Developing Appropriate Engineering Responses to Seasonal Effects for Pavements Serving Remote Communities

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Abstract

The roads that connect remote communities with other communities, and particularly with urban areas, are crucial for the economic and social survival of those remote communities. They do not experience high traffic volumes, but must remain open to traffic continuously at all seasons even if the ride quality is somewhat diminished. Yet the revenue available to fund pavement maintenance and reconstruction is very little given the length of road to be maintained and the small taxation base. This paper therefore gives particular attention to overcoming and/or reducing the impact of the spring-thaw weakening problem, particularly as it results in rutting. Consideration is given to drainage needs and to sensing and predicting areas which are likely to be problematic and to justifying adequate funding for pavement maintenance on the basis of socio-economic benefits.

Introduction

The northern periphery of Europe is an area of sparse population. People are usually concentrated in small coastal towns and villages, with fishing, forestry and, in some locations, tourism providing the main sources of employment and the backbone of the local economies. Whilst very self-sufficient compared to towns closer to the urban areas further south in Europe, yet these remote communities depend on efficient access. Fish and fish products, wood and wood products must be transferred to their main markets which are much further south, while tourists from those market centers must be able to access the remote areas. Health and education provision and supplies must all be brought in.

There is a strong political will to encourage these peripheral communities to prosper and for rural depopulation to be prevented. Yet there are many hindrances to this, not least of which is the economic provision of the road infrastructure. To connect remote communities with each other and their markets, roads have to traverse rugged landscapes. These roads are often long and tortuous, cross very poor subgrades, have poor alignments (hindering drainage), can’t be built of high quality road building materials (as quarries may be at a large distance) and are required to
operate in, seasonally, extremely cold or extremely wet conditions and suffer high rainfall. Thus deterioration rates tend to be fairly high due to the economic initial construction, the harsh weather and the high axle loads necessary to economically access markets and services. Yet these practical issues are not the only ones of concern. The increasing use of economic models of road financing, applied to the low-volume use of these remote roads, leads road authorities to preferentially fund high-volume pavements further south. Furthermore, local taxation will, given the high length of the roads and the low population volumes, inevitably be small per kilometer, preventing this from being a significant alternative revenue source.

For these reasons an international pavement engineering team was established (see ‘Acknowledgements’) with funding from the European Union to more efficiently address pavement problems in the study areas. Known as ‘Roadex’, the first project largely addressed winter maintenance issues [1]. This paper reviews aspects of the work of RoadexII [2], particularly as regards spring thaw damage issues. Figure 1 shows the RoadexII study areas.

**Improving Pavement Materials and Subgrades**

The chief distress that is observed in low-volume roads is rutting. Some develops year round, but the greatest is seen during spring-thaw when the aggregate in the upper layer is thawed due to warmer weather but when the lower subgrade and margins remain frozen due to being buried, respectively, under the upper pavement layers and under snow banks and soil. Typically the road surfaces are repaired each spring by reshaping the wearing course material such that it is common, after some years, for the thin structural layers to have become mixed together with the subgrade material.

To establish whether non-traditional, but commercially available, chemical treatments (enzymes, polymeric additives, surfactants, etc.) can help to prevent such rutting, several were applied to typical unbound materials. Figure 2 shows some sample results for treated and untreated aggregate. It can be seen that, when aggregate was frozen, thawed and then tested in a repeated triaxial test according to the SHRP P46 [3] test protocol, permanent deformation builds up quite rapidly for the untreated material but a polymeric additive largely halts this. Overall it was observed that:

- Most treatment agents require a great proportion of fines to be efficient,
- Many treatment agents require fairly long curing/drying times,
- Enzymes and ionic stabilizers may be efficient on fine grained soils, but not on coarse,
- Some polymer stabilizers show promise in reducing the effects of moisture and freeze-thaw cycles on permanent deformation development (e.g. Figure 2).

Many treatments, therefore, will not be applicable for aggregate layers in seasonal frost areas.

**Limiting Rutting upon Spring Thaw**

Permanent deformation in aggregate layers was assessed further using a simple-to-perform Tube Suction test [4] and repeated load triaxial tests. Table 1 summarizes the main properties of the most important aggregate types used. They were compacted at near-optimum moisture condition. Some were then allowed to suck water in from a supply at the specimen base and some were then frozen and then allowed to thaw. A moderate quality metamorphic
aggregate from Scotland (“Quarriebraes”). a crushed base course and a gravel sub-base (both from Koskenkyla in Northern Finland) were assessed.

Most of the repeated load triaxial tests were performed according to a test procedure specifically developed to simulate the effects of seasonal variations including a freeze-thaw cycle [5]. Results similar to that shown in Figure 2 were obtained from the triaxial tests. A loss of quality upon freezing was apparent. It appears to be mostly due to increased water content caused by suctions developed during freezing and only a little by de-densification due to ice formation. It is not clear from the testing whether fines in the mix always have a direct effect (though sometimes they do), but they certainly have a secondary effect, allowing the aggregate to hold more water and this leads to much more rapid build-up in plastic strain development. This ability to hold water, due to capillary suction, is undesirably exploited on freezing because cryosuction effects, which act at the freezing front, are able to pull in more and more water, if it is available, from the edge or bottom of an aggregate layer.

Data such as that presented in Figure 3 shows how the rate of accumulation of permanent deformation increases with stress level – that is, how close to the static failure stress is the repeatedly applied stress state. Accordingly, it would be sensible, for design purposes, to ensure that the stress experienced by the pavement doesn’t exceed a certain fraction of the failure stress in order to reduce the rate of deformation accumulation (and, hence, rutting) to an acceptable level. Previous researchers [6] have suggested a ratio of $q/q_f = 0.7$ – i.e. the deviatoric (or shear) stress applied, $q$, is limited to 70% of that needed to induce static failure, $q_f$, under, in other respects, the same stress conditions. The data obtained in Roadex tended to confirm this, but indicated that this limit should be set at 50-55% (of the failure condition of the aggregate at optimum moisture condition) when the aggregate is very wet and fines prevent rapid drainage [5, 7]. A non-linear finite element program, was thus used to compute the stress in pavements made from the tested materials and a simplified chart-based stress analysis formulated to allow the stress applied and that tolerable to be compared and, hence, design against rutting to be achieved. A further simplification was to adopt in-situ testing to replace the triaxial test.

**Drainage**

From the foregoing, and from experience, it is clear that reduction of water in the pavement is a priority. In cold climates ice and snow cause particular problems blocking ditches and culverts during spring thaw when rapid drainage of water from the pavement and rapid clearance of ice and snow melt is important to restore pavement performance. To ameliorate problems it is advisable to clear ditches in the fall and to insure that ditches are faced with coarse graded aggregate that will help to prevent sloughing of weaker embankment and cutting face materials into the ditch during the thaw season.

Site studies clearly showed the greater rutting which occurs on the uphill side of roads which traverse sidelong ground. For example a 9km length of road Rv 858 in the Nord region of Norway has been measured to rut at a mean rate of approximately 1mm/year on the upslope side of the pavement and only 0.4-0.5 mm/year on the downslope side. Road HW21 near Kilipsjärvi (Finland) yielded figures of 2 and 1 mm/year respectively for the same situation. Road Rv 861 on the Norwegian island of Senja showed 21.6mm of rutting in 13 years on the upslope side and only 12.7mm on the downslope side over a 1.2km length. 10% of this pavement had ruts greater
than 33.9mm on the upslope side but the corresponding downslope rut depth was only 23.4mm. Over a 155km distance of low volume national roads in Norway, mean rut depth increase per year was 1.06mm in cuttings, 0.98mm on sidelong ground and 0.72mm on embankments. The 90%ile values were, respectively, 1.61, 1.48 and 1.08mm. Taken together it is clear that proximity to the water table is a key issue.

Drainage has the possibility of improving matters, not so much in draining water during spring thaw but in limiting water availability in the fall thereby reducing the amount of water which will be frozen into the pavement over the winter. At the commencement of thaw, the drains may well remain blocked and ineffective, but they are expected to reduce the length of the thaw weakening period as they begin to function at the end. Monitoring of gravel roads in Finland showed a 53% reduction in spring thaw damage the year after drains were installed, but this reduction diminished to only a 24% improvement 5 years after drain installation. This, and other, more anecdotal, studies suggests that drain cleaning / restoration every two years is almost always economic.

**Hindering Thaw Weakening**

**Classifying Thaw Phases.** On thawing the free moisture content in the pavement and subgrade rapidly rises, softening these layers and allowing them to rut under traffic loading. Dielectric measurements were taken at several sites as a means of monitoring this change [8]. As free water appears on thawing, the dielectric value of the ground rapidly rises due to the much greater dielectric value of water than ice. Figure 4 shows the clear relationship between the dielectric reading and temperature. This change in water condition / dielectric property was also monitored with ground penetrating radar. From these measurements and a series of surface observations it was noted that the following thaw phases could be defined:

1. Freeze-thaw cycling phases occur during fall when short freezing periods are followed by warmer periods. One factor affecting the severity of the following spring thaw weakening is the number of freeze-thaw cycles that occurred during the fall and how shortly after these cycles the road begins its final freezing process, as water can then get frozen in place.
2. Spring thaw commences with a surface weakening phase when air temperatures rise above zero and the wearing course starts to thaw and may become plastic. GPR surveys revealed that surface thaw weakening is often concentrated where wearing course thickness is greater than 150 mm.
3. Next, a deep, structural, thaw weakening starts as the frost thaws deeper in the road. The main cause of softening is thawing of ice lenses producing excess water. In many cases, the ditches are filled with snow or ice at this time so the structure is only able to dry slowly through evaporation.
4. A fourth phase is when a frost susceptible subgrade is thawing. If the water permeability of the subgrade is low then silty and clayey subgrades can become plastic and can flow.
5. Early during the thaw, under thin surfacings, dynamic loads can cause high water pressures in the underlying layers such that, if the pavement is not porous enough or the bound layer not stiff enough, severe cracking, potholing, delamination or deformation of the surface can result.
Classifying Affected Sites. Based on surveys conducted in the Vaasa Region of Finland [9] and in this project, the following spring thaw site classification is proposed for gravel roads, by subgrade type and road topography:

A. Moraine subgrade in a low lying and wet valley
B. Moraine subgrade soil in wet and transversely sloping ground
C. Frost susceptible morainic hummock
D. Peat sites
E. Bedrock related damages
F. Silt or clay subgrade in a flat and even area
G. Silt or clay subgrade in a low lying and wet valley
H. Silt or clay subgrade in transversely sloping ground
I. Other sites

In addition to this classification classes A-I are divided into three (1-3) subclasses depending on the recorded severity of the spring thaw damage:

1. Mild problems: spring thaw problems are not severe and do not occur annually,
2. Medium problems: light or medium severe thaw problems are found almost every spring,
3. Severe problems: medium or severe structural thaw problems are monitored annually.

When damage does occur a systematic monitoring approach is used in Finland for gravel roads. A visual evaluation of spring thaw damage is used to divide road sections into 4 classes based on damage severity. A guidebook is provided to help field crews with the classification. These classes are:

Class 1: Driver must almost stop the vehicle to check road is passable. The vehicle bottom could touch the damaged road surface. The road structure has been severely mixed.
Class 2: Driver must lower his speed appreciably when passing the damaged section. The road surface has squeezed out and plastic soft spots force the driver to select a driving path.
Class 3: The road structure, for the most part, has adequate bearing capacity, but drivers need to reduce their speed slightly due to deformations and softened areas.
Class 4: Very slight spring thaw damage.

The results have proven to be quite reliable and they have provided the Finnish road administration with an excellent perspective on the total length and severity of spring thaw damage in the country. As the load restrictions are imposed locally by the area road supervisors, it would seem that this approach has indirectly led to reduced spring damage (Table 2).

Monitoring & Managing Roads to Limit Damage. It is highly desirable to use information on thaw-affectable sites and the type of thaw problems experienced, to control trafficking during the spring-thaw period. Different countries adopt different strategies: no restriction; closure for a period based on local or regional meteorological data; restrictions based on local experience; and restrictions generated from buried temperature sensors and displayed locally and at diversion routes. In the future, trafficking restrictions are likely to be based on temperature sensor data supplemented with that from dielectric and water table sensors (already trialed) and in-situ GPR, Falling Weight Deflectometer and Dynamic Cone Penetrometer data all processed though some kind of expert system. It may also be advantageous to use driver-collected observations on the progress of thaw to add detail and to fill-in road condition between sensor locations.
Improving Funding

Available socio-economic models to describe pavement maintenance requirements (e.g. HDM 4 [10]), normally deal with road user costs consisting of time delay costs, vehicle costs and accident costs. As the amount of traffic is always the dominating figure in the calculations, the models always favor a very good condition of high volume roads and barely keep the low volume roads alive. In order to give people living in rural areas better social conditions, the Roadex II project sought to find ways to include the significance of the rural road condition. In particular there is a need to take a closer look at the social improvements, due to roads, that accrue for people living in rural areas if road conditions are to improve due to better funding. The study therefore investigated several approaches / policies for encouraging a more holistic response, recognizing that successful approaches should deliver:

- target limits for (e.g.) roughness, rutting and bearing capacity, usable by contractors in road maintenance contracts,
- social acceptability in funds dispersal,
- practical methods of evaluation and computation, and
- definition of a lowest acceptable road condition properties - so called “shame values”.

Of the available approaches mention may be made of the Norwegian socio-economic model, HIPS [11], that is used to find the optimal long-term road condition at network level - when the total costs for the society are the lowest. The total costs are the sum of the road manager’s costs to maintain and to improve the road condition, and the road user costs (time, vehicle operation, accident and road works delay costs). Using this approach since 1995, there are now almost no temporary load restrictions in Norway at spring thaw; the model indicating that the costs of damage to the road system due to trafficking while it is thawing are more than offset by the societal savings resulting from keeping the road open.

Scotland has found ways to preserve and develop small communities in rural areas by defining “Fragile Areas” [12]. These are identified by means of properties like population density, long term unemployment and income support by government. Lifeline rural roads have also been identified as “Transport links which have no substitute … where any diminution in the quality, reliability or availability of the [link], is likely to have a significant impact on the social or economic viability of an affected community.” In the project, nine key roads were appraised on this basis according to the Scottish Transport Appraisal Guidance (STAG) [13]. Several of these roads were found not to be in a ‘fit-for-purpose’ condition, i.e. unable to give sustained economic and social prosperity in the societies served. Additionally many of the proposed road schemes will give indirect benefits like increased employment, reduced transport costs and better accessibility to markets and customers.

There is also a need to look at the health impacts, especially for professional drivers as major impacts are caused by the road surface irregularities [14]. Based on the results from a field study and a literature survey a “shame level” for the roughness expressed as IRI is recommended. The recommended value, as an average of 20m, is $\text{IRI}_{20} < 3 \text{ mm/m}$.
Conclusions

It is clear that moisture, drainage, frost damage (particularly in respect of rutting), construction material and funding level all have major influences on the behavior of the low volume pavements which have such a critical role in the survival of communities in the northern periphery of Europe. Probably these same issues will affect pavements in other places which serve population centers in remote, cold or rain affected areas. Only by considering all aspects can sensible maintenance strategies be involved which will have general acceptance by users, communities served and road authorities. The study has shown that technological measures need to be appropriately applied and coupled with the input of all stakeholders. Only then can their adoption, with an adequate engineering and socio-economic understanding, deliver a road network that is maintainable for its purpose, year-round.

Acknowledgements

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References

Various authors, 2001, Final reporting, project CD - ROADEX I, Northern Periphery. See www.roadex.org.
Various authors, 2005, Final reporting, project CD - ROADEX II, Northern Periphery. See www.roadex.org.
Table 1: Aggregate materials used in triaxial and tube suction testing.

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<th>Code</th>
<th>Moisture Content (%)</th>
<th>Fines Content (%)</th>
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<tr>
<td>Quarriebraes Wet</td>
<td>Qb</td>
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Table 2: Total length of monitored spring thaw damage on gravel roads in Finland 1998 – 2003.

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<td>876</td>
<td>949</td>
<td>1000</td>
<td>464</td>
<td>252</td>
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Figure 1  Study areas (hatched) of (Left-Right) Scotland, Norway, Sweden and Finland. Shaded but un-hatched areas are also parts of the EU’s Northern Periphery, but were not part of the project reported here.

Figure 2  Permanent deformations measured during the resilient deformation test following a freeze-thaw cycle - Lillby aggregate (Nord region of Norway).
Figure 3  Plastic strain rate information obtained from test on Quarriebras Qc material (saturated, high fines).

Figure 4  Dielectric values versus temperature profiles at the Koskenkylä Percostation site in Finland, note unfrozen water between 0 and -2°C (after [8])