The Stiffness Approach to Unbound Road Design with Geosynthetics

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ABSTRACT

Resource access roads present the extremes of problems associated with soft subgrades, extremely heavy axle loads, and very low traffic volumes. The very low cost tolerance associated with these roads has led designers to adopt access road structure designs using geosynthetics. Design methods which take *rut depth* as the key criterion exist. However, road *stiffness* has a large impact on vehicle operating costs and after all, the roads are built for the vehicles. Therefore, against the background of the significance of overall truck transportation system design and costs, considering the relationships between the roads and the vehicles using them, a long term project to examine geosynthetic-built access road *stiffness* was embarked upon. The results to date are presented.

1 INTRODUCTION

It's a well kept secret that the forest sector is Canada's most important industry, contributing more to the balance of payments than the next four sectors, *combined* (CPPA 1984). Transportation of the raw forest products to the mills is vitally important, and represents from ⅓ to ⅔ of the cost of obtaining the raw material, depending upon the site. On average across Canada, about ¾ of the movement of raw forest products to mills is accomplished by extremely heavy trucks (CPPA 1986), usually running on private access roads.

The road-building effort is stunning: on the order of 34,000 km of new forest road is constructed annually, over five times the length of public highway built (Douglas 1992). The roads are virtually always unbound structures, made of locally obtained materials, and if heavily trafficked, surfaced with crushed material or high quality pit run gravel. Asphalt or other bituminous surfacings are not used, as it is necessary to be able to "heal" damaged surfaces by scarifying and recompacting them.

The typical gross weights of the trucks used in these hauls continue to climb. Currently, it is not unusual to see off-highway trucks weighing more than four times what is allowed on public roads, with axle loads at least double the limits imposed on public roads.

These heavy vehicles are particularly sensitive to the rolling resistance generated at the tire/road interface. Second to grade resistance, rolling resistance is typically the next largest contributor to power requirement, and thus fuel consumption. It is unfortunate that the best stands of timber are often interspersed with peat and muskeg deposits: poor subgrades for roads carrying such heavy vehicles. Finally, the cost ceiling for resource access roads is very low: expensive road building can render harvesting operations infeasible.

The solution to this tangled problem of soft subgrades, extremely heavy vehicles, locally obtained materials, and low cost tolerance? Construction with geosynthetics.

2 THE GEOSYNTHETICS SOLUTION: PREVIOUS RESEARCH

A strong international research effort has been directed at the problem since the early 1980s. The research has been thoroughly delineated elsewhere (Douglas 1993, Douglas and Valsangkar 1992), however, it is worthwhile at least to outline the approaches that others have used.

The development of research approaches has passed through a couple of stages. Early work was concerned with the structural capacity of geosynthetic-built roads. Analyses were based on bearing capacity. Later research was concerned with how the development of ruts was influenced by the geosynthetic inclusions in the road structure. Design methods based on some relationship between rut depth, traffic, and the characteristics of the geosynthetic and the road materials were proposed. The designer's task is to determine the required granular base type, thickness, and geosynthetic type, based on some tolerable *rut depth* as the key design criterion.

This approach is an extension of the design approach used for more conventional bituminous pavements. Unfortunately, it is inappropriate for the design of the *unbound* pavements used by these enormous haul vehicles.

3 THE DESIGN PROBLEM: STIFFNESS RATHER THAN RUT DEPTH

Ruts are not a problem, in practice. Routine maintenance practices obliterate them. In addition, because of the sensitivity to rolling resistance, the road structure's *stiffness* is a far more important criterion to be accounted for in the design: fuel is a major component of the vehicle's operating cost; fuel is consumed partly to overcome rolling resistance; rolling resistance is influenced by road stiffness (as well as road roughness); therefore, road *stiffness* ought to be the key design criterion (Douglas 1993).

4 EXPERIMENTAL APPARATUS AND TESTS

The research programme was therefore directed toward studying the stiffnesses of geosynthetic-built unbound road structures placed on soft subgrades. Model tests were carried out at 1/10 and 1/3 scale in a steel box and concrete test pit, respectively. Repeated load tests were performed, where the same peak load was applied at a frequency of approximately 0.5 Hz, for up to 30,000 repetitions.

The test pit is approximately 3×4×2 m deep, and is provided with a gravel underdrain, filtered with a nonwoven geotextile. In test phases I and III, repeated sinusoidal loads were applied through a circular steel plate 0.3 m in diameter to the model road structures, using a Mayes servo-hydraulic programmable loading system, with the vertical load and average vertical displacement logged graphically on an XY plotter, or to hard disk by high speed digital data logging software. Road structures consisted of crushed rock or sandy gravel (Table 1), resting on a woven geotextile placed at the base/subgrade interface (Tables 2, 3). Some tests also employed a geogrid at mid-depth in the granular layer (Table 4).

The steel test box is 1.2×0.3×0.6 m deep, and is similarly equipped with a filtered underdrain. Repeated square wave loads were applied to a steel channel 75 mm wide resting on the model road surface, using a Bellofram pneumatic system with analog control. Again, vertical load and average vertical displacement were logged using the high speed digital system. The model road bases were made of a sand with $D_{10} = 0.2$ mm, coefficient of uniformity $C_u = D_{60}/D_{10} = 4.5$, and coefficient of curvature $C_c = D^2_{30}/(D_{60}D_{10}) = 1.3$. All tests performed in the box (test phase II) used a woven geotextile at the sand/subgrade interface (Table 3).

In all tests, the subgrades consisted of "reconstituted" milled horticultural peat. The peat has great advantages in such model studies, as very large volume subgrades can be produced rapidly and consistently, using a cycle of wetting, mixing, and draining first outlined by Jarrett (1984). The peat has a near-linear load-displacement response, and closely approximates Winkler behaviour.

Table 1. Phase I aggregate characteristics (after Douglas and Valsangkar 1992).

	Pit run gravel	Crushed rock
insitu water content (%)	0.0	2.0
insitu dry unit weight (kN/m^3)	15.2	18.5
standard Proctor maximum dry unit weight (kN/m^3) (ASTM D698[a])	---	20.7
optimum water content (%) (ASTM D698[a])	---	7.0
dry rodded unit weight (kN/m^3) (CSA CAN3 A23.2-10A[b])	17.2	---

[a] except that full range of grain sizes used
[b] except that vibration was used

Table 2. Phase I geosynthetic characteristics (after Douglas and Valsangkar 1992).

	Mass/unit area (g/m^2)	Tensile modulus[a] (kN/m)	Tensile strength[a] (kN/m)	Elong at failure[a] (%)
nonwoven geotextile (test results: ASTM D4595)	150	22.0/21.2	4.86/5.26	163/147
geogrid (manufact. literature Tensar 1987)	400	NA	15.0/15.0	NA

[a] machine/cross machine directions

Table 3. Phase II/III geotextile characteristics (after Douglas 1991).

Property	Value
(i) Manufacturer's literature: ("typical values, Terrafix 1991) (to CGSB standards as of Feb 1991)	
grab tensile strength (N)	525
tear (N)	308
elongation at break (%)	20
(ii) Measured in this test program: ASTM 4595-86	
wide strip tensile strength (kN/m) machine direction	15.0
wide strip tensile strength (kN/m)· cross-machine direction	13.5

Table 4. Phase I model construction details (after Douglas and Valsangkar 1992)

Designation	H/D	Base material	Geotextile at interface?	Geogrid at mid-depth?
PA1, PA2, PA4	0.0	--	no	no
RA3	0.5	loose pit run gravel	yes	no
RA4, RA5	0.5	compacted crushed rock	yes	yes

5 ANALYSIS OF RESULTS

The stiffness of the road sections was defined as the slope of the average vertical pressure-average vertical displacement plot. Stiffness *k* so defined was plotted against log(*N*), where *N* was the number of load repetitions. Such plots were produced for all peat subgrades, and for all model road sections. Figure 1 shows typical results (Phase I).

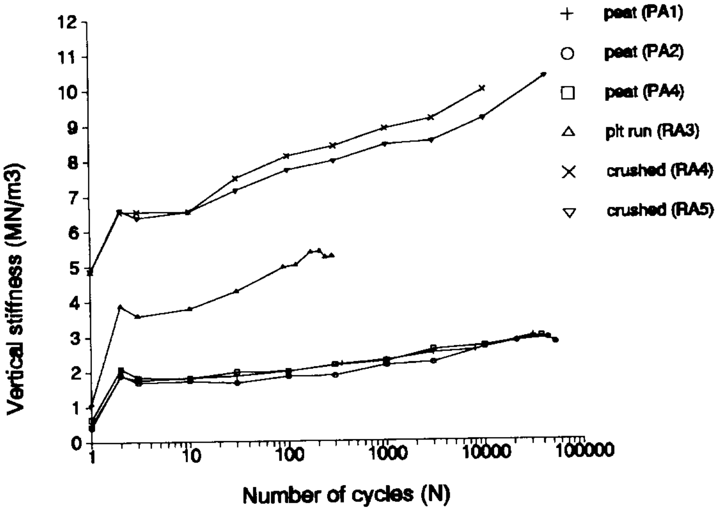

Fig. 1. Peat stiffness k_p and road section stiffness k_r vs log(*N*) curves: phase I results (Douglas 1993).

A dimensionless stiffness ratio, $K^* = k_r/k_p$ was defined, where k_r was the model road section's stiffness, and k_p was the peat subgrade's stiffness. This stiffness ratio is road section stiffness expressed as a multiple of the subgrade's stiffness.

When the stiffness ratio K^* was plotted against log(*N*), remarkably flat curves were produced, and it was considered that the stiffness ratio was essentially independent of the number of load repetitions. Therefore, *average* stiffness ratios were calculated, K^*_{av} for each model road configuration.

Model road section dimensions were expressed by two non-dimensional ratios. The thickness of the base was expressed by *H/D* or *H/B*, where *H* was the thickness of the granular layer, and *D* was the diameter of the circular plate in the pit tests ($D = 0.3$ m) and *B* was the width of the loaded strip in the tests conducted in the box ($B = 75$ mm). Further, in some cases in tests conducted in the pit, model road structures had a geogrid at mid-depth in the granular layer. The depth to a secondary geosynthetic was expressed by the ratio *h/D*, where *h* was the depth to the secondary geosynthetic.

A single non-dimensional parameter was used to account for differences in road cross sectional details. The "construction parameter" was defined $C^* = [(H/D)^2 + (h/D)^2]^{0.5}$ for the axisymmetric tests performed in the test pit, or $C^* = [(H/B)^2 + (h/B)^2]^{0.5}$ for the plane strain tests performed in the steel box.

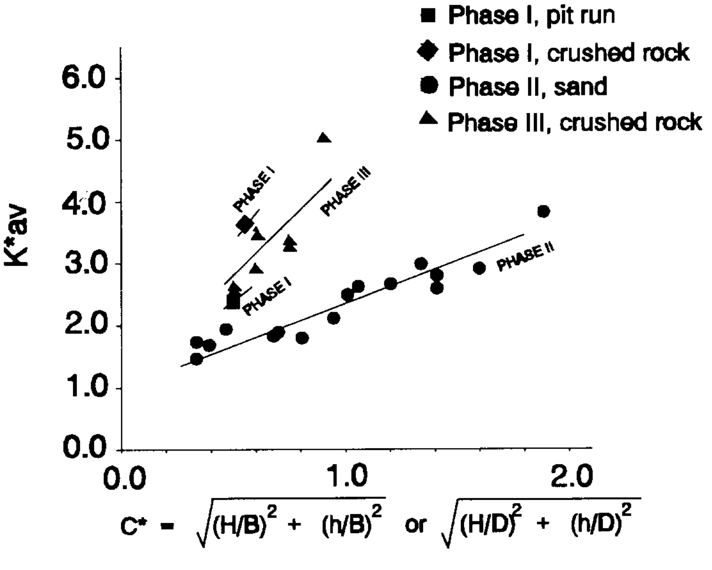

Fig. 2. Average stiffness ratio K^*_{av} vs construction parameter C^* for all tests (Douglas 1993).

Remarkable plots were produced when the average stiffness ratio K^*_{av} was graphed against the construction parameter C^*. Figure 2 shows the results for all tests conducted to date, including axisymmetric tests conducted at large scale in the pit (Phase I and Phase III) and plane strain tests conducted at small scale in the steel box (Phase II). In Phase II where a large number of tests were possible, a relatively straight line relationship is noted. The same sort of relationship can be envisaged for Phase III, although it must be noted that far fewer points were recorded. The two cases in Phase I had only single test values.

6 PROPOSED DESIGN METHOD

Figure 2 is the foundation for the proposed design method, based on road stiffnesses. In practice, *bearing in mind that roads are built for vehicles* the designer would have some minimum road stiffness in mind, which would result in some maximum tolerable rolling resistance. The subgrade stiffness would be determined or estimated. With these two stiffness values in hand, some target average stiffness ratio K^*_{av} would be established.

Design plots of K^*_{av} vs C^* would be consulted. The slopes of these plots (which also incidentally reflect loading type, plane strain or axisymmetric) varies with the type and condition of granular material used in the road base, and also the type of geosynthetic used. The value of the construction parameter C^* accounts for the base thickness and the presence or absence of a secondary geosynthetic, and its depth. Combinations of base material type, geosynthetic type, and granular depth could thus be assessed, to arrive at the least expensive, acceptable road design.

7 FUTURE WORK

Future work will continue on a number of fronts. It would be desirable to carry out a pilot study to develop a set of K^*_{av} - C^* curves applicable to one manufacturer's geosynthetics. All that is required for this is to carry out a battery of repeated loading tests as a parametric study, in order to generate the data needed to produce a pilot design chart. The chart could then be assessed in practical design trials.

Numerical models are contemplated which, once calibrated against the high quality physical model data produced to date, would reduce the need for extensive further physical model and field testing.

A three-parameter model, first assessed for use in predicting monotonic stiffnesses, has been examined as a candidate. The model assumes that the subgrade is a bed of perfect linear springs (the Winkler model), that the geosynthetic is a perfect tensile membrane incapable of sustaining shear, and that the granular base is a perfect shear layer (the Filonenko-Borodich and Pasternak models, Kerr 1964). To be valid, such a model must predict both the vertical stiffness, and the displaced profile of the base and/or geosynthetic. The three-parameter model would be attractive because it has a simple, closed-form solution. However, it has not been used successfully for either the prediction of monotonic stiffnesses (Douglas 1987), or for the repeated load stiffnesses.

It had been planned to report the results of attempts to predict the behaviour of the physical models using finite element software, which caters to geosynthetic elements. High quality model tests, where the stiffness was determined together with precise observations of the surface profile of the base as it deflected under repeated loading would be necessary to completely validate the finite element predictions. Unfortunately, the necessary displacement transducers and software had not arrived in time for the study to be included in the current paper by the submission deadline. It is hoped that preliminary results can be reported at the Conference proper.

Work will be undertaken in the summer of 1994, to begin to determine the geosynthetic-built road stiffness - rolling resistance relationship. Model tests will be carried out in the test pit described earlier, where the resistance offered to a rolling pneumatic tire will be correlated to the measured vertical stiffness of various candidate geosynthetic-built roads placed on the peat subgrades.

With these results in hand, it should be possible to begin to sketch in the complete picture of the relationship between tire behaviour, road structure design, geosynthetic attributes, and subgrade characteristics.

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