Advantage

Restricted to FERIC Members and Partners Vol. 5 No. 7 March 2004

Contents

Benefits of using a structural design catalogue for forestry roads

Abstract

Structural design catalogues enable road builders and field personnel to optimize aggregate thickness based on field conditions, thereby reducing overall road construction costs, increasing road performance, and reducing maintenance costs. Catalogue users can select a design suitable for a given level of road performance and traffic as well as for various subgrade and aggregate properties.

Keywords:

Road construction and design, Structural design catalogue, Thickness design, Subgrade, Base course, Aggregate.

Authors

Glen Légère
and
Steve Mercier
Eastern Division

Introduction

Few forestry companies in Canada use structural design models to design their roads, even though the benefits of this engineering approach can be substantial. Overdesigning a road represents significant costs, whereas underdesigning the road may result in poor road performance and costly repairs. Many mathematical models have been developed to facilitate the development of design catalogues for unpaved roads. The public sector has been using proven design models for decades, and has developed structural design catalogues tailored for specific conditions.

Using a design catalogue can reduce overall road construction costs by reducing gravel thickness, optimizing the use and delivery of existing gravel resources, increasing road performance, and reducing maintenance costs. The objectives of this report are to introduce the general concept of a structural design catalogue, to describe the potential benefits of developing a catalogue, and to provide general guidelines and steps to follow to develop a catalogue adapted to your operation's specific conditions.

Why would I need a structural design catalogue?

Applying too much gravel significantly increases a road's construction cost, but an insufficient thickness may increase future maintenance costs and decrease trucking productivity. A structural design approach allows cost-effective optimization of thickness and material choice. This approach speeds up the design, bidding, and approval processes, enhances budgeting accuracy, and lets contractors build roads that meet a performance standard selected by the company using site-specific materials.

The catalogue guides road builders through an objective approach to defining the appropriate thickness of each type of available aggregate given the aggregate's properties (strength), the properties of the subgrade, the volume and nature of the traffic, and the expected performance and reliability of the road. The options proposed in the catalogue guide the choice (for example) between a thinner layer of high-quality aggregate and a thicker layer of lower-quality materials; the nearest gravel source may not always prove to be the most cost-effective. The catalogue may also recommend options such as the use of geosynthetics, soil stabilization, corduroy, and brush mats.

A catalogue can take various forms, such as graphs, tables, and spreadsheets. For example, the design chart in Figure 1 illustrates the difference in required base-course thickness between a poorly graded sand (SP) and a well-graded gravel (GW) on a soft subgrade for various traffic levels. In this example, the required thickness to provide the same performance differs by more than 100% (300 versus 150 mm), based on 3000 round trips with a loaded truck. If the cost of a poor quality material (e.g., SP) is $5/m³ (a pit close to the construction site), higher-quality material (e.g., GW) could be hauled from farther away (e.g., $9/m³) and still provide equivalent performance at a lower cost. Similar charts can be produced for the various combinations of materials and haul distances encountered in a given operation.

If developing a typical design catalogue costs approximately $30 000, a company can quickly recover this cost by saving 6000 m³ of gravel (at $5/m³). For a company such as Tembec (Kapuskasing division) that hauls 60 000 m³ of gravel per year, this cost represents only 10% of their *annual* volume. The cost of the catalogue can also be shared by several divisions with similar operating conditions and spread out over a few years. Once the cost of the catalogue has been recovered, ongoing savings in gravel costs increase net revenue. FERIC plans to report on the return on investment from using a structural design catalogue in a future implementation project with a member company.

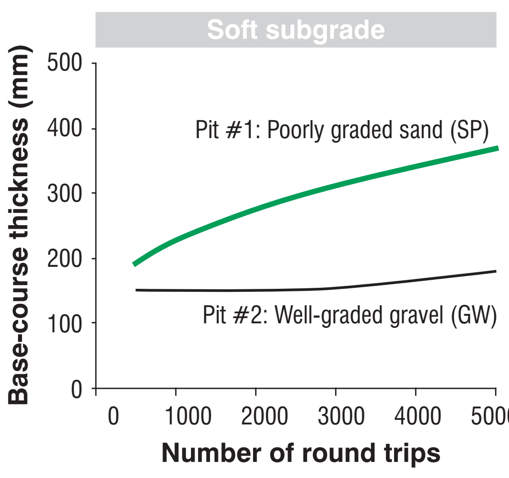

Figure 1. Example of a thickness design chart for two different base-course materials on a soft subgrade at various traffic levels.

Implementation: how to build a catalogue

The development of a catalogue requires some investment and effort to collect detailed information on the materials available from various pits. This data provides the underlying criteria for your design, and as such must be of adequate quality and precision; therefore, we recommend it's production be entrusted to a geotechnical or road-design engineer. The

Forest Engineering Research Institute of Canada (FERIC)

Eastern Division and Head Office
580 boul. St-Jean
Pointe-Claire, QC, H9R 3J9
(514) 694–1140
(514) 694–4351
admin@mtl.feric.ca

Western Division
2601 East Mall
Vancouver, BC, V6T 1Z4
(604) 228–1555
(604) 228–0999
admin@vcr.feric.ca

Find us Online! www.feric.ca

Publications mail #40008395 ISSN 1493-3381

remainder of this section describes the basic steps required to build a structural design catalogue. FERIC can provide further assistance in its development, ensuring that it is tailored to your needs. Please contact the authors for details.

Choose a design model

Few models currently exist for the structural design of unpaved roads. We believe that the STP program (USDA 1996) offers one of the most appropriate solutions for forestry use because it uses a two-layer approach (i.e., subgrade and surface layers) and can account for the use of variable tire pressures. The design method described by AASHTO (1993) can also be used for multi-layer design (three layers).

Determine the type of road

The following data must be known to calculate aggregate thickness with various design models:

Traffic levels

The level of traffic over the road's working life is a primary consideration. Although the total wood volume hauled or total number of trucks both provide an indication of the stress that will be imposed on the road, calculations should ideally be based on a standard unit. The primary unit used to predict road life represents the cumulative number of repetitions of an "equivalent single-axle load" (ESAL) expected during the road's working life. One ESAL unit is defined as the potential road damage caused by an 18 000-pound (80 kN or 8164 kg) single-axle vehicle with dual wheels. Many equations have been developed to calculate ESAL values for various axle configurations and tire pressures (Copstead 1991, Haas 1997, USDA 1996).

Serviceability

In all design models, users must define the limit after which reconstruction or major maintenance is required ("terminal serviceability"). For unpaved roads, failure is defined as permanent deformation (rutting), and the presence of this failure indicates a loss of serviceability (i.e., whether the road surface remains usable). A 2-in. (50 mm) rut depth is commonly used as the terminal level of serviceability for *primary* unpaved roads (AASHTO 1993, USDA 1996). However, deeper ruts (3 to 4 in. = 75 to 100 mm) may be acceptable for *secondary* and *tertiary* roads. Although other surface distress problems such as potholes may also determine terminal serviceability, they are not normally considered in the design models.

The overall purpose of the base-course layer is to spread the applied loads and diminish stresses on the subgrade sufficiently to prevent its deformation and minimize surface rutting. Unfortunately, current design models do not consider the influence of maintenance in the equations used to model aggregate surfaces. However, optimizing grading to eliminate rutting increases the traffic volume at which rutting begins to develop and thus provides a higher *reliability* level during the road's design life.

Reliability

The reliability of a road design represents the probability that the road will perform as anticipated over the design life despite variability in the input variables and environmental conditions. To simplify and to ensure that even the worst areas are properly built, designers should generally design to account for the weakest terrain along the road (e.g., poorly drained subgrades) rather than the average condition;

if conditions vary greatly, consider using different designs to compensate for short, weak stretches, optimize overall safety factor, and reduce the overall cost.

Characterize the subgrades

The ability of a subgrade to support loads transmitted by the aggregate layer is an important factor in determining aggregate thickness. Thus, subgrade conditions must be well documented by choosing a representative sampling area. Subgrade strength depends on the soil's characteristics (closely related to its soil classification), density, moisture content, and plasticity. The California Bearing Ratio (CBR) is one widely used design value. An excellent subgrade has a CBR value approaching 30, versus values <1 for a poor subgrade into which your boot would sink as you walked. Hard-packed, crushed-aggregate running surfaces reach CBR values >80 even in a *soaked* state. Figure 2 presents a range of CBR values for various soil classifications.

The CBR value of the subgrade can be determined through laboratory testing or actual field measurements. The preferred method is to use values obtained in the field during the time of year when vehicles will use the road. For field measurements of subgrade strength, USDA (1996) recommends devices such as the dynamic cone penetrometer (DCP; MDOT 1993) and the Clegg Impact Soil Tester (the "Clegg Hammer"; Clegg 1985). Soil samples should also be collected to represent all regions and types of subgrade along the road and classified using the Unified Soil Classification System (USCS; ASTM 2000, Hamilton 2000) or another proven system. The moisture content should also be documented, especially for cohesive soils (clays

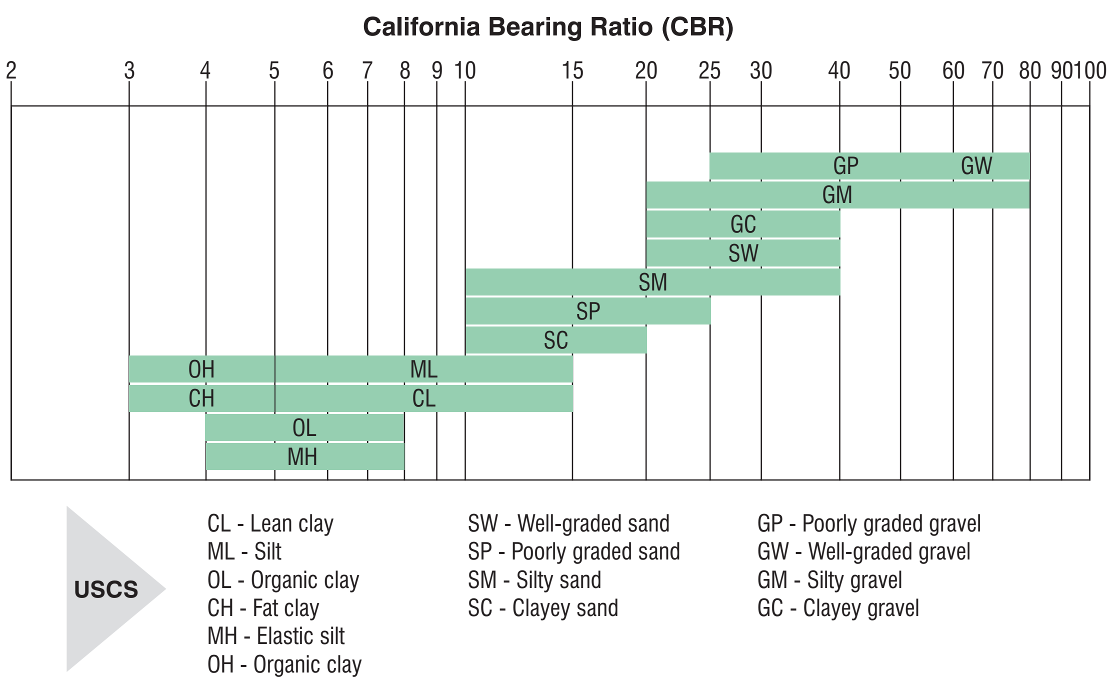

Figure 2. Range of CBR values for various soil types defined in the Unified Soil Classification System (adapted from APAI 2003).

and silts), as it can significantly affect strength. It is extremely important to keep water away from the subgrade, by providing adequate cross-drainage, building proper ditches, and avoiding construction on low ground with a high water table.

Characterize the aggregate sources

A catalogue must list the location of aggregate sources (pits), pit size, and the correct soil classification and mechanical properties (i.e., strength) of materials obtained from these sources. The strength of the base course depends mainly on the aggregate gradation, particle shape, aggregate quality, compaction, and (to a lesser degree) moisture content and plasticity of the material (USDA 1996). Strength can be determined through laboratory testing. The methods described above to obtain *in situ* subgrade strengths can also be used, although each instrument has its limitations depending on the type of soil and compared with laboratory tests. When producing crushed material, select appropriate aggregate specifications (Légère and Mercier 2003). If the base-course material (the structural layer) is also used as the wearing course, increase the thickness of this layer to account for aggregate loss and deterioration (i.e., wear). In this case, the base-course thickness should be at least twice the maximum particle size. Adequate surface crowning (usually 4 to 6%) must also be maintained to ensure proper surface drainage.

Build your catalogue

A catalogue can take the form of a series of design charts for different subgrades or regions (Figure 1), a series of tables, or even a spreadsheet. The inputs (e.g., traffic, serviceability, reliability) should be reviewed by experienced roads personnel to ensure that the chosen parameters reflect each operation's unique needs. The objective is to provide an easy-to-use decision-support tool tailored to your needs and operating conditions. The data used to generate the catalogue will grow with time and the catalogue will become more accurate after field validation of the initial results. To ensure that the catalogue's quality improves, monitor the performance, construction cost, and maintenance cost of roads designed based on the catalogue. Collect field data on soils and road conditions (e.g., moisture content, drainage problems, rutting, and failure) during the time of year when vehicles use the road. Finally, calculate the return on investment for your catalogue by keeping track of the costs of producing and implementing the catalogue and the savings that result from using it.

Acknowledgments

The authors thank Mark Stanley for participating in the development, implementation, and ongoing validation of a design catalogue developed by FERIC for the northeastern Ontario divisions of Tembec Industries Inc.

References

AASHTO. 1993. AASHTO guide for design of pavement structures. American Association of State Highway and Transportation Officials, Washington, DC. 322 p.

APAI. 2003. Asphalt paving design guide. Asphalt Paving Association of Iowa, West Des Moines, IA. 125 p.

ASTM. 2000. Standard practice for classification of soils for engineering purposes (Unified Soil Classification System). American Society for Testing and Materials, West Conshohocken, PA. Standard D-2487-00. 12 p.

Clegg, B. 1985. Clegg impact test guidelines. The University of Western Australia, Dept. of Civil Engineering, Nedlands, Australia. 25 p.

Copstead, R. 1991. Using the region 6 surface thickness program to predict some effects of tire pressures on roads. USDA Forest Service, San Dimas Technology and Development Center, Pacific Northwest Research Station, San Dimas, CA. 4 p.

Haas, R. 1997. Pavement design and management guide. Transportation Association of Canada, Ottawa, ON. 389 p.

Hamilton, P. 2000. The dirt on gravel: identifying soils you can use for road construction. For. Eng. Res. Inst. Can. (FERIC), Pointe-Claire, QC. Advantage 1(11). 8 p.

Légère, G.; Mercier, S. 2003. Improving road performance by using appropriate aggregate specifications for the wearing course. For. Eng. Res. Inst. Can. (FERIC), Pointe-Claire, QC. Advantage 4(13). 6 p.

MDOT. 1993. Users guide for the dynamic cone penetrometer. Minnesota Department of Transportation, Office of Materials Research and Engineering, Physical Research Section, St-Paul, MN. 13 p.

USDA. 1996. Earth and aggregate surfacing design guide for low volume roads. USDA Forest Service, Engineering Staff, Washington, DC. 301 p.