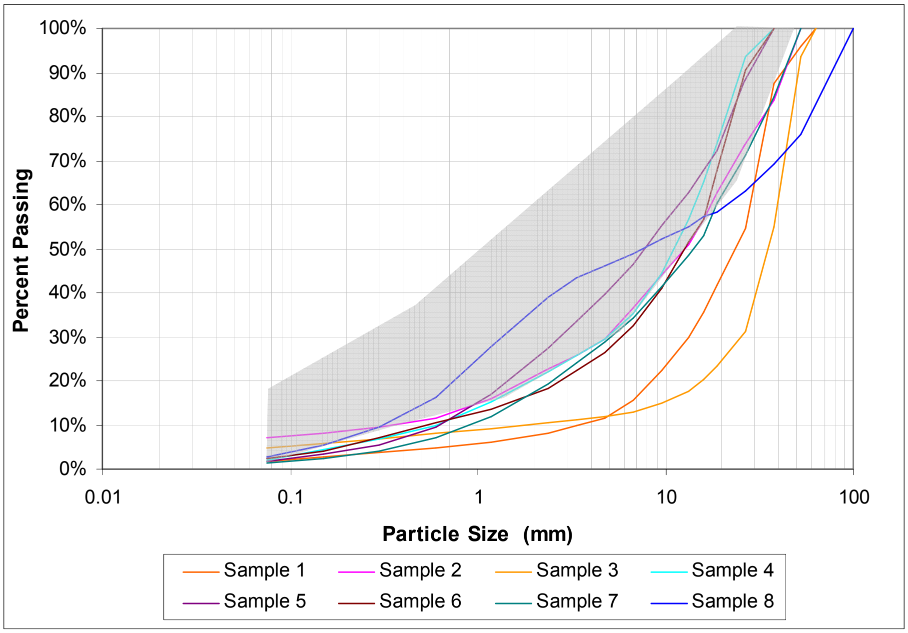

Figure 7 – Results from sieve analysis of east cape forest road aggregates

Analysis of the sieve test data shows that maximum permitted aggregate size ranged from 37.5mm to 100mm. The range of fines was from 1.4% to 7.2%. The coefficient of uniformity ranged from 8 to 73. These results show that a great variation exists in the grading of aggregates used on East Cape forest roads. Furthermore, most of the tested aggregates fall outside of the combined envelope for surface course aggregates – suggesting that the aggregates currently used in the East Cape region tend to use material that is too large and has insufficient fines to produce an effective surface layer.

However, the natural soil on which the roads are being built on the East Cape are predominately silty clays, dominated by fines. In most cases the natural soil is only lightly compacted, and very rarely are geotextiles or stabilisers, such as lime or cement, used to improve pavement engineering properties. The forestry companies recognise that over time the surface aggregates will be 'pushed in to' the natural soil to produce an aggregate/natural soil mix that acts as an improved layer. Further research is required to determine whether an existing aggregate grading specification, or a hybrid of several specifications, can produce a pavement that better meets the needs of an improved layer than the current aggregate does.

Conclusion

A formal survey of New Zealand forest roading engineers has commenced to determine the extent of current forest road engineering capability and deficiencies in New Zealand. Early results from this survey have identified conflicting views of what aggregate grading should be used for surfacing unsealed forest roads. A subsequent examination of a selection of aggregate grading standards demonstrated that the standards vary widely within and between countries. Furthermore, there is a considerable overlap between the specifications for surface course and base course aggregates. This variation and overlap between standards highlights the difficulty facing forest managers when attempting to determine the most appropriate aggregate grading standard for their unique aggregate sources and forest road conditions.

A range of East Cape aggregates was tested and found to have widely varied gradation. Furthermore, the tested aggregates fell outside of the envelope for surface course aggregates and, in some cases, also fell out of the envelope for base course aggregates. Further research is required to determine an aggregate grading standard that will best suit East Cape aggregate sources and conditions. This research will be conducted as part of the forest road engineering research programme underway at the School of Forestry, University of Canterbury.

Acknowledgements

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