

Road Condition Management of Low Traffic Volume Roads in the Northern Periphery



ROADEX SUB PROJECT A PHASE I
STATE-OF-THE-ART STUDY REPORT



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PREFACE

When Roadex project was initiated the goals, given by the Steering Committee for sub project A (SPA) were to look for the best practices in the field of low traffic volume road condition management, focusing especially on ways to optimize the use of traffic restrictions or to minimize the damages to the road network if restrictions are not applied. Apart from surveying technical solutions used across the partner road districts, the work group was also given the goal of comparing different monitoring and decision making practices when dealing with bearing capacity problems. The project has two phases: phase I: state-of-the-art study which was concluded in 1999-2000 and phase II: field tests focusing on best practices during 2000-2001. The final report in a form of multimedia CD will be prepared during 2000-2001.

The Roadex steering committee nominated Timo Saarenketo from Roadscanners Oy, Rovaniemi, Finland to be the Sub Project A (SPA) work group chairman. The other nominated work group members, representing each district, were: Stuart Bell from The Highland Council, Scotland, who is the committee secretary, Geir Berntsen from Troms County, Norway, Peder Henriksson (1999) and Sara Sundberg (2000 -) from the Northern Region, Sweden and Erkki Vuontisjärvi from Lapland Region, Finland.

The SPA work group has been very active, it has had meetings in Rovaniemi, Luleå and in Inverness in 1999 and in Tromsø and Kukkolaforsen in 2000. The biggest project the work group has accomplished is the completion of a questionnaire focusing on the general information about the partner districts and their areas as well as

national practices on road and rehabilitation design procedures, material specifications and about heavy transport and load restrictions. The work group has also arranged seminars and interviews in each partner district, excursions to monitor and compare the road condition, as well as visits to special test sites in each district.

This state-of-the-art report, which completed phase I is based on questionnaire answers, interviews and field trips in each partner district as well as a literature review. The report covers only a small part of the extensive data collected by the work group and this data will be published in the final report. Work group members representing partner districts have prepared data and the text for the national practices and techniques. Ulla Maijala from Roadscanners has arranged and preprocessed the data. This report is edited and written by Johanna Saari and Timo Saarenketo and the language has been amended by Kent Middleton, all from Roadscanners Oy. Several people in each partner district have also helped with this report and a special thanks is addressed to them. Roadex Project Steering Committee and its chairman Tapani Pöyry have provided encouragement and valuable guidance for the work.

Rovaniemi July 16, 2000

Timo Saarenketo, chairman

ROAD CONDITION MANAGEMENT OF LOW TRAFFIC VOLUME ROADS IN NORTHERN PERIPHERY AREA



1. INTRODUCTION - THE PROJECT

1.1. Roadex Project

The road districts of Lapland in Finland, Northern Region in Sweden, Troms County in Norway, and the Highlands in Scotland have initiated a technical, transnational collaboration. The aim of this collaboration is, through the exchange of experience, to identify best practice strategies and develop procedures in order to deal with common challenges associated with the maintenance of low traffic volume road networks in sparsely populated northern regions.

The Roadex project is partly financed by an EU (ERDF, Article 10) funded Northern Periphery Programme, which is a cooperation between the northernmost regions of Finland, Scotland, Norway and Sweden.

The project was started in 1998 as a pilot project between the four road administration bodies. The work is divided into two sub projects: Sub project A deals with road condition management issues; and sub project B studies winter maintenance problems common to the partner road districts. Both sub projects aim at technical exchange through studies, discussions and trials, and at identifying the most effective strategies in the studied issues, which could be applied in other Northern Periphery road districts. Roadex project will be completed by the end of 2001, but technical partnerships between partner road districts are to continue via professional networks established during this pilot project.

1.2. Sub Project A: Road Condition Management: Goals and Focus

At present, the main inter-urban highways of Scotland, Norway, Sweden and Finland are in relatively good condition. In comparison, the less frequently trafficked rural roads have suffered from financial neglect and fall well below modern standards. They have not been designed to cope with the combination of seasonal freeze/thaw cycles of the northern climate and the heavy axle loads of modern transport. The quality of road performance in this part of the road network will cause much debate in the years to come.

The focus of this sub project is on low traffic volume roads of the partner districts of Lapland, the Northern Region, Troms County and the Highlands, which have less than 1000 vehicles average daily traffic (AADT). In the four partner districts, these roads total 32.800 km, which is 85% of their total road network. Gravel roads are also given special attention, as they have some distinct characteristics and a notable role in the local road networks of the Nordic partner districts.

A special interest of this sub project is in the use of traffic restrictions in the partner districts. During a period of thawing the road structure can deteriorate dramatically in a very short time. Basically, road district managers can deal with the problem in two ways: (a) by imposing load restrictions for the sensitive road sections, or (b) by improving the road structure layers. Traffic restrictions cause logistical disadvantages for local livelihood. Road reconstruction, on the other hand, is expensive.

The goals assigned to this sub project are:

- (1) to identify best practices in road condition management of the partner districts,
- (2) to reduce load restrictions imposed for low traffic volume roads.

This report presents the results of phase I of the project, a comparison study of each road district's current policies and techniques in tackling the issues. The data collection for this study was carried out during 1999 through a large questionnaire, work group sessions, interviews and field excursions in each partner district. Besides presenting the operational conditions of the partner road districts and their practices in low traffic volume road management, this report also attempts to identify state-of-the-art practices from each partner road district.

The identification of current and best practices has been worked out by individual partner districts following the guidelines established in the work group. Evaluations of the group chairman are given in addition. When selecting the best practice techniques, attention has been given not only to the functioning of a practice or technique in the given environment, but also to its transferability to other partner districts.

In the next phase of this project, cases of selected state-of-the-art techniques will be examined and verified in co-operation. The final results of the Roadex project will be published during autumn 2001 as a multimedia CD.

2. INTRODUCTION TO THE AREA

2.1. General

Each of the four partner road districts is responsible for a comparatively large network of public roads located in a sparsely populated region (table 1). The total area of the four road districts (310.821 km²) is bigger than the land area of Italy, for example, but the population of the area is only 1,1 million. Settlement in each road district is also concentrated in few regional centers often situated on coastal lowland.

The terrain across the regions varies from high alpine mountains to rolling forested hills, marshlands and coastal plateaux. The bulk of overburden material in the whole area is derived either directly or indirectly from glacial action. Thus the dominating subgrade soil type is glacial till, which is often frost susceptible and therefore a cause for many road defects. Another special subgrade soil type common to the regions is peat. Outcropping bedrock is abundant in places.

The core of the regions' industrial activities is based on the raw materials supply of forestry, fishing, and mining. Tourism is also an important source of income in all regions. While employment today is generally shifting from traditional industries to the service sector and to the

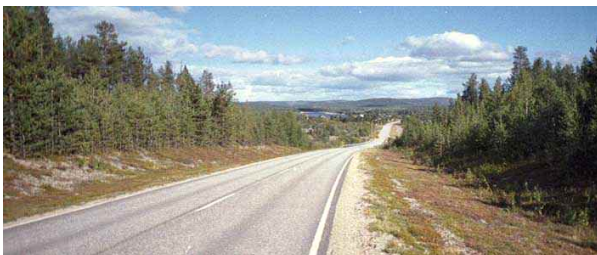
information technology driven 'new economy', there is no tendency towards diminishing transport needs of industries and their raw material suppliers. Modern industrial logistics require even more year-round performance and stability of the rural road networks.

In the following sections, some environmental and social characteristics of each partner road district are presented in more detail.

	Lapland, Finland	Northern Region, Sweden	Troms, Norway	Highlands, Scotland
Population 1000 inh. (% of total national)	196 (3,8 %)	520 (5,9 %)	150 (3,4 %)	208 (4,0%)
Area (km ²) (% of total national)	98 937 (29%)	160 000 (38%)	25 984 (8%)	25 900 (33%)
Inhabitants per km ² (average national)	2,0 (17)	3,2 (21)	5,8 (14)	8,0 (66)
GNP, million euro in current prices (% of total national)	3 015 (3 %) (Fin: 121 bill euro)	12 000 (5%) (Se: 228 bill euro)	- (Nor: 213 bill euro)	3 410 (3,6%) (Scot: 95 bill euro)

General facts of the NP partner district areas.

2.2. Lapland, Finland



The Finnish National Road Administration's Lapland Region administers national public roads in the province of Lapland, an area which comprises 29% of the area of Finland, but only 4% of the total population. Settlement in Lapland is concentrated around the industrial centres on the coast of the Baltic Sea, and the administrative center Rovaniemi, situated at the crossing of inland waterways and other transport channels. Approximately 48% of the province's 196,000 inhabitants live in the four cities of Rovaniemi, Kemi, Tornio and Kemijärvi.

The terrain in Lapland is lowland along the Gulf of Bothnia and becomes hillier northwards, with the highest fjelds in the north-western Lapland rising to 700m - 1,300 m above sea level. The landscape is characterized by large conifer forests, which alternate with marshland, lakes and rivers. Only the northernmost part of Lapland

is above the timber line. About 30% of the area belongs to various nature preservation programmes.

The climate is notably temperate considering the northern location. In winter time, south-western winds bring mild and moist weather to the southern and western parts of Lapland; somewhat more cold continental climate can be felt in the eastern parts. Snow covers the land 6-7 months of the year.

Forestry, pulp and paper product industries are very important to the region's economy. There is also significant iron and steel production on the Baltic Sea coast (Kemi-Tornio area), but mining activity in Lapland has decreased. Two thirds of the population is employed in the service sector, where the share of public services is notably high.

The main transportation channels in Finland are roads (67%) and railways (26%). Timber transportation on roads is an essential part of raw material deliveries to the forest industry. Lengthy transportation distances have led to high haulage weights. Peat and woodchip transportation as well as fuel deliveries also require large total weights. As to the daily goods and agricultural transports, production and logistical centres are concentrated mainly in southern Finland and most of their transportation is along the main road network.

2.3. The Northern Region, Sweden

The Swedish National Road Administration's (SNRA) Northern Region is comprised of Sweden's two northernmost provinces Västerbotten and Norrbotten, account for 38% of the total land area of the country. The region has 520.000 inhabitants and an average population density of 3,2 inh./ km² (whereas the average of Sweden is 21,5 inh./ km²).

By geographic characteristics, the area can be divided into three regions: the coastal region, the inland and the mountains. The densely populated Baltic Sea coast is flat with beaches and archipelagos. Three quarters of the region's population lives in the towns and cities along the coast. The biggest city, Umeå has over 100 000 inhabitants.

The inland is a sparsely populated region with pine forests and mires divided by big rivers. The large mountain area in the west, with high alpine mountains towards the Norwegian border, has almost no permanent inhabitants. The highest mountain in Sweden, Kebnekaise (c. 2100 m) is located in Norrbotten. In the north-east, the border to Finland is marked by the big Torne river.

The coastal region has relatively high annual mean temperature and low annual mean precipitation (500 mm). The inland is characterised by higher precipitation. In the mountains the climate is cold with abundant precipitation (850 mm). During winter season, normally from November to April, the region is covered by 0,6- 0,8 meters of snow by the coast and 1,2-1,3 meters in the mountains. During the winter the temperature very seldom reaches above 0°C and if it does it is usually for a very short time.

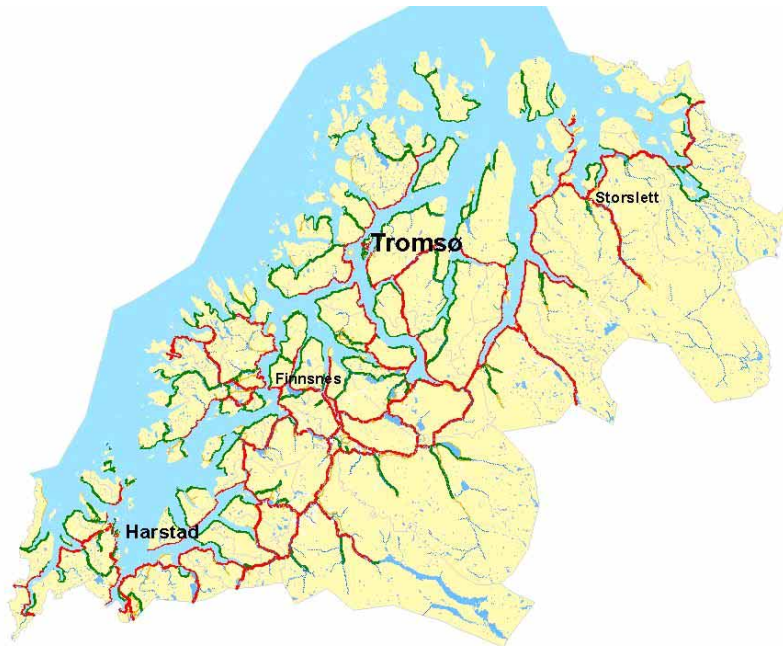
The most common soils are moraine, peat and fluvial outwash. The fine grained soils are most common in the eastern coastal areas. In general, igneous rocks dominate the bedrock. In the mountains there is younger sedimentary bedrock.



Approximately 47% of all goods transportation (tnkm) in the Northern Region is on roads. Especially the forest industry is highly dependent on the functional road network. Timber is transported from the inland to the big paper pulp industries and sawmills along the coast. To obtain the right pulp quality it is essential that the timber is fresh and that the just-in-time deliveries function all year round.

The share of railway transports is relatively high, 38%. Approximately 15% of goods transports use the seaway. The ore and iron industry is also dependent on the road network, but uses rail and seaway for most of the transports. The Ore Line between Luleå and Narvik is vital for both the ore field region in the very north of Norrbotten and the sizeable iron industry (SSAB) in Luleå. This rail freight line is one of the most important in Sweden and carries more than 20 million tons of freight per year. In terms of total annual cargo tonnage, Luleå is Sweden's leading bulk shipping harbor, with a turnover of 7.5 million tons. Iron ore shipments from LKAB account for 4 to 5 million tons. The growing tourist industry is expecting an improvement of the road network, especially in its ability to reach the remote mountain areas, which can offer excellent wildlife experiences.

2.4. Troms County, Norway



Troms County is a 25.984 km² large area on the North Sea coast; the second northernmost and the fourth largest among the counties in Norway. The county has 150.000 inhabitants, about half of whom live in densely settled areas along the coast. The population density in Troms County is 5,8 per square km. The county has three towns: Tromsø (57.000 inh.), Harstad (23.100 inh.) and Finnsnes (11.000 inh.) The population in Norway has increased by 22.9 % since 1961. For the Northern Periphery area in Norway this figure is only 6.7 %, for Troms County 17.6 %.

Alpine mountains which spread throughout the county characterize the terrain. About 70 % of the land area is over 300 m and 13,7 % over 900 m above sea level. The highest mountain is Jiekkvarri (1.833 m). On the North Sea coast, Troms has many large islands and fjords. Because of the islands and fjords, the coastline is very long - 4861 km. This is 32.3 m coastline for each inhabitant. The islands cover an area of 5708 m². The most popular recreation areas are in the inland near the Swedish border and Lyngsalpene.

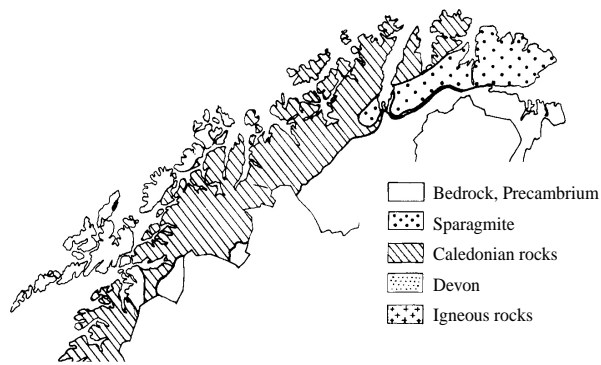
Climatic conditions change significantly from the coast to the inland. The coastal climate is effected by the Gulf Stream. Temperature amplitude through the year is much less on the coast than in the inland. In the inland the temperature can change from -40°C in the winter, to +30°C in the summer. The frost depth in these areas is more than 3 m. Precipitation is higher on the coast. The



average precipitation in Tromsø is 1031 mm/year.

Tromsø is known for having very much snow during the winter. In 1997 the snow depth in Tromsø reached the maximum depth of 2.40 m. During winters when snowfalls are intensive, Troms experiences numerous avalanches. Avalanches, risk for avalanches and bad weather conditions (wind in combination with snow) caused more than 430 road closures in Troms County in the winter 1999-2000.

The common structure of the Fennoscandian shield has a basement of precambrian rock. Approximately half of Norway consists of Precambrian rocks, and the rest consists of younger metamorphic rocks of the Caledonian Mountain ridge; the same mountain ridge as in Scot-



Geological map of Troms County

land. In Troms County precambrian rock is predominant on the coast and in the area near the Swedish border. Between these areas there are caledonian rocks (a compound of different nappes). The most common rock types are gabbro, mica schist, mica gneiss, marble and clay slate. The precambrium rocks consist mainly of granite gneiss and gneissic granite.

The soils in the region originate mainly from glacial, glaciofluvial and glaciomarine action (material transported by glaciers and the melting water from glaciers) and they vary from clay to high quality gravel. The aggregates are harder in the northern part of the county, which is why material from gravel pits in the north is often used as road building material.

Beneath the highest coastline there are fluvial deposits. Most of the clay is found in this area. When the ground-water washes out the salt in the clay it becomes very sensitive. These soils cause stability and settlement problems for earth construction.

The all-important industry and export in Troms County is fish and fish products; this industry is the biggest single employer and goods transporter (measured in tons km) in Troms County. Agriculture and forestry also have needs for road transportation - however in Troms County only 0.89 % of the land area is cultivated and 12.4 % is productive forest area (compared to average figures in Norway 2.88 % and 23.0 %).

Troms has also several shipyards mostly active in the maintenance and building of fishing boats and other smaller vessels. The county has one mining company (Skaland) and one smelting plant (Finnfjordbotn), but the mining industry mainly uses sea transports. Local construction materials suppliers transporting concrete goods, ready-mix concrete, and gravel, places demands on the bearing capacity of the roads in some areas.

Transports on roads have increased significantly in Norway throughout the 1990's, replacing some of the traditionally favoured sea transports. Today, approximately 55% of goods in Norway are transported by road, 35% by sea, and 10% by railway. The total transport performance in Troms county is approximately 400 mrd tnkm.

2.5. The Highlands, Scotland

The Highland Council covers the largest geographical area of Scotland's 32 all-purpose Councils, representing a population of 208,000 across 25,784 km² (one-third of the Scottish mainland, 10% of the whole of the U.K.) and is almost equivalent in geographical size to Belgium. Only 4% of the population of Scotland live within the Highlands and the overall density is only eight persons per square kilometer, compared to a Scottish average of 66.

The Highlands coastline extends to around 1900 km and is bounded by both the North Sea and the Atlantic Ocean. Much of the area is mountainous with around 80% of the land rising to over 300m. The population is very much concentrated in the more fertile and productive coastal low lands of the Inner Moray Firth, where a number of the larger towns are situated, including Inverness which is the largest with a population of around 42,000. Valleys are used as route corridors for most of the main roads away from coastal areas.





The Atlantic Gulf Stream reaches the West Coast of the Highlands. This current of warm water gives rise to much of the mild, wet weather that Highland experiences. Winter in the Highlands is characterised by its unpredictability. Drivers can be caught out, with dry pleasant weather in Inverness concealing the atrocious conditions that have closed the main road some 60 km to the south. The temperatures often drop below freezing overnight, before rising again during the day. The temperatures also vary according to height above sea level and distance inland. The result is that ‘frosts’ or freeze-thaw cycles (temperature below 0°C) can occur many times through the winter. For example at one of the higher road monitoring stations, there were 72 frosts during the winter of 1998/1999. For the majority of these events the temperature was around minus 4°C, with the lowest at minus 9°C.

The geology of the Highlands is as varied as its weather. Approximately 25% of the land has bedrock at or near the surface. Over 40% of the land surface of Highland is covered with peat. Blanket peat around 1 metre deep covers hill slopes, while basin peat occurs in bogs and can be several 10’s of metres deep, giving considerable problems to the road designer.

The main industries in the Highlands are those involving fishing, forestry and tourism. Fishing and forestry involve the transportation of heavy products from remote ports or areas to the main conurbation’s of Scot-

land (the ‘central belt’) and causes serious problems with the road network. These industries are yet vital to the viability of rural communities, providing direct and indirect jobs and injecting money into these areas.

Road transport is the overwhelmingly most common mode of transport for goods (70%) as well as passengers (83%). Rail transport counts for 3%, and seaway for 16% of goods transport. There are currently many initiatives to try and make more use of the railway for freight and passengers. The outlying islands (Western Isles, Orkney and Shetland) rely on air transport services, with the movement of goods generally by sea transport.



3. ROADS AND ROAD ADMINISTRATION IN THE NORTHERN PERIPHERY

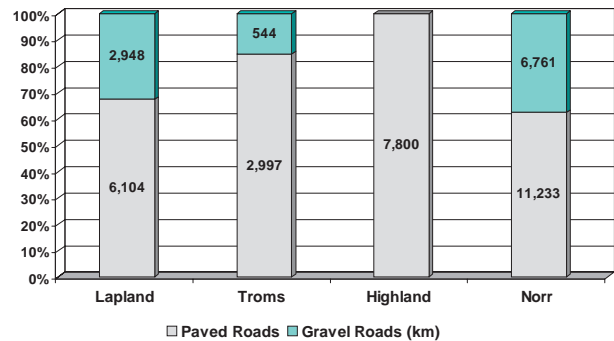
3.1. General

Roadex project partners are local authorities of national road administrations with total responsibility for planning, development and maintenance of public road networks in their area. The criteria for public roads which fall within the mandate of the district road administration offices varies somewhat from country to country.

Common to all four road districts is a large share of low traffic volume roads (AADT < 1000), as well as high seasonal fluctuation of traffic volumes. About 85% of the total length of public roads in the partner road districts fall within the low traffic volume category <1000 AADT chosen for the scope of this study. Meeting the requirements of heavy haulage particularly on these secondary roads presents a common challenge.

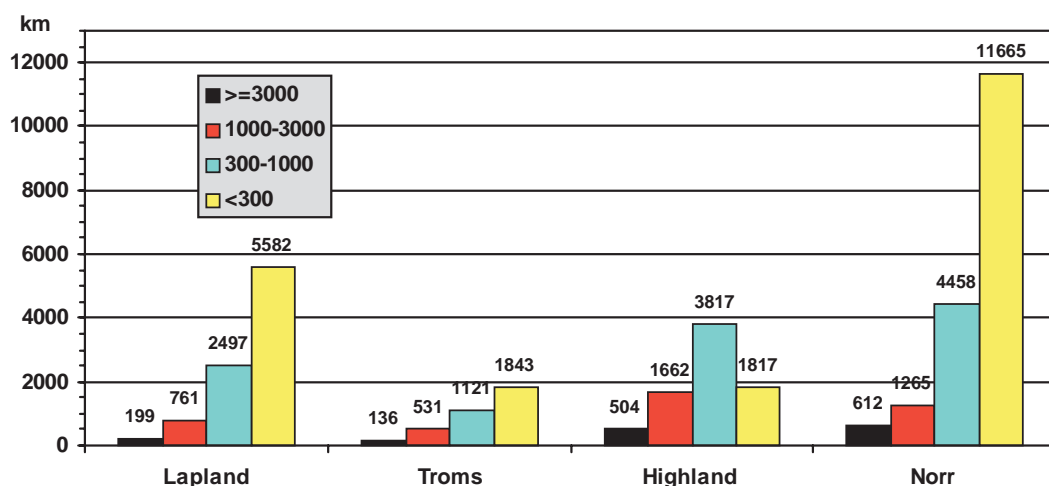
Gravel roads are a specific item in low traffic volume road management in the Nordic countries. In the road districts of Lapland (Finland) and the Northern Region (Sweden) gravel roads represent over a third of the total public road network. This study will separately highlight issues related to gravel roads where appropriate.

The tasks of the road districts vary from total control and maintenance of the road network to a more limited



The share of gravel vs. paved roads in each road district.

role of road management without means of supplying maintenance and road construction services. The separation of public administration tasks from the production of services has gone furthest in Sweden and in Finland, where it has been a major reason for developing standardised methods for road condition and service quality evaluation. Given the possibilities of modern information systems, the development of new approaches to road condition management is ongoing in all partner districts.



Length of partner road districts' road networks by traffic volume (AADT).

3.2. Lapland Region, Finland

The Finnish National Road Administration agency (Finnra) was internally divided in 1998 into Road Administration, a public authority responsible for the management of national roads; and Production which is preparing for open competition in the maintenance of public roads as a state-owned enterprise. Maintenance, construction, rehabilitation, as well as road survey and design services fall within the operations of Finnra Production. A changeover to contract-based projects in road construction is currently taking place, and road design is almost completely done on a consultancy basis.

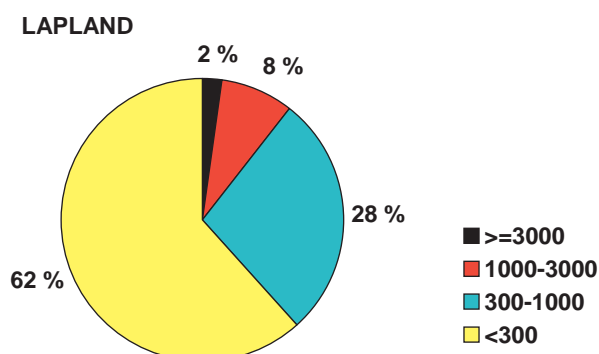
Lapland Region, as the local authority of Finnra Road Administration, is responsible for national roads in the province of Lapland. The road district has 84 employees (-99) working in the four sections of Staff, Strategic Planning, Procurement of Works and Services, and Traffic Service. The Strategic Planning section is responsible for road network information, rehabilitation plans and preliminary designs. The production of road condition surveys, design, and rehabilitation measures is generally assigned to other units of Finnra Production or to private contractors.

Locally the road administration is presented by eight area supervisors, who supervise maintenance contractors and have the authority to grant licenses for road users when necessary.

The national public road network in the district totals 9.052 km. 2.229 km of the road network is classified as main roads, 2.243 km as regional roads, and 4.580 km as connecting roads. The road district also manages 384 km of pedestrian and light traffic ways built along the public roads.

There are also 1.300 km of public municipal streets and roads in Lapland, controlled and maintained by municipalities. Private roads include 13.800 km of forest roads mainly controlled and maintained by the National Board of Forestry, landowners, paper industry, or forest centres, and 3.300 km of other private roads. State subsidies are given to the maintenance and rehabilitation of 1.600 km of private roads. In the recent years, subsidies were granted only for road development.

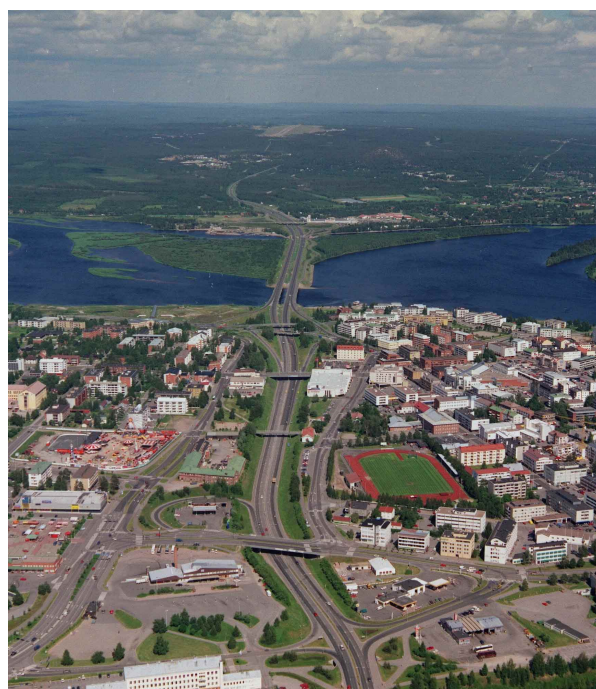
The largest traffic volumes in Lapland Region have been measured in Rovaniemi (21 119 AADT) and in Tornio (19 675 AADT). Tourist traffic increases traffic volumes noticeably during Christmas and New Year, Easter and from Midsummer to the end of July. Summer traffic is 1.1...2.5 times higher than the annual average. In winter a major part of tourist traffic is directed towards the ski resorts of Western Lapland.



Road Class	length km	% of total	AADT
Main	1 278	14 %	1584
Main 2	951	10 %	902
Regional	2 243	25 %	388
Connecting	4 580	51 %	169
Total	9 052	100 %	

Road classification and traffic volume of public road in Lapland, Finland

A third of the total national road network in Lapland, 2.948 km, is gravel roads. These are usually connecting roads with very low traffic volume. Of the paved roads, 6.104 km in total, most have oil gravel or other cold mix pavement (3.754 km). The so-called 'cut back asphalt' (1.243 km) and asphalt concrete (1.107 km) are other commonly used surface materials.



3.3. The Northern Region, Sweden

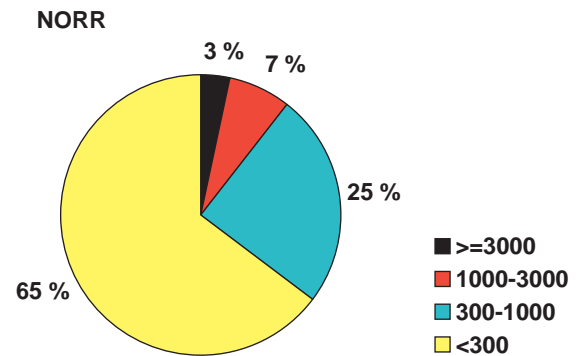
The Northern Regional Road Management Directorate of the Swedish National Public Roads Administration (SNRA) controls and manages national and county roads, which in its directorate have a total length of 18.000 km. Other roads in the directorate, which are not the responsibility of SNRA, are municipal roads (6.000 km) and private roads (53.500 km). Most of the large network of private roads are small forest roads often owned by forest companies (46.000 km). Approximately 7.500 km of private roads are controlled by local associations, which receive government subsidies to a certain percentage of maintenance costs.

The road administration in the Northern Region employs 500 people. The district road administration office has 170 workers, the separate profit centres of SNRA in the district: Construction and Maintenance employ 300 and Consulting Services 20 employees.

Traffic volume in the public road network of the Northern Region varies from 1900 AADT on national roads to 350 AADT on county roads. High traffic volume roads are concentrated on the coast and around the inland towns Gällivare and Kiruna. Seasonal variation of traffic flows is clearest in the mountain areas where tourism is a growing business. Especially during spring, the traffic is rather dense. That is paradoxically also the peak season for

frost heave and other frost related damage.

A notable amount, 6.761 km or 38% of the public roads in Northern Region are gravel roads. In the Northern Region 65% of the roads have traffic volumes <300 AADT.



Road Class	length km	% of total	AADT
National roads	2 050	11 %	1900
County roads	15 950	89 %	350
Total	18 000	100 %	

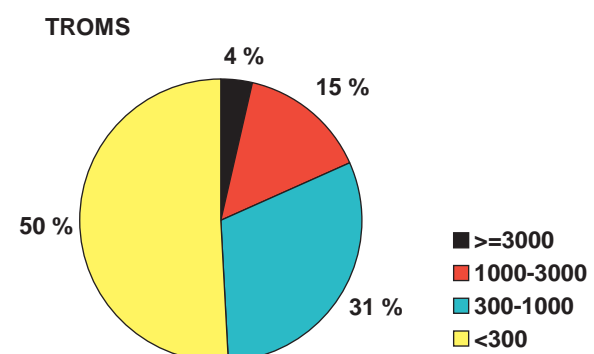
Road classification and traffic volume of public roads in the Northern Region, Sweden

3.4. Troms County, Norway

The Troms County Roads Office of the Norwegian Public Roads Administration (NPRA) controls all national and county roads within Troms County.

The number of equivalent fulltime employees at the Public Road Administration in Troms County is 513. There are 118 people working at the Public Road Administration office in Troms. The county is divided into four areas, each having a local administration centre (125 employees). The Troms County Road Administration has four departments: Administration, Road Development, Traffic, and Production. The Road Development department and partly the Traffic Department deal with most road condition management issues and include units e.g. for planning, reinforcement and pavement, and road technology.

The total length of public roads within Troms County is 5.310 km, 1.707 km of these are national roads, 1.818 km county roads and 1.784 km municipal roads. For county roads, the county municipality is responsible for fi-



Road Class	length km	% of total (average)	AADT
National roads 31.12.1999	1.706,9	48%	1190
County roads 31.12.1999	1.818,2	52 %	278
Total	3.525,1	100 %	

Road classification and traffic volume of public road in

nancing and strategy. Each municipality has their own road administration. Thus the municipal roads do not fall within the scope of this study and they are not included in the statistical presentations. The length of bicycle and public foot path administered by Troms county road administration is 117 km (1999).

In addition, hydropower companies and organisations connected to forestry and agriculture, as well as private landowners control a network of private roads in the district. The forest roads have a total length of 1.329 km, of

which 425 km are year-round roads for lorries, 864 km are year-round roads for tractors, and 40 km are winter roads for lorries

The average traffic volume of the national roads in Troms County is about 1200 AADT. However, 50% of the national and county roads and 87,5% of the county roads have less traffic than 300 AADT. The highest traffic volume areas are near the three towns, Tromsø, Harsstad and Finnsnes, and densely built-up areas near Andselv/Heggelia and Setermoen. Typical traffic volume peaks on secondary roads are in March and in June-July.

3.5. The Highland Council, Scotland

The Highland Council is an all-purpose local public authority. The Council's Roads and Transport Service has a structure consisting of three sections controlling different aspects of the service, with eight area managers who are responsible for service delivery at the local level.

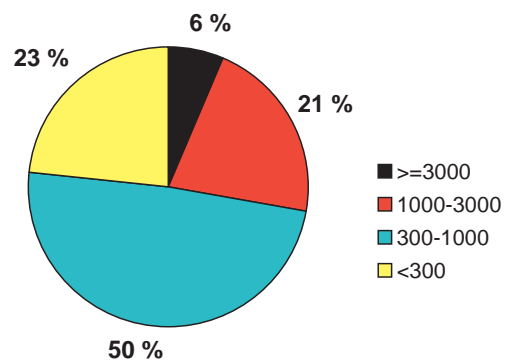
Public roads in The Highland Council area are split by responsibility and maintenance authority. The main arterial routes (Trunk Roads) are generally the busiest. These 962 km are the responsibility of the Scottish Parliament through the Scottish Executive. The Highland Council is responsible for the remaining 6.838 km of public roads, which are divided by their strategic importance to three categories Premium Roads, Strategic Roads, and Rural Distributors. The Highland Council currently manages the Trunk Roads on behalf of the Scottish Executive, although this will change in 2001 under new Government legislation.

There are a large number of private roads (mainly forestry) in the area, although no general statistics of them are available. Indications from one of the main forestry businesses suggest that at least 1.130 km of roads are in their ownership and these are principally constructed of gravel. State-owned forest roads, which are not the responsibility of the Highland Council total approximately 5.740 km.

All public roads in the area are paved. The heavier trafficked Trunk Roads generally consist of at least three layers of a bituminous bound material. Council roads are all surfaced with at least one layer of bitumen bound macadam. Among Council roads there are lengths of 3-4 m wide 'single track' roads with passing places. These roads may have been original horse or cart tracks on subgrades completely unsuitable for the weight of today's traffic.

The amount of traffic on the Highland Council roads varies considerably, depending on location and time of year. Some roads around Inverness carry over 20.000 vehicles per day, while some remote West Coast roads may

Public roads in the Highland Council area by traffic volume (AADT)



Road Class	length km	% of total	AADT
Trunk roads	962	12 %	
Council roads	6.838	88 %	
Total	7.800	100 %	

Road classification and traffic volume of public road in Highlands Scotland.

have less than 150 vehicles per day. The variation over the seasons is also considerable, with some of the quiet remote roads experiencing a 100% increase from winter to summer, due to tourism. The popular skiing resorts in Aviemore and Fort William also give rise to traffic fluctuations in winter.



4. DESIGN AND DIMENSIONING OF LOW TRAFFIC VOLUME ROADS

4.1. Standard road structures and dimensioning principles

Even though there are similar basic principles for pavement structure design and dimensioning, each country has adopted individual methods and structures for their practice. An extensive report about the current practice in pavement structure is given in COST 333 report “Development of New Bituminous Pavement Design Method” published by European Commission Directorate General Transport.

Lapland, Finland

In Lapland, the pavement structure has to be able to withstand stresses caused by dynamic axle loads, frost action and freeze thaw cycles, and pavement wear due to the studs in tires. The technical life time used in road design is normally 20 years for asphalt roads, 15 - 20 years for soft bitumen roads, and 10 years for gravel roads.

The Finnish pavement structure dimensioning system was introduced in 1985 and reviewed in 1991; it is based on dimensioning tables for each pavement structure type and subgrade soil type, and it is still used in some projects in the country. According to this procedure, pavement structure type and thickness are chosen on the basis of AADT, the amount of heavy vehicles, prognosticated increase of traffic, technical lifetime, and width of the road, which are also the parameters used for calculating equiv-

alent axle loads. Target bearing capacity values (MN/m²) for sub base, base, and pavement surface are determined by chosen structure type and the calculated equivalent axle load. In general, pavement structure layer thickness depends on traffic volume and subsoil type. The amount of heavy traffic is decisive in road structure dimensioning.

Table below summarizes standard pavement structures in Finnish Lapland. The most typical low traffic volume road structure consists of 40-60 mm of oil gravel or soft bitumen wearing course on the top, 150-200 mm of base course made of crushed gravel, 150-200 mm of sub base, which is normally natural sandy gravel and on wet subgrade soils 200-300 of filter course made of sand. The total thickness of the pavement structure varies normally 450 - 600 mm in low traffic volume roads. Due to environmental reasons old oil gravel pavement are now been replaced with heated or emulsified soft bitumen PAB-V pavements. Seal coating is used only on some dry and good quality gravel roads.

Today, however, most pavement structures in the Lapland region are designed using the analytical pavement design software APAS (Analytical Pavement Structures). Apas uses NOAH calculation module in pavement response calculations and the program calculates stresses, strains and displacements by using multilayer elastic theory.

Gravel roads AADT < 500	Seal coat AADT < 500	PAB-V, Oil gravel AADT < 1000	PAB-B AADT 800- 1800	Asphalt concrete AADT > 1000
wearing course -50 mm	seal coat -15-25 mm	PAB-V, -40 mm	PAB-B -40 mm	AB + ABK (bound base) -150 mm
bonding layer -150 mm	base course -250 mm	base course -150 mm	base course -200 mm	base course -250 mm
sub base -150 mm	filter course -300 mm	sub base - 150 mm	sub base -200 mm	sub base -250 mm
filter course -200 mm		filter course -300 mm	filter course -300 mm	filter course -300 mm

Standard pavement structures used in Lapland:

The Northern Region, Sweden

The design standards for new road sections (ROAD94) give in tabulated form the required layer thickness of particular materials. The dimensioning is based on traffic volume and frost action. The design life is normally 20 years for bound layers and 40 years for the rest of the structure.

The design procedure is based on traffic flow and on stress and strain calculations using linear elastic theories. Failure criteria are fatigue cracking at the lower edge of the bound layer, and permanent deformation at the top of the subgrade. The layer thickness is dependent on the chosen construction type, the number of equivalent standard axles, and the type of material in the subgrade and the climatic zone. The equivalent number of standard axles is calculated from AADT, the percentage of heavy vehicles, the number of standard axles per heavy vehicle, and the assumed changes in traffic during the intended life-time.

To limit the frost heave a protection layer, in most cases sand, is used between the sub base and the subgrade. The thickness of this protection layer is dependent on the evenness standard given to the road and on the frost susceptibility of the subgrade. The total thickness of the unbound layers is dependent on traffic or on frost heave.

Due to the infrequent construction of new roads in northern Sweden there are very few roads with these ROAD94 structures in the Northern Region. The roads with lowest traffic volume (AADT<1000) in the area have thinner and weaker structures. A typical structure is 250-350 mm of sand over the subgrade soil or embankment, 80-100 mm of unbound roadbase (base course) in the middle, and 40 mm of a bitumen-bound wearing course or 50-100 mm of a gravel wearing course on the top.

1. Gravel pavement	2. Gravel-bitumen pavement	3. Gravel-bitumen pavement	4. Rock-bitumen pavement (only when AADT > 2000)
50mm Gravel wearing course	45mm Bitumen-bound wearing course	45mm Bitumen-bound wearing course	40mm Bitumen-bound wearing course
100mm Roadbase for gravel road	0-190mm Bitumen-bound roadbase	0-190mm Bitumen-bound roadbase	80-180mm Bitumen-bound roadbase
150-450mm Subbase for gravel road	80mm Unbound roadbase	150mm Unbound roadbase	40mm Grouted macadam
0-300mm Protective layer	420mm Subbase of crushed material 0-2400mm Protective layer	350mm Subbase of uncrushed material 0-2400mm Protective layer	460mm Subbase of crushed rock 0-2300mm Protective layer

Typical road structures in new roads according to
Typical road structures in Highland Council roads

Troms County, Norway

There are three design levels for roads in Norway. Level 1 is an empirical method, based largely on the use of design charts and classification of all materials according to their bearing capacity. The following procedural description and examples follow this method. Design level 2 is an empirical method with additional material property measurement elements (e.g. FWD backcalculation, CBR-test). Design level 3 is a theoretical method embracing mechanical stress and strain calculations.

The road structure in Norway normally has three layers, each of these divided into two sublayers. The pavement has an upper layer, wearing course, and a lower layer, binder course. The base is divided into an upper (normally a bituminous layer) and a lower base layer. On the subgrade, the sub base normally consist of natural gravel or crushed rocks. The drainage course is currently replaced with geotextile.

The decisive factor for the thickness and quality design of pavement and base layer is design traffic volume. The design traffic variable is calculated using average traffic volume, maximum permitted axle load, annual traffic increase, design life, number of lanes, shoulder width, and percentage of heavy vehicles. Different dimensioning tables are used for primary roads, collector roads, access roads, gravel roads, and parking lots.

Sub base requirements are based on design traffic volume and bearing capacity of the subgrade. Subgrade material types are classified depending on their bearing capacity as follows:

1. Gravel Roads	2. Traffic volume < 3000 AADT	3. Traffic volume > 3000 AADT
gravel wearing course 5 cm subbase gravel - 10 - 70 cm depending on subgrade	wearing course - 4 cm soft asphalt concrete upper base layer asphalt gravel - 5 - 6 cm lower base layer crushed well graded gravel 10 cm upper subbase layer gravel, coarse aggregate... min. thckn. 15 cm lower subbase layer gravel, coarse aggregate... thickn. 0-100 cm depending on subgrade and traffic vol. subgrade	wearing course - 4.5 cm asphalt concrete binder course - 3.5 cm asphalt concrete upper base layer asphalt gravel - 7-9 cm lower base layer penetration macadam 10 cm upper subbase layer gravel, coarse aggregate... min. thckn. 15 cm lower subbase layer gravel, coarse aggregate... thickn. 0-100 cm depending on subgrade and traffic vol. subgrade

Typical road structures in Troms area of roads with different traffic volumes-

Material in the subgrade	Bearing capacity group
Rock cut, rock material, T1	1
Gravel, sand, Cu≥10, T1	2
Gravel, sand, Cu<10, T1, Rock cut, rock material, T2	3
Gravel, sand, moraine, T2	4
Gravel, sand, moraine, T3	5
Clay, silt, T4	6
Peat	7

T1-T4 is the soils frost susceptibility, Cu - coefficient of uniformity

Typical road structures used in Troms County are pre-

The Highlands, Scotland

The current design standards for road structures has been developed as the result of practical experience, laboratory research and full scale road trials. The result is a tabulated design procedure that produces layer thicknesses of particular materials. The design documents are contained in the Design Manual for Roads and Bridges (published by Her Majesty's Stationery Office HMSO) for the Highways Agency (England) and Scottish Executive (Scotland).

The structural layers are defined in the Design Manual as: foundation - the platform on which the more expensive and structurally significant layers are placed; road base - the main structural layer; and surfacing - which enables a good ride quality with skid resistance and crack resistance.

Pavement design is based on Traffic Flow (annual average daily traffic, AADT) at the road opening. Standard practice is to design the foundation for the construction traffic loading. The equilibrium CBR (California Bearing Ratio) is determined by testing or estimation from a table and is dependent on the level of the water table, the anticipated construction conditions, and the type of soil. The strength of the subgrade is a major factor in determining the thicknesses of layers to be provided.

The design for the pavement uses the current traffic volume and amount of heavy good vehicles, projected over a 20 year period to give the number of 'standard

axles' (an 80kN or 8 tonne axle) for the design life of the road. The design traffic value is given in million standard axles (msa). (For the comparison designs in this study, corrections were made to convert to a 10 tonne axle.) The layer thicknesses are selected from charts using the traffic details and chosen material types.

Whole life costs show that pavements are most economical with a 40 year life. Flexible pavements are designed to have a 20 year design life for their first stage to a critical condition and needing major maintenance. This major maintenance is then considered to give the pavement a further 20 years of life, a total of 40 years.

Four different types of pavement are allowed, Rigid, Rigid Composite, Flexible Composite, and Flexible, but there is generally only one type of road structure used in the Highland Council area. This flexible pavement consists of a bound surfacing (consisting of a wearing course and base course) typically 100mm thick, below which is a bound roadbase, which will normally be greater than 130mm thick, but could be up to 500mm for highly trafficked roads. The bound material will probably be either Dense Bituminous Macadam (DBM) or a Hot Rolled Asphalt (HRA). Road designs for trunk roads will generally use Hot Rolled Asphalt for the wearing course, base-course and roadbase. Both are bitumen bound crushed rock materials, with the asphalts generally chosen for larger traffic volumes (owing to their greater density and better durability). Below the roadbase material is a crushed rock sub-base of minimum thickness 150mm for good

1. Gravel Roads	2. Council Roads	3. Trunk Roads
Gravel Wearing Course 30cm max	DBM Wearing Course 4cm	HRA Wearing Course 4cm
Gravel Basecourse 75cm max	DBM Basecourse 6cm	HRA Basecourse 6cm
	DBM Roadbase >9cm Bound roadbase is normally >13 cm thick	HRA Roadbase >12cm Bound roadbase is normally >13 cm thick; can be up to 50 cm for highly trafficked roads
	Crushed Rock Sub-base >15cm, to ensure a minimum pavement thickness of 45cm	Crushed Rock Sub-base >15cm, to ensure a minimum pavement thickness of 45cm
	Non Frost Susceptible Capping Layer >25cm, depending on ground conditions	Non Frost Susceptible Capping Layer >25cm, depending on ground conditions
	DBM= Dense Bituminous Macadam	HRA= Hot Rolled Asphalt
	For low traffic volume roads the bound roadbase can be replaced by 15-20cm of crushed rock roadbase.	

subgrade conditions. On the lower traffic volume Council roads it is common to replace the bound roadbase material with a crushed rock roadbase. For poorer conditions the sub-base layer thickness is increased, or it is used with a granular ‘capping layer’, to give an overall thickness of up to 750mm (150mm crushed rock sub-base on 600mm of granular fill). A surface dressing is normally applied to DBM wearing courses to provide skid resistance.

Typical road designs in The Highland Council Area are produced in accordance with the Design Manual for Roads and Bridges (issued by the Scottish Executive).

4.2. Frost design principles

Climate factors, such as temperature and moisture have great effect on road performance, a road can deteriorate rapidly even without traffic stress. In the Northern periphery area the Scandinavian countries are exposed to severe winter conditions and frost can penetrate deeper than 3 meters and even sporadic permafrost can be found under roads in some high mountain areas. On the other hand the Highlands in Scotland suffer mainly from freeze-thaw cycles and frost normally penetrates only a few tens of centimetres during winter seasons. The following sections will describe, in brief, the current practice in managing the frost problems in NP partner districts.

Lapland, Finland

Frost design and dimensioning principles in Finland are based on the classification of the frost susceptibility of subgrade soils, and if soils are frost susceptible, on the classification of subgrade frost conditions. Area differences in Finland are taken into account by using different transition wedge depths, which also equal soil replacement depths. These transition wedge depth calculations are based on the freezing index, once in 10 years. The transition wedge depth also relates to the total thickness of the pavement structure in areas of difficult subgrade conditions and in the Lapland Region it is 2.0...2.2 m except in the Southwestern part of Lapland where it is 1.8...2.0 m.

Subgrade soil frost susceptibility is determined by gradation and especially by the amount of fine fraction (< 0.074 mm) of soils. Subgrade frost conditions are classified into 1) easy, 2) medium and 3) difficult conditions. Easy conditions prevail when the ground water table is deeper than 1 m from the bottom of transition wedge depth (i.e. in Lapland more than 3.2 m). Medium frost condi-

Gravel roads in the Highland area are in essence “low-cost” forest roads. The materials used tend to be obtained adjacent to the roadline, with only small amounts of high quality material being brought in, possibly to provide a wearing course. The sub-base can be glacial moraines, weathered rock or gravel and laid to a maximum depth of 750mm depending on the CBR of the sub-grade present. A wearing course is then laid to a maximum depth of 300mm, this is dependent on the nominal size of material available. Crushed and screened rock is a luxury only used when a high performance specification is required.

tions prevail if subgrade soil is moist and the water table is closer to the surface than 3.2 m, but the subgrade soil is homogenous. Conditions are classified as difficult when the groundwater table is close to the grade line and subgrade is heterogeneous, i.e. it contains boulders and soil layers with different permeability properties, and if bedrock is present. Difficult conditions also occur when the road is located on a slope and ground water is flowing under the road.

The Northern Region, Sweden

Paved roads shall be designed in Sweden so that the frost heave of the carriageway during an average winter will not exceed the following values:

Evenness class:	1	2	3	4
Allowable frost heave (new roads) [mm]:	160	120	80	50
Allowable frost heave (after rehabilitation) [mm]:	320	240	160	100

Gravel roads and roads with surface dressing on a gravel base should be designed so that the frost heave during a mean winter does not exceed 160 mm (240 mm after rehabilitation). The transition wedges shall be 16 m long if the soil is highly frost susceptible and 8 m long if the soil is medium frost susceptible.

There are different ways of designing a road structure so that the allowable frost heave is not exceeded. One alternative is to choose a structure according to the tables “design taking frost heave into account” in ROAD94.

Another way is to calculate the frost heave in accordance with the frost heave model “Tjale” (described in

VVMB 906 “Calculation of frost heave in a road structure”). Important parameters for the calculations are the thermal conductivity and the freeze resistance of the material in the road structure, the frost susceptibility of the subgrade soil, the freezing index, the permanent load and the distance to the ground water table.

An alternative way of achieving enough frost protection is to insulate the subgrade, using for example cellular plastic insulation. The distance between the insulation and the surface must be $> 0,5$ meter to reduce the risk for slipperiness due to frost (black ice). The necessary insulation thickness for polystyrene cellular plastic in the climatic zone 4-6 is 80-140 mm.

Using alternative materials in the road structure, for example slag, is another way to decrease the thickness of the structure. Blast furnace slag, for example, has a lower thermal conductivity ($0,3-0,6 \text{ W/m K}$) than conventional gravel or rock material, which results in a thinner structure but still the same level frost protection. Slag is frequently used in road structures in the Region Norr.

Troms County, Norway

Frost index is not a parameter in the Norwegian design procedure for pavement structure, but the frost index still must be considered when choosing binder stiffness in the bituminous layers.

The frost depth in sand/gravel is used when planning permanent construction (bridges etc.) and when constructing the transition structure when the frost susceptibility changes. Troms road region has many of uneven frost heave problems especially with culverts.

For permanent construction the frost depth every 100th year (F_{100}) is used as design frost depth. For culverts and other frost heave problems the design frost depth is the frost depth once every 10th year (F_{10}).

Classification		% weight of aggregate < 19 mm		
		< 0.002 mm	< 0.02 mm	< 0.2 mm
T1 - not frost susceptible			< 3	
T2 - low frost susceptible			3 - 12	
T3 - medium frost susceptible		> 40 or	> 12 and	< 50
T4 - very frost susceptible		< 40 and	> 12 and	< 50
Frost design in Norway				
AADT	Type of road	Subgrade	Frost protection with	
			sand, gravel, stone	insulation
0-1500	All	1,2,3	b	B
1500-15000	Main and collector roads	1,2 3	b h_5 (max. 1.5 m)	b h_{10}
> 15000	Main roads	1 2 3	h_2 (max. 1.2 m) h_5 (max. 1.5 m) h_{10} (max. 1.8 m)	h_{10} h_{10} h_{10}

1 = homogenous condition, few and small frost heave
2 = some variations, some problem with uneven frost heave expected
3 = strongly variations, large and uneven frost heave expected
b = only necessary to design for bearing capacity
 h_2, h_5, h_{10} = frost depth every 2., 5. and 10. year

Frost design and dimensioning principle in Norway

On roads with traffic volume < 1500 AADT Troms does not use frost dimensioning for the road structures. For main and collector roads with traffic volume 1500-15000 AADT non-frost susceptible roads are built only if the variation in frost susceptibility of subgrade soil is very high and significant frost heave is expected. When using non-frost susceptible sand/gravel the thickness of the structure shall correspond to 5 years frost depth. If frost insulation is used, then the design frost depth must correspond to F_{10} , but not more than 1,5 m.

The thickness of frost insulation is calculated for each municipality in Norway. The frost index and annual mean temperature are important parameters in these calculations, and the thickness is calculated for frost index F_2 , F_{10} and F_{100} .

The Highlands, Scotland

The only requirement for frost design in Scotland is to ensure that frost susceptible materials are not used in the upper 450mm of the road structure. Occasionally this would be increased to 600mm or even 800 mm for certain known colder areas. In most cases this involves increasing the designed pavement thickness using either a crushed rock sub-base or a ‘capping layer’ of non-frost susceptible granular material.

4.3. Comparison of pavement structure design methods; three cases

In order to compare the pavement design methods used in NP area districts, a series of comparative design calculations were performed for three types of subgrade soils: sand, moraine and silt. The basic assumptions in these calculations were the following: road width 7 m, speed

limit 80 km/h, traffic volume 1000 AADT and dimensioning time 20 years. The average freeze index value was of each road district was used in the calculations. The results of these calculations are presented in the following table.

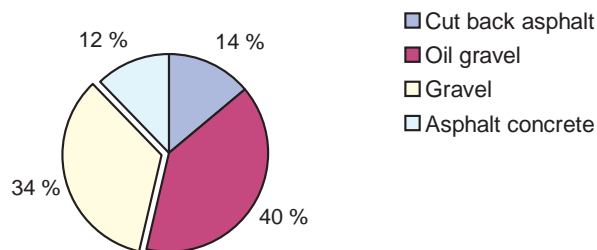
Finland, Lapland Sand AB, pavement 5 cm base 20 cm subbase 20 cm total 45 cm	Moraine AB, pavement 10 cm base 20 cm subbase 20 cm total 50 cm	Silt AB, pavement 10 cm base 20 cm subbase 25 cm filter 50 cm total 105 cm
Norway, Troms Sand wearing course 4 cm upper base layer 6 cm lower base layer 10 cm sub-base - gravel 10 cm on Cu for the sand total 30 cm	Moraine wearing course 4 cm upper base layer 6 cm lower base layer 10 cm subbase - gravel 40 cm (upper 15 cm, lower 25 cm) total 60 cm	Silt wearing course 4 cm upper base layer 6 cm lower base layer 10 cm subbase - gravel 50-100 cm (upper 15 cm, lower 45-85 cm) Depends on undrained shearstrength total 80-120 cm
Scotland, Highland Sand DBM Layers 23cm: DBM wearing course 4 cm DBM base course 6 cm DBM road base 13 cm Crushed Rock: Subbase 22 cm total 45 cm	Moraine DBM Layers 23cm: DBM wearing course 4 cm DBM base course 6 cm DBM road base 13 cm Crushed Rock: Subbase 22 cm (Gravel/Rock: Capping 25 cm) total 45-70 cm	Silt DBM Layers 23cm: DBM wearing course 4 cm DBM base course 6 cm DBM road base 13 cm Crushed Rock: Subbase 35 cm (Gravel/Rock: Capping 60 cm) total 58-118 cm
Sweden, Norr Sand Wearing course: 4 cm soft asphalt (alt. asphalt concrete) Upper base layer: 7 cm soft asphalt base (alt. hot mix base) Lower base layer: 8 cm unbound roadbase Subbase: 42 cm of crushed material Design, taking frost heave into account: Protective layer: 0 cm Total thickness: 61 cm	Moraine Wearing course: 4 cm soft asphalt (alt. asphalt concrete) Upper base layer: 7 cm soft asphalt base (alt. hot mix base) Lower base layer: 8 cm unbound roadbase Subbase: 42 cm of crushed material Design, taking frost heave into account: Protective layer: 0 cm Total thickness: 61 cm	Silt Wearing course: 4 cm soft asphalt (alt. asphalt concrete) Upper base layer: 7 cm soft asphalt base (alt. hot mix base) Lower base layer: 8 cm unbound roadbase Subbase: 42 cm of crushed material Design, taking frost heave into account: Protective layer: 39 cm Total thickness: 100 cm

Results of the comparative calculations

4.4. Road construction materials

Lapland, Finland

Distribution of road surface types in Lapland



Currently, asphalt pavements in Lapland are made mainly using AB16/100 mixture, which means 0-16 mm dense graded mixture 100 kg /m². In some heavily trafficked roads with AADT > 5000 open graded split mastic asphalt SMA 16/100 has also been used. The maximum grain size of aggregates is usually 16 - 18 mm, in some case 20 mm or even 25 mm to improve the bearing capacity without using stabilisation or a bitumen bound base. Bitumen viscosity is 120 in Southern Lapland and 200 in the Northern part of Lapland. The filler used in asphalt has been standard calcium filler.

Soft bitumen asphalt pavements type PAB-B 16/100 or PAB-B16/80 have been used in roads with medium traffic volume. Pavement types are PAB-B16/100 (43 mm pavement thickness with <16 mm aggregate) or PAB-B16/80 (35 mm pavement with <16 mm aggregate). Bitumen type in PAB-B pavements is normally B650/900, which equals about 800 viscosity, in some special case harder 400-600 bitumen have also been used.

Low traffic volume roads are currently paved mainly using soft bitumen emulsified PAB-V pavements that are made in 50...70 C° temperature. Bitumen viscosity is usually 1500 and in some cases 3000. Anti stripping agent is used together with bitumen. Maximum grain size is normally 16 mm and material amount is 100 kg/m² (PAB-V16/100).

The most common pavement used before 1995 in low traffic volume roads was soft bitumen asphalt type PAB-O, also called oil gravel pavement. This pavement is cold mix pavement made of 16 or 20 mm dense graded crushed gravel aggregates. This pavement type has evaporating components, which is the reason it is no longer used for pavements except for some small scale patching operations.

Crushed aggregates for bituminous pavements in Lapland are made both of crushed gravel and of hard rock deposits. The use of hard rock has been increasing dur-

ing recent years because available gravel deposits are diminishing, and because the strength of hard rock aggregates is usually better. Finnish National pavement aggregate strength requirements are mainly followed, but if high strength aggregates are not available in the area, lower class aggregates have been used. That is especially in low traffic volume roads where rutting due to studded tires is not a problem.

Pavement type is chosen primarily based on AADT. Yearly costs determine the final decision between different pavement types. Availability and quality of aggregate also have an influence on decision making.

Usually base course has to be made using crushed aggregate. In old and low traffic volume roads the sub base is mainly made of natural gravel, but it has also been made of crushed aggregate. Sub base material does not have strict requirements for grading or aggregate strength compared with base material.

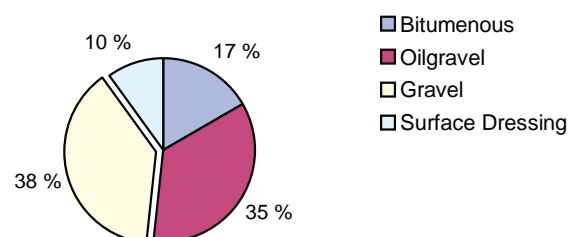
Filter course is made of sand. The sand material must not have a high fines content, organic compounds or stones greater than 50 mm and capillary rise must be less than 0.9 m.

In Lapland the gravel road wearing course is made mostly of crushed gravel or crushed glacial moraine.

The main criterion used for paving gravel roads has been traffic volume, normally 250...300 AADT, but if road structures are good and there are no frost problems, gravel roads with daily traffic even under 100 have been paved in order to save on maintenance costs. On the other hand, during the last few years some badly deteriorated sealed roads have been changed back to gravel roads because of a shortage in rehabilitation funds.

The Northern Region, Sweden

Distribution of road surface types in Northern Region



The mineral aggregate used for road construction can consist of both crushed natural gravel and crushed rock. The use of hard rock has increased during recent years due to regulations concerning the use of natural gravel. The strength and durability of the different layers in the

road structure is secured through certain requirements on the quality of the mineral aggregate and binder used for the layers in the structure.

The ball-mill value is used to describe both the durability and the strength of the mineral aggregate for bituminous layers as well as unbound layers. The impact value is also used, to a certain extent, to describe the strength. There are requirements on the particle size distribution for the aggregate in the subbase and the unbound road-base as well as in the wearing course and the bound road-base

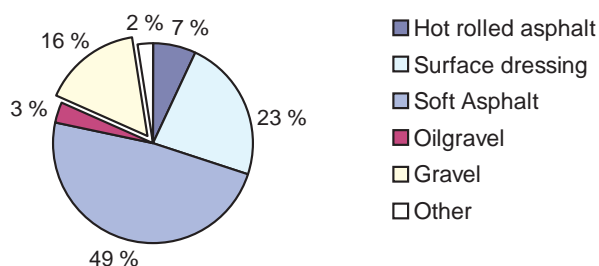
Materials for base course and sub-base may also consist of slag or other industrial by-product. These shall retain their volume and shall not exhibit any tendency to decompose. They must also be acceptable from an environmental and health perspective.

Protective layers shall consist of non-frost susceptible friction soil, it is most common to use sand, where either the (0.075/16) content is less than 12% by weight or the capillarity is less than 1 meter. The organic content shall not exceed 2% by weight.

Oil gravel is still the most common pavement in the Northern Region, even though it is not used anymore due to environmental reasons. Today semi-hot mixes are used for roads with an AADT less than 1500-2000. Standard viscosity for bitumen at 60°C is between 2000-15000 mm²/s, depending on traffic volume and whether the bitumen is being used for wearing course or base course. Cold mixes are becoming more common as the techniques, for using harder bitumen as the base on the emulsion are developing.

Troms County, Norway

Road Surface on National and County Roads in Troms County



In the Norwegian design procedure it is possible to use different types of materials. The layer thickness is dependent on the bearing capacity of the material (material coefficient). Each material has specifications for grading, strength and durability. The aggregate quality specifications mainly depend on traffic volume and where in the road structure it is used.

On roads where the traffic volume is more than 3000 AADT, hot asphalt mix is used in wearing and binder course. Most common is asphalt concrete with bitumen B85-B180 and maximum grain size equal to 16 mm. The layer thickness is about 110 kg/m². Stone mastic asphalt is used where the traffic volume is very high. The binder in the stone mastic asphalt is often stiffer than the one used in an asphalt concrete.

On roads where the traffic volume is less than 3000 AADT soft bitumen asphalt is the only asphalt type used today. In addition, remix of the wearing course is very popular.

The bitumen used in soft bitumen asphalt has a viscosity at 60 °C between 6000-15000 mm²/s. On main roads and where the bearing capacity of the road is sufficient, the stiffest bitumen is used. The maximum grain size is normally 16 mm, but when used for patching or for the levelling mix, the maximum grain size is 11 mm. The layer thickness of the wearing course is normally 100 kg/m² when using soft bitumen asphalt.

Oil gravel and cut back asphalt have been used previously, but not anymore. Oil gravel provides a good pavement surface on low traffic volume roads, but is too soft. Cut back bitumen is not used any more due to health and environmental problems caused by the solvent.

Troms has, for several years, used surface dressing on low traffic volume roads. These surfaces are too weak to resist the stress from graders that are removing ice and snow from the roads. Use of a 40 mm layer of soft asphalt is performing better on these roads and the lifetime is increased by 50-100 %.

During the past four years a lot of remixing of the wearing course has been applied in Troms. The equipment is purchased from Finland. When remixing, the road is heated to 50-90 °C. Then the hot pavement is milled and at the same time 20-40 kg/m² of new material is added. The old and new asphalt is mixed together in a mixer mounted on the equipment, soft bitumen is added and then the material is paved using a paver on the back of the remix machine. When using remix on soft bitumen asphalt, normally very soft bitumen asphalt (viscosity 1000 mm²/s) is added. When using hot mix asphalt the same type of material as the original asphalt is used as additional material.

The aggregate strength is measured using an impact test to examine the aggregate's ability to resist crushing. For testing durability Norway uses an abrasion test. The results from these two tests are used in an equation for calculating a value called Sa-value, this value describes the suitability for the aggregate very well. The Ballmill test is also used for testing strength and durability of the aggregates in the same way as the Los Angeles test.

As base course material Troms has been using crushed gravel on almost every kind of roads until 1988-90. At

least 30 % of the aggregates > 4 mm have to be crushed. During the last decade crushed gravel has been used in the upper base course only when the traffic volume is less than 300 AADT. On all other roads, stabilised material, as an upper base course, must be used, but crushed gravel or crushed rock may be used as a lower base course.

The most common base course material is called asphalt gravel. This is a mix of uncrushed or crushed gravel and bitumen B180-B370. This asphalt is proportioned using the Marshall test.

Non-frost susceptible or non water susceptible materials must be used for subbase. Norway has requirements for the grain size distribution (coefficient of uniformity) and for the mechanical quality of the aggregates. Rock, crushed rock and gravel is used for subbase.

As a filter course geotextile is normally used. The requirements for the grading of sand filter course depends on the materials on both sides and whether it is difficult to find usable sand close to work site.

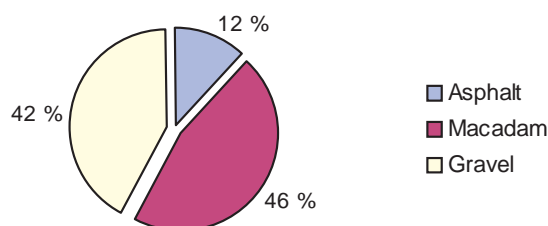
The Highlands, Scotland

adams generally use a 100 penetration bitumen, with the asphalts using a 70 or 50 penetration bitumen. The asphalts are gap graded, the macadams are continuously graded. Generally the nominal aggregate size increases with thickness of each course, typically 10 or 14mm for wearing courses, to 28 or 40mm for base courses.

The granular sub-base is generally Type 1, defined in the Specification Clause 850SO (a Scotland specific clause). The sub-base is almost exclusively a crushed rock material, graded to be within quite strict limits. Below this layer a further layer (a capping layer) may be used on poor subgrades. This material can be a crushed rock or gravel, but does not have such strict grading limits.

Most of the private roads are gravel sometimes with a crushed rock surface, although there is limited published information on these roads. For these roads the specification is crushed rock or gravel with fairly loose grading curves. The wearing course gravel will generally have a higher fines content than the lower layer. In practice almost any local material will be used if it is thought it will be successful.

Distribution of road surface types in Highland, including forest roads



The selection of road construction materials varies according to each site. For Trunk Roads, the wearing course is normally Hot Rolled Asphalt to British Standard BS 594. This document gives grading, strength and binder limits, but these are not detailed in this report as this material is used in the higher traffic volume roads, not the roads covered by the ROADDEX project. The other bound layers on trunk roads are generally bituminous bound asphalts.

Most of the Council roads are close graded bituminous macadam's to BS4987, with a surface dressing applied to give texture and to seal the surface against the ingress of water. All materials used are in accordance with the Specification For Highway Works (part of the Manual of Contract Documents issued by the Scottish Executive).

Two main materials are used for the bound layers: bitumen bound macadams and bitumen bound asphalts. Both generally use crushed rock or crushed gravel aggregates, and both can use a similar bitumen type. The mac-

5. TRAFFIC LOAD RESTRICTIONS

5.1. Allowed normal axle loads; other requirements for heavy vehicles

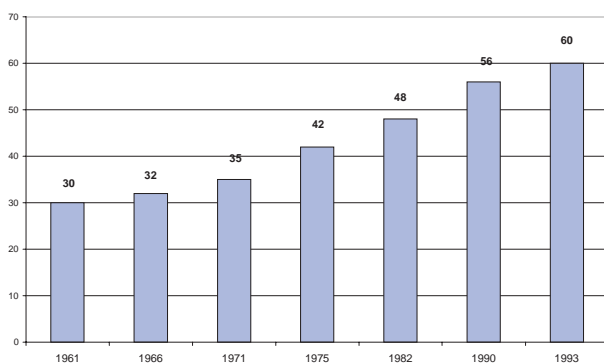
Lapland, Finland

In Finland, uniform maximum axle loads of 100 kN (10t / 11,5 t) applies to all road classes. The highest allowed bogie load depends on the number of axles and axle spacing and varies between 110 and 240 kN. The maximum allowable total weight for all roads is 60 tons and this total weight requires seven axles. Road districts give separate licenses for super heavy transportation projects.

There are currently 45 bridges with weight limitations in Lapland.

Super single tires are allowed with a recommended maximum tire pressure of 850 kPa.

Maximum dimensions for trucks in Finland are: length 25.25 m, width: 2.6 m and height: 4.2 m



Allowed total weights in Finland since 1961
(Finnish Trucking Association)

The Northern Region, Sweden

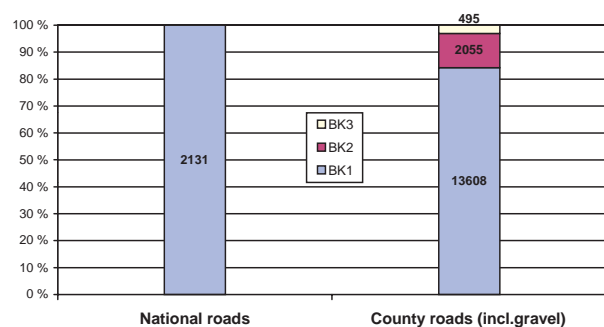
The maximum allowed axle and bogie loads and total weight depend on the classification of the road by bearing capacity. Region Norr uses three bearing capacity classes, with the following maximum loads:

	Driving axle	Axle	Boggie	Triple	Total weight [ton]
BK 1	11,5	10	19	24	60
BK 2	10	10	16	22	51,4
BK 3	8	8	2	13	37

Approximately 2.800 km of public roads have permanently restricted maximum axle loads and total weights. Often this restriction is due to one or two weak bridges in the road section, so it is sometimes possible to reduce significantly the length of load restrictions just by reconstructing a smaller bridge. During the winter season when the ground is frozen, it is possible to temporarily upgrade many of the BK1 and BK2 class roads. This means that during 4-5 months every winter only 4% (700 km) of public roads in the road district have permanent load restrictions - these mainly due to weak bridges. The Road Authority can also give licenses for super heavy load transportation projects.

Super single tires are allowed in Sweden. There are no restrictions concerning tire pressure.

Maximal allowed vehicle dimensions are: length 25.25 m, width 2.60 m (load included).



Permanent bearing capacity restrictions in Northern Region

Troms County, Norway

Maximum allowed total weight for a vehicle in Norway is 50 tons. In Troms County, 90,3 % of national and county roads permits this load, 9,3 % only permit 40 ton total weight and 0,4 % have 28 or 32 ton maximum weight. The road network is divided into four groups depending on their bearing capacity. Road class directs maximum permitted axle load as presented in following table.

Maximum axle loads in each road class in Norway

Axle combination	Distance between axles	Ton axle load			
		Bk10	BkT8	Bk8	Bk6
Axle load - single		10	8	8	6
Driving axle - single		11,5	8	8	6
Load from two axles	1,30-1,79	18 ¹⁾²⁾	14	12	9
	1,20-1,29	16	12	12	9
	0,80-1,19	15	11,5	11,5	8,5
	< 0,80	10	8	8	6
Load from three axles	1,30-1,80 ³⁾	24	19	16	12
	1,00-1,29 ⁴⁾	22	18	16	12
	< 1,00 ⁴⁾	16	12	12	9

¹⁾ 11,5 ton on driving axle

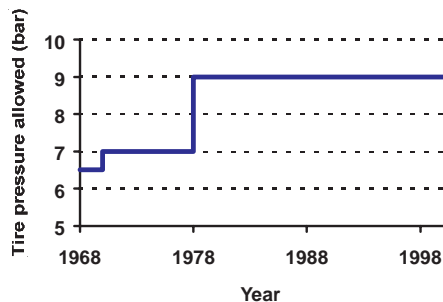
²⁾ 19 ton on twin tires or air suspension

³⁾ Both distances

⁴⁾ One or both distances

The maximum allowed vehicle length is 22 m, and 78,3 % of the national roads in Troms permit this length. The rest permit for 18,75 m. For the county roads 95,9 % permit length 18,75 m and the rest 15 m. Maximum vehicle width is 2,6 m.

The public road office in Tromsø has the authority to give licenses for super heavy load transports inside Troms County or directed to neighbouring counties.



Development of maximum allowed tire pressures in 1968 - 1999

The Highlands, Scotland

The regulations concerning traffic loading are complicated, with vehicle configuration playing a large part in the allowable axle loads. In general the maximum allowable axle weight is 9.5 tonnes, but where the axle is a driving axle, this can be increased to 10.5 or 11.5 tonnes, depending on the arrangement of tires.

The maximum allowable vehicle weight is 41 tonnes over a minimum of six axles, (with driving axle restricted to 10.5 tonnes and all other axles no greater than 8.5 tonnes). An exception is for vehicles involved in inter-modal transport operations (rail/road), where the maximum allowable weight is 44 tonnes. Such a vehicle must be coming from, or going to, a railhead. Some roads are 'weight restricted' simply because the road width and alignment is unsuitable for all but the smaller vehicles.

Single tires (also known as 'super single' tires) are allowed but must have a road contact width greater than 300mm. For vehicles above 38t road friendly suspension and twin tires (on all axles except drive axle) must be used (EU Directive 85/3). The tire manufacturers dictate tire pressures for their tires. For normal tires the maximum pressure can be up to 9 bar. For special tires, i.e. for non-standard use, the pressures can be up to 9.9 bar.

The maximum vehicle dimensions are

Length 16.5m (articulated vehicles) or 25.9m (road train with two trailers)

Width 2.6m (although allowable load width is 2.9m)

Height - no restriction, but vehicles greater than 3m must have warning notices in the cab.

Bridges with a clearance of less than 5.5metres are signed with the allowable height.

For transportation of loads up to 80 tonnes, The Highland Councils gives authorisation. The Scottish Executive gives the authorisation for transportation loads >80 tonnes. The U.K. Department of the Environment, Transport and the Regions (DETR) gives authorisation for transportation of loads >150t, width >6.1metres or length >27.4 metres.

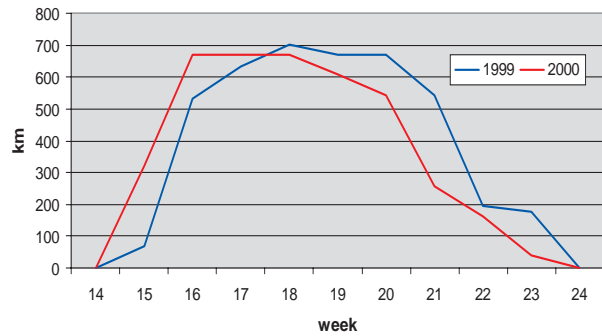
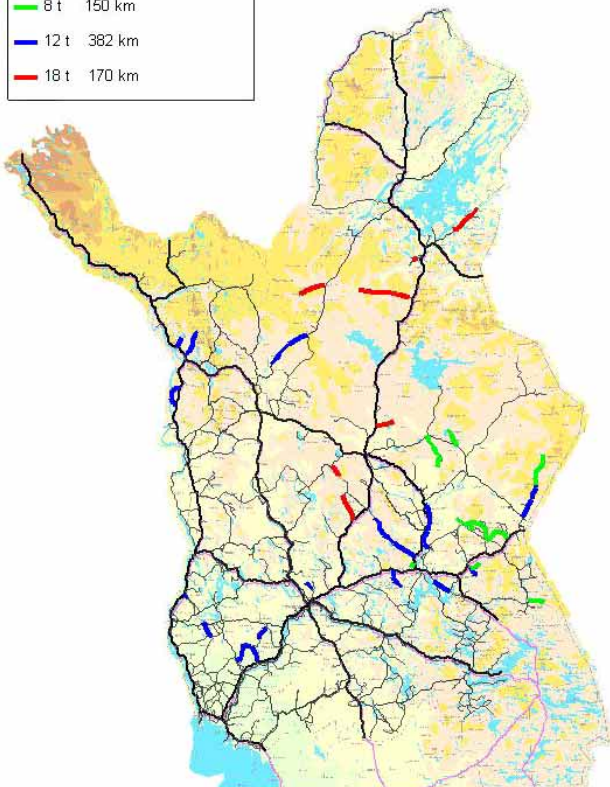
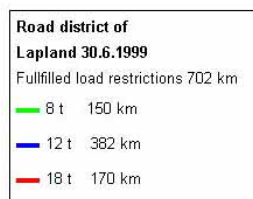
5.2. Temporary load restrictions

Lapland, Finland

In the Lapland Region load restrictions are mainly applied on gravel roads. Approximately 650 km of roads are annually subject to load restrictions, around 20% are paved roads. Load restrictions used are 4, 8, 12 and 18 tons of total weight. Sometimes a frost damage period is so bad that some road sections must be closed to all traffic. These however are roads of minor importance and not needed for public transportation.

The decisions for load restrictions are made by the road district and they are applied mainly during the spring frost thawing period from April to May. Load restrictions are marked by traffic signs and information of load restrictions is provided by the road district office, traffic information centers and area supervisors.

Before the load restrictions are applied a meeting is arranged with transportation companies to inform them

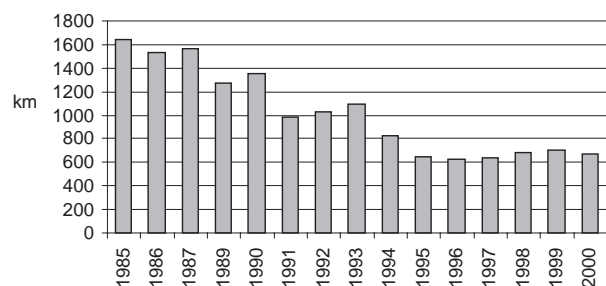


The development of the amount of weight limitations in Road District of Lapland in 1999 - 2000

about foreseeable restrictions and to discuss the possibilities to minimize the problems during the frost thawing period. This practice has especially helped timber transport companies to arrange their operations in advance so that the restrictions do not interfere with their work. Exceptional permits still have to be granted for food, fuel, agriculture and animal transport. In some special cases, short-time permits are also granted for mornings after frosty nights for other short-time deliveries.

In 1999, load restrictions were imposed on a total of 706 km of secondary roads. The amount of load restrictions has decreased rapidly in recent years, and today is only about a half of the amounts in mid-1980's.

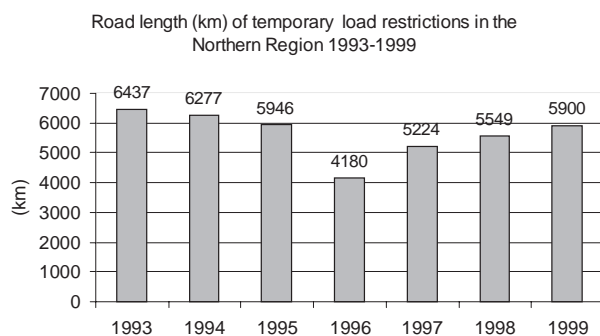
Road length (km) of temporary load restrictions in Lapland during 1985-2000



Development of temporary load restrictions in Lapland in 1985-1997

The Northern Region, Sweden

In the Northern Region, the relative length of axle load restrictions is the highest of all project partner districts. An average of 5.840 km or 33% of the public road network in the Northern Region in the time 1988-1997 was closed to heavy traffic because of spring thaw. These restrictions prevail for an average of 50 days in April - May. Approximately 1.400 kilometres of the restricted roads are paved. It is primarily roads with single surface treatment on unbound road base that are closed to heavy traffic for preventive reasons. The rest, approximately 4.400 km, are gravel roads. This means that about 60% of the gravel roads in the region are affected by frost damage restrictions.



Temporary load restrictions in the Northern Region in 1993 - 1999.

Decisions regarding axle load restrictions are made based on visual evaluation of the road surface and the local engineer's observations of road performance in the area. The Road District decides when to impose load restrictions. During weekends the responsible contractor can decide about restrictions, but the first workday the road district must make the decision whether the restrictions shall continue or not.

In 1996, SNRA submitted new guidelines, concerning springtime load restrictions, in response to transportation needs, especially those of the logging industry in the area. According to the new guidelines, restrictions shall not be imposed on paved roads unless there is a strong indication of potential damage to the road (for example a marked tendency to wheel track formations). For gravel roads, at least 1 % of the road length must show signs of severe damage before load restrictions can be imposed.

Road users are informed of restrictions by traffic signs. Every year the forest industry is informed of the current road condition. There are regular meetings where special transportation needs are discussed and agreements are reached e.g. about operating transports at night time when the roads are frozen. Timber trucks may be granted permission to use certain problematic roads, provided they are repaired after use.

Troms County, Norway

Spring time load restrictions are no longer imposed in Norway since 1995. Still, in 1994, 50% of national roads and 96% of county roads in the Northern Periphery area in Norway had load restrictions. The new policy is based on the results of the research project BUAB, completed in 1994, which concluded that the gains to the road user, from abolishing of all load restrictions, would exceed by double the costs to the road owner, provided that the surface life was maintained at present level.

Currently load restrictions are only used when it is certain that the road surface will break down during the spring thaw. The Director of Public Roads in each county decides when and where to impose load restrictions, based on reports from local maintenance supervisors. A load restriction is announced in newspapers, on the internet and on local and national radio broadcasts. Traffic signs will also inform road users of load restrictions. The public road administration holds meetings, once or twice a year, with transportation businesses and other significant road users such as the army, to discuss co-operation and special transports needs.

Normally the length of the spring thaw in Troms County is 4-8 weeks. The previous practice was to commence the restriction period when the thaw depth was 10-20 cm. The lifting date was dependent on total frost depth and the ratio between permitted axle load during spring thaw and in summer. (For example, with the ratio of spring thaw/summer axle load 0.8, the load restriction was lifted the thaw depth was 1.25 m.)

The Traffic Department, via district personnel, observes and reports how the condition of the roads changes during the spring thaw. They also use frost tubes to measure the thaw depth.

The Highlands, Scotland

Temporary restrictions in the Highlands are not made for spring thaw conditions at present, as the frost thaw weakening is not usually significant. However where a road is subjected to increased use of heavy trucks and is deteriorating, restrictions on use can be imposed to prevent further damage. Such preventative weight restrictions are typically applied for single track roads where timber transportation takes place, or on road sections with weak bridges and retaining walls. Emergency restrictions can be made for 6 weeks and temporary restrictions for 18 months; normally such restrictions become permanent unless mitigating measures are taken.

The region is divided into eight 'areas', and in each of those areas the Area Roads and Transport Manager decides on the application of road restrictions. Any proposal requires the Roads and Transport Committee to



approve before legal measures can be taken. This procedure involves publicising the proposal and providing a period for objections. Consultation with Freight Transport Association, Load Haulage Association and other bodies is carried out when a road order is proposed. Should objections not be resolved then a Reporter selected by the Scottish Executive would decide whether the Order should be made. Restrictions are often applied to bridges even if the road requires it, as the public can more easily accept bridge restrictions than road restrictions.

To date there are around 175 km of roads restricted in use in The Highland Council area. The highest allowed restricted total weight is 17.5 tonnes, but this can be reduced to 7.5 tonnes or even 3 tonnes.

5.3. Controlling the implementation of axle loads and load restrictions

Lapland, Finland

In Finland the police and local area supervisors control load restrictions, but only the police can impose fines. Area supervisors are only allowed to contact the police when they observe overload transportation. Fines are used as overload penalties and the amount of the fine is stepped according to the amount of overload.

The police control axle loads as a part of traffic surveillance. Axle loads are measured using portable scales. Finnra also conducts axle load measurement to study the amount of loads. The area supervisor's duty is to make observations on load effects to the road structures. An inventory of road damage is made annually. The results of these inventories are a basis for rehabilitation measures.

The Northern Region, Sweden

The police control axle loads as a special part of traffic surveillance. The Road Authority, who also pays for the whole of the traffic surveillance, decides on the level of control. The public often contacts the Road Authority if they suspect an overload. The Road Authority then contacts the police if a control is to be made. A progressive fine is used as an overload penalty. Both the driver and the haulage company are subjected to the penalty.

The police have 4 stationary and 3-4 portable weigh-scales for the load control. There is also an on-going R&D project to test different types of WIM (weight-in-motion) measuring devices in cold climate. These devices are installed in the pavement on the national road E4 outside Luleå, but they are only used to indicate that there might be an overload. In order to prosecute, the vehicle must be weighed on a stationary or portable scale.

Troms County, Norway

The Traffic Department of the Troms County road administration office also has the responsibility to control axle loads and total weight of the vehicles via district offices. It possesses six stationary scales for measuring triple axles up to 30 ton as well as transportable scales for measuring wheel load up to 10 ton. These scales are tested as scales used for trading.

There are different kinds of sanctions when a vehicle is overloaded:

- the haulage company has to pay a fine (there are fines set for both axle loads and total weight of the vehicle; the highest of these two will be used)
- unloading the vehicle
- the driver will be reported to the police and will receive a penalty
- if the overload is extreme, the driver can lose his licence to drive, the haulage company can lose their permit to do transportation and the vehicle can be denied to be used for transportation.

The Highlands, Scotland

The Highland Council as the roads authority does not enforce weight restrictions. Only the police can enforce weight restrictions. On roads with a 7.5t or a 17t restriction, enforcement is based on the plated vehicle weight, irrespective of whether the vehicle is empty or not. On roads with a 24t and other restrictions enforcement is more difficult. For enforcement to succeed the vehicle must knowingly pass an authorised public weighbridge on its intended journey. Unfortunately there are insufficient numbers of these weighbridges in this area to allow ef-

fective enforcement.

In addition to the above actions, there is a Traffic Commissioner, employed by Central Government, who has the power to set up police checkpoints and weigh all heavy goods vehicles using portable weighmats. Overloaded vehicles can be impounded until the load has been reduced to an acceptable level, and other penalties can be imposed.

There are currently no axle restrictions in the Highland Council's area primarily because they are difficult to control. It is more effective to restrict the length and width of vehicles (which effectively restricts the heavier vehicles) as this is easier to enforce. Recent campaigns to prevent overloading and subsequent damage to the roads have been heeded by haulage companies and have had some success. Additionally many of the timber haulage vehicles are now fitted with 'self weighing' trailers, so that overloading should be further contained.

Comparisons

The following table summarises how traffic load restrictions are controlled in the partner road districts.

	Finland	Norway	Scotland	Sweden
control enforcing authority	the police	Troms County road admin./ Traffic dept.	the police	the police, on assignment of the road admin.
primary object of control	axle load	axle load, wheel load	vehicle length and width, plated vehicle weight	axle load
control equipment	portable scales	stationary/ transportable scales	weighbridge, transportable scales	stationary/ transportable scales
sanctions	stepwise progressive penalty fees	penalty fees, unloading, revocation of license	penalty fees, unloading, revocation of operator license	progressive penalty fees (both driver and the haulage co.)

5.4. The effect of load restrictions, now and future aspects

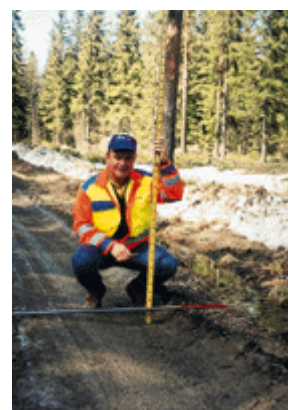
Lapland, Finland

According to customer satisfaction surveys conducted in Lapland, heavy transport carriers are mainly satisfied with road conditions. Load restrictions are mainly applied to gravel roads. The most effected transports are those of timber and peat. Cooperation with transportation companies together with road structure improvements has enabled that, since 1988, 25-30 km of load restrictions has been removed annually in Lapland. To monitor the effects of traffic load and frost, an inventory of road damage is made annually for a part of the road network. The results of these inventories are a basis for rehabilitation measures.

In the future the goal is to continue to reduce load restrictions by using road structure rehabilitation measures. In Lapland severely damaged roads with bearing capacity problems are repaired approximately 25 km/year. A future goal is to develop real-time pavement condition monitoring systems to optimise the timing of load restrictions. In the future more attention will be given to the understanding of the mechanism of deformation caused by spring thaw weakening of the road structure.

tions, an extra cost of 900 MSEK (105 million euro) strikes the forest industry every year; a major part of that cost is incurred in the Northern Periphery area.

Inspections are currently being carried out as to how the guidelines by the Road Authority, to diminish load restrictions, since 1995 have affected the performance level of the road network. The long term effects are difficult to predict; if the funding for maintenance and upgrading of the road network is insufficient it will be difficult to reduce load restrictions in the future.



The Northern Region, Sweden

The forest industry in Sweden is highly dependent on a functional road network. Due to temporary load restric-

The effect of low tire pressure to gravel road deformation during the spring thaw season. Left photo describes results of a standard vehicle after 6 passes and the right photo deformation after CTI-vehicle with lower tire pressure after 30 passes.

There are ongoing research projects for the purpose of reducing load restrictions. One of these is testing a technique called CTI (central tire inflation). CTI is a device with which the driver can control tire pressure while driving. If the tire pressure is reduced, the contact area between the tire and the road surface increases, which leads to lower shear stress in the upper layers of the road structure.

Tests show that a 60-ton CTI-vehicle can drive on a weak gravel road during the thaw period without causing too much damage. In fact, the standard vehicle after six passes had caused ruts of about 25 cm, while the ruts caused by the CTI-vehicle were only about 1 cm after 6 passes and 16 cm after 30 passes. This is an interesting technique, which will be further developed in the future. In Sweden there are also experiences of low truck speeds (i.e. 50 km/h) being less damaging to the road than normal truck speeds.

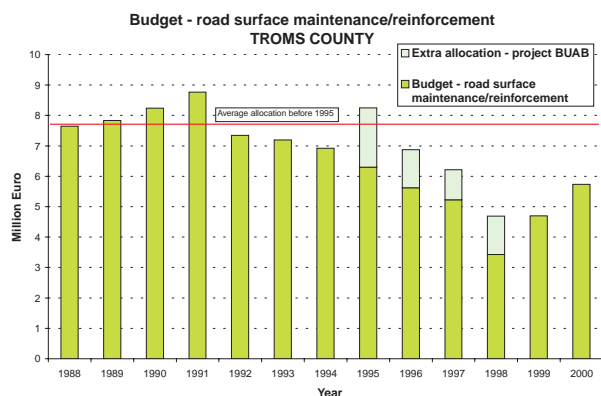
Troms County, Norway

Very few road sections have broken down after ending the use of temporary load restrictions in 1995. Rutting depth has increased both on national and on county roads, but this development cannot entirely be blamed on the heavier axle loads during spring thaw. The decrease in road maintenance funding has also caused the road network to deteriorate.

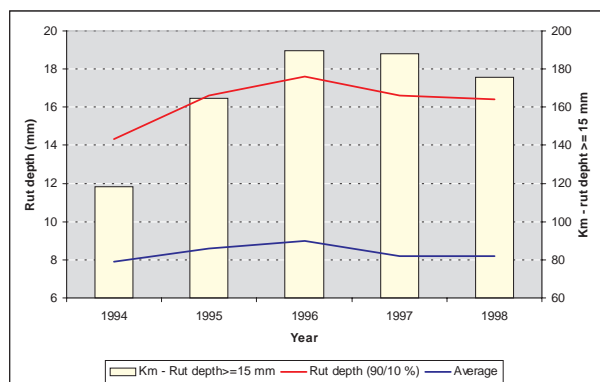
For many of the roads in Troms County, which currently have maximum allowed axle loads less than 10 tn, the industry and the local authorities ask for reinforcement of the road or for new bridges. However, currently the road authority is facing the problem of insufficient financial allocations for maintaining the structural condition of the roads; a lot of repair measures carried out today only repair the road surface and do not address the cause of these defects. In the future if the funding remains at the same level as today or decreases, the road authority will have to reconsider springtime load restric-

tions. The situation also calls for the development of rehabilitation methods that are more cost-effective than those previously used.

As a part of the BUAB project, road users' needs were investigated with the main conclusion that savings in transport costs would be approximately 91 MEuro per year (1993) if the road network performance would remain at the same level. If the load restrictions were lifted without increasing the allocations for maintaining the road surface and rehabilitation of roads with low bearing capacity, the transport cost would increase by 49 MEuro per year (1993). If the allocations are not increased the increase of deterioration of the roads in Troms region might be seen in some years.



Development of allocations for roads in Troms region since 1995. The red line presents average allocation before 1995. Extra funding was granted as a result of BUAB project, to be able to maintain the performance level of the roads. By 1997, the total allocations have however declined under the previous funding level.



Development of rut depth after lifting the temporary load restrictions in Troms County 1995.

The Highlands, Scotland

There are only a limited number of restricted roads in Highland and the general view is that the roads are in a reasonable, although deteriorating, condition. The transportation companies would like unrestricted access to all areas, but appreciate that this will not be possible without significant investment. In the current economical climate such funding will very rarely become available, unless a private developer or investor supports the upgrade of the road infrastructure. As the funding of improvements to the large amount of old roads with insufficient bearing capacity becomes increasingly difficult, it is likely that more restrictions will be imposed.

One element of the road network, which may create future restrictions, is the bridges. Until the late 1970's, the maximum allowed vehicle weight was 32 tonnes, which then increased to 38 tonnes without checks on the carrying capacity of the bridges. However, with the planned introduction of 40/44 Tonne vehicles from January 1999, the Government's Department of Transport announced in 1987 that a programme of assessment and

strengthening of trunk road bridges would be undertaken, to ensure that these could safely carry the current 38 Tonne vehicles and the proposed heavier vehicles.

The Scottish Office commenced its element of this programme on Trunk Roads in 1989 and had, by then, written to all Local Roads Authorities advising that it expected them to undertake their own similar programmes, on a similar timescale. The following is The Highland Council position at July 1999.

There are some 871 bridges carrying adopted public roads, which have not been assessed. Of that number, 56 are in private ownership, the great majority being owned by Railtrack p.l.c.

In many cases, assessment has confirmed or will confirm that a bridge is sub - standard, and that strengthening or replacement is required. It is estimated that the total cost of upgrading Council bridges to meet modern loading requirements is £ 50 million. (approx 80m Euro). Obviously with funding being restricted year on year, it will be difficult to maintain unrestricted access to all parts of the area.

	OWNERSHIP		
	The Highland Council	Private	Total
No. of bridges to be assessed	1,450	60	1,510
Assessment completed by July 1999	635	4	639
No. of bridges not assessed	815	56	871

6. ROAD CONDITION MANAGEMENT

6.1. General Road Condition Problems

Lapland, Finland



The most significant problems in road condition management in Lapland, according to interviews conducted during the study in the district office, are those related with poor quality base course material, frost action in subgrade, peat subgrade, and insufficient drainage especially where the road is constructed on a slope. Typical damages are longitudinal cracking, uneven frost heave, and shoulder deformation.



The Northern Region, Sweden



Typical road condition problems on secondary roads are poorly performing drainage, road structures that are too thin, poor quality base course materials (excessive fines content), frost susceptible subgrades, and peat under the road structure. The main pavement related problem in the region is ageing, but transverse cracking, plastic deformations in certain recycled pavements, and pavement disintegration also occur in some areas. Shoulder deformation and longitudinal cracking are the most common road structure related damages.



Troms County, Norway

Uneven frost heave due to frost action, shoulder deformations and thaw weakening can be experienced especially where roads are constructed on slopes so that half of the road is in the road cut, the other half resting on an embankment. Restoring insufficient drainage was previously a continuous task for maintenance, but as the funding for road maintenance has fallen, the maintenance of ditches has been left out from the routines. Today drainage is restored only as a part of a reinforcement project.

In some low traffic volume roads in Troms County problems are related to the use of too soft binder in cold mix recycled pavements which has led to deformations. Poor bitumen-aggregate adhesion has caused pavement disintegration in road curves.

The spring thaw causes a lot of problems especially on gravel roads.



The Highlands, Scotland

According to district engineers, major problems appearing now in the road structures in the trunk roads relate to the use of a lean-mix concrete roadbase in new road construction from around 20 years ago. The concrete is breaking into 'slabs' which are rocking under traffic causing transverse cracks and leading to water ingress and further deterioration. For the Council roads, peat and very soft silt subgrades are the main cause of problems, resulting in rutting and cracking, especially at the road edge. Many of the older roads also have drainage problems. The type of subgrade, the form of land, and the landowners on each side retaining the land to their use are factors which limit drainage possibilities in the Highlands. In many parts of the older road network, high grass verges also prevent water from flowing away from the roadway. The pavement defect requiring attention is normally a loss of surface texture, which causes a skidding hazard. Surface dressing (sprayed bitumen emulsion with layer of single size stone) is widely used to restore skid resistance and seal the surface against water ingress.



6.2. Road condition data bases

Lapland, Finland

The following pavement condition measurements are conducted systematically in Lapland : IRI, rutting, GPR (pavement structure layer thickness measurements), distress mapping. The results are stored in the road-register-based road condition data base KURRE and used for maintenance planning and rehabilitation design.

The HIPS (Highway Investment Programming System) system is used for road network planning and to calculate long term optimal road condition. The needed financing to keep the road network in optimal condition can be calculated by using HIPS system. HIPS utilizes the AADT and road condition measurement data from road register and KURRE and yearly updated degeneration and cost models.

T&M Sora system is used for gravel road management. Frost thaw weakening data is stored in T&M Sora's data base and is utilized for rehabilitation programming.

The Northern Region, Sweden

SNRA's PMS data bank stores roughness and rut depth data, which is collected systematically on a network level since 1987. Deflection data is collected and stored on project level. Distress data is generally not recorded in the data bank; road construction data (layer thickness) is stored when attained using GPR or probes. Another database containing actual and historical data of road maintenance treatments is also connected to the PMS.

Road condition data from the PMS data bank is used by the SNRA's seven regions e.g. for analyses of increasing rut depth and/ or roughness of the road network, as well as for socio- economic calculations. Maps and lists from the PMS are used to make presentations about the roads. PMS is also used for annual maintenance plans for pavements in the Northern Region.

Troms County, Norway

FWD, roughness and rutting measurement results are stored in the road database. Area pavement engineers use the roughness and rutting results together with pavement distress data to evaluate the need for pavement rehabilitation. The results of these evaluations are presented to the main regional office, where rehabilitation project prioritisation and project planning is done. In doing this, special attention is paid to the rate that roughness and rutting values increase in different road sections.

The road database also includes various other road data such as the cross slope of the road, traffic volume, pavement history, width of the shoulder and the asphalt layer, permitted speed and axle load, and curvature. Additionally there is a database with digital pictures of paved roads for every 20 m in both directions. These pictures are also being updated every year. Lately, the road administration has started to register information on the drainage system, culverts and places with frost heave problems in the road database.

The information stored in the road database is used in the rehabilitation project planning and prioritising. The need to start collecting more information about elements of the road network is connected to the new practice of contracting out road maintenance tasks.

The Highlands, Scotland

For the trunk roads, a PMS/SERIS (Scottish Executive Road Information System) database is maintained, for which measurements are carried out with 3-5 year intervals. The database has residual life models for each factor, made according to British models. PMS has three data sets: raw data, trended data and disassembled data sets. Together with the structural data collected from the road SERIS allows reviewing traffic volume data and traffic safety data. SERIS software allows on-screen road condition visualization with digital video image of the road at 5 m intervals linked to GIS maps.

For Highland roads there is not an appropriate road network length database; the road condition evaluation is not performed in a systematic way, and the evaluation data collected by road supervisors is not stored in any database.

6.3. Road Condition Evaluation Methods

6.3.1. Roughness and rutting surveys

Lapland, Finland

Since 1990-91 rutting and roughness measurements have been carried out throughout Lapland, annually on the main roads and biannually on other roads, using a special PTM (Serviceability level measurement) vehicle. This vehicle carries a system which measures roughness on the right wheelpath using a laser sensor, and rutting on transverse sections using ultrasonic sensors. The measurement results for network level road surveys are stored per 100 m mean value in the PMS database. For project level surveys, the so-called 5m-IRI value (IRI mean value per 5 meters) and 10 m mean rutting value are collected in order to provide more exact information about the road condition.

The Northern Region, Sweden

The IRI value and rut depth are measured annually on about 50% of the paved roads in the Northern Region. Main roads are measured every year and low traffic volume roads are measured every second year. The roads which have a width less than 4 m, as well as short paved sections in the middle of gravel roads are not measured. On high volume motorways every lane is measured; on other roads the lane with a higher amount of heavy traffic is measured.

Troms County, Norway



Roughness and rutting measurements on the road network in Region Troms are carried out extensively each year, using a road survey vehicle. This vehicle measures roughness (IRI) from both wheel paths, the rutting value using 17 sensors in a transverse direction, as well as the cross slope and curvature radius of the road using a gyroscope technique.

Roughness and rutting values are first stored in a portable computer. A road survey car measures, for example, rut depths and cross slopes every meter, but only the median value for every 20 m is stored in road data bank. Roughness and rutting measurement results together with pavement distress data are used to evaluate the need for the pavement rehabilitation. Special attention is paid to the rate at which the roughness and rutting values are increasing in different road sections.

The Highlands, Scotland

Rutting evaluation for Trunk roads is based on measured data obtained from a specially constructed vehicle which operates at traffic speeds. The vehicle measures longitudinal profile, rut depth, texture depth and alignment features (such as gradient, crossfall and radius of curvature), and video is used to assess cracking and other distress. Skid resistance is measured using Scrim technique. Other measurements, including GPR and FWD, are taken using other equipment when necessary.

Roughness and rutting are not routinely measured on the lower traffic volume roads on the Highland Council network.

6.3.2. Pavement distress / defect mapping

Lapland, Finland

A visual inspection of all paved roads is carried out at three year intervals to keep a systematic register of classified distress factors. Distress mapping is conducted visually by two men driving slowly along the road and recording observations with a laptop computer connected to a DMI. The data are stored in the road-register-based road condition data base KURRE, and a special “distress sum” index is calculated from the data. This sum index describes the extent of pavement distress in the form of sq.m/ 100m.

The distress data is used in pavement design, where it is the most important single factor. In Lapland Region, the paved road network has been inspected 2-3 times since 1988-89 when this distress mapping method was introduced.

Drainage is not evaluated systematically on paved roads at network level, but when a road section is selected for pavement rehabilitation program, the cross slope of the pavement and the condition of the ditches and culverts are evaluated. The condition of culverts is also evaluated before each long-term maintenance contract.

For gravel roads, there are three different condition evaluation systems:

(1) In the “T&M Sora” gravel road management system, a visual evaluation of the thickness and condition of the wearing course and condition of drainage (ditches and culverts) is carried out using a GPS -based system. The T&M Sora road condition classification A, B,C indicates the necessity for rehabilitation measures.

(2) Another gravel road classification system used in Finland focuses on the spring thaw weakening of the gravel road. Visual evaluation is based on the severity of the thaw weakening and is repeated each year on gravel roads with known spring thaw problems. This method was first used in Southern Finland during the early 90’s and was first applied in Lapland during 1996-97. The results of this monitoring system are used to allocate rehabilitation funding to the most problematic roads.

Lapland Region aims at decreasing the amount of road sections subject to spring thaw weakening by 25 km a year. Systematic evaluations have contributed to a decrease of the total length of affected roads, but at the same time the number of short road sections showing thaw weakening has increased. Another observation made during the course of the systematic mapping is, that spring thaw problems can appear in different locations in different years.

(3) The third gravel road inspection system used in

Lapland is called “Soratala”. Data collecting for this database is done by maintenance contractors, following specifications of the national gravel road quality monitoring system. The inspection reports are delivered to the controlling road administration and the data is registered on quality monitoring forms and in the gravel road condition monitoring information database (Soratala). The information stored in Soratala is accessible on the intranet.

The Northern Region, Sweden

The Swedish PMS system has no systematic procedures for distress mapping. Each district evaluates damages using its own method. Distress mapping is carried out mainly by maintenance contractors following precise orders. Each contractor must keep a record of the distress information from the area, as well as compile a list of anomalies. The distress types recorded are: rutting, cracking, shoulder deformation and potholes. During the year 1999 SNRA Construction and Maintenance unit started to use GPS in the collection of road condition information.

On gravel roads, distress mapping is carried out either during spring thaw period or the fall rain season in order to evaluate the need for axle load restrictions. (In the Northern Region at least 1% of the road length must show signs of severe damage before load restrictions can be imposed.) Information about the condition of gravel road is collected both at the network level and at an individual road level, but not at project level.

There is no systematic approach for collecting information about drainage performance. In maintenance contracts, the number and condition of culverts is documented. According to current policy, deficiencies are reported if less than 80% of drainage functions are required.

Troms County, Norway

Damages on the road network in Troms County are evaluated using a newly purchased VidKon system which takes a digital photograph of the road at 20m intervals. The pavement distress data collection out annually and this information is stored in the database of the County Road Office. Detailed distress evaluation is made when a section was chosen for paving program.

The defects to which most attention is paid are deformation along with longitudinal and transverse cracks. Alligator cracking has not been a problem on soft bitumen pavements.

Gravel roads in Troms County have received relatively little attention, and there is no systematic approach for

collecting distress information about their condition. The wearing course thickness on gravel roads should ideally be 50 mm, but in many instances this has not proven to be the case.

The Highlands, Scotland

Road condition evaluation of the road network of Highlands is performed visually by road area supervisors who make lists of the defects for the roads in the area. The condition evaluation is made throughout the year with 1-3 month intervals between routine checks for road safety reasons, but it is not based on any systematic approach. Each supervisor can emphasize different factors in his evaluation. Currently the system is based on professional experience more than on systematically measured data.

However the Council has recently purchased a number of vehicle mounted video recording devices with DMI,

with the intention of surveying the whole road network on a regular basis and archiving the information onto CD.

The Trunk Roads (Scottish Executive) are regularly measured using the Multi-function Road Monitor, a vehicle designed by WDM which gathers a lot of geometric and distress information at traffic speeds.

All gravel roads belong to local landowners or to forestry companies. Forestry roads are classified according to local requirements, with any distress noted and controlled by local measures.

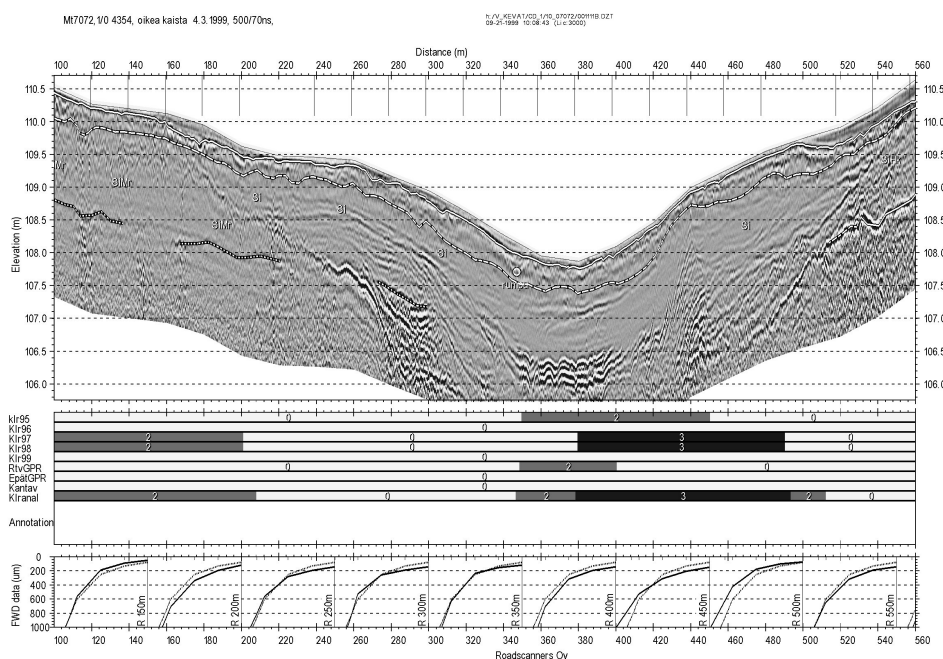
There is no systematic approach to monitoring road drainage problems other than visual inspections. Problem areas are known and are subject to routine maintenance at certain times of year and after particular environmental conditions. For new road construction the drainage design forms an important part of the project and accommodates both surface water runoff and ground water.

6.3.3. Bearing capacity and pavement structure measurements

Lapland, Finland

Bearing capacity measurements in Lapland are carried out using Swedish KUAB falling weight deflectometer (FWD). During the early 90's measurements were repeated at three year intervals, taking approximately 10 readings from each road section. At present FWD measure-

ments are made at 100 m intervals although the time interval is longer. The E2-value is calculated from the measurement results and this value is still used in the PMS system, even though it is generally accepted that it does not accurately illustrate the bearing capacity of the road.



GPR data from a gravel road collected in April presented together with spring thaw weakening data and FWD data.

Surface curvature index (SCI) and base curvature index (BCI) are better indicators and are used in project level surveys.

The FWD measurement data analysis is performed in Finland mainly using APAS software. This software can also be used for the dimensioning of the new road structure. Another FWD data software called KARHU is used to provide a general overview of the bearing capacity of a specific road section.

FWD data is also analysed together with ground penetrating radar (GPR), roughness and rutting data and pavement distress data for project level road condition analyses, using Road Doctor software.

The GPR technique was tested first in Lapland in 1986 and the road district purchased its own GPR system in 1998. Since then, GPR technique has been applied practically in every road design and rehabilitation project. In the area of subgrade soil evaluation GPR is used to identify soil type, to estimate the thickness of overburden and to evaluate the compressibility and frost susceptibility of subgrade soil. In road structure surveys, GPR has been used to measure layer thickness, to detect sub-surface defects and to evaluate base course quality. In quality control surveys GPR techniques are used for thickness measurements, to estimate air void content of asphalt, and to detect asphalt segregation. Electrical resistivity surveys (2D imaging) are used especially for measuring the thickness of soft clay and silt subgrade layers.



Finnra GPR van

Road structure sampling is carried out in pavement design projects; usually pavement thickness and the quality of the base course material are evaluated from the samples. A new Tube Suction Test (TST) is also used to monitor the moisture susceptibility of unbound aggregates, as well as in proportioning the binder content of a new stabilised structure. The amount of sampling has decreased significantly during the last few years since the integration of GPR results has optimised the amount of sampling and laboratory analyses needed.

The Northern Region, Sweden



Sampling pavement structure samples using a diamond drill technique

Bearing capacity measurements are not performed systematically in Sweden on a network level. Falling Weight Deflectometer (FWD) surveys are applied only in paving and rehabilitation projects. The surveys are performed to serve dimensioning purposes, for which the E-value of each road section is required by the road authority. Static plate bearing test surveys are applied in road construction quality control surveys.

Core samples are taken in road rehabilitation projects. The requirement is one sample per kilometer and it is taken using varied techniques. A special technique used in Sweden is the continuous sample through the road structure that is taken with a diamond drill core into a plastic tube. DCP technique has been tested in Sweden by VTI but the experiences were not too encouraging due to problems with big stones and boulders.

Ground Penetrating Radar (GPR) has been used in road rehabilitation and pavement design projects and it has also been used to make 3D-models for the pavement thickness in roads.

Troms County, Norway



Bearing capacity measurements play a very important role in pavement evaluation on both project and network levels. FWD surveys are carried out more for rehabilitation design purposes than for quality control. FWD is however used to check that the long term quality demands of the rehabilitation projects are achieved. In rehabilitation projects, over 90% of all FWD measurement points should meet deflection specifications for a 10 ton axle load (or 8 ton if the permitted axle load is only 8 ton).

Spring thaw weakening is monitored, using FWD, by performing three measurements during the thawing period. The worst results are used in evaluating the quality of the old structure and dimensioning the new structure. Surface Curvature Index (SCI), maximum deflection, number of heavy vehicle, diameter of the loading plate and the load are used for calculating the bearing capacity. The whole deflection bowl is used to evaluate the condition of the road structure and the subgrade. As an example deflection value 90 cm from the load centre is used for subgrade quality estimations. When layer thickness is known it is possible to backcalculate also FWD-deflection, but this is only done in special cases because the backcalculations are very time consuming.

Dynaflect technique has been used in Norway for bearing capacity measurements alongside FWD, but this technique is no longer used in Troms. Dynaflect is used to locate weak sections of road. In order to do this, ratio $D0 / (D0 - D300)$ is calculated and evaluations are made based on the following rules:

ratio value	< 3:	problems in the base course
	3 - 5:	problems in the sub-base layer
	> 5:	problems in the subgrade soil

The same numbers are used in FWD analysis, but here the ratio $D0 / (D0 - D200)$ mm is used.

Core samples and occasionally DCP are also used in pavement structure investigations. The Road Database includes core sample results at 500 m intervals, but this register is about 25 years old and it has not been maintained according to modern standards. DCP test results can also be stored in the Road Database.

The Highlands, Scotland

In the past there have been some pilot FWD programmes, but as yet these have not formed part of a systematic FWD survey of the Highland road network.

For individual rehabilitation projects, the basic road structure and identification of weak road sections is made visually, with the background of local knowledge and experience. Bearing capacity measurements using deflectionograph or FWD have occasionally been used to support decisions made, but generally only on the heavier trafficked Trunk Roads.

Most rehabilitation projects will involve sampling of the existing structure, using a combination of coring and trial pits, to allow decisions to be taken regarding re-use of existing materials and selection of the most appropriate pavement structure. GPR is not routinely used, but we are keen to make more use of this technique than at present. On the higher traffic volume roads GPR is sometimes used for individual projects where there are doubts about the subgrade.

6.4. Quality standards - worst allowed road condition

Lapland, Finland

The main policy in Finland is that road condition should not cause traffic safety hazards.

On paved roads, national quality objective levels have been determined for distress sum index, rutting and IRI values. The quality level of rut depth is 13-18 mm depending on speed limit. The IRI values should be between 2,0-6,5 mm/m. Speed limit and AADT have an effect on these objective levels. The quality levels of distress sum index are 60-160 m² / 100 meter road section.

So-called shame levels have been considered but they are not yet in use.

Gravel roads are evaluated visually according to a national quality monitoring system, on a scale of 1 to 5. Quality value 5 refers to the best quality level. The evaluated properties are evenness, dusting and compactness.

Quality value 1 is unacceptable, and value 2 is only acceptable on 10% or 20% of road length at the maximum, depending on road class. The aim is to maintain majority of the gravel road network in a condition corresponding to value 3.

The Northern Region, Sweden

In Sweden there have been numerous discussions about the definition of lowest allowed road condition. There are several guidelines for the level of damage allowed before it must be repaired. The maximum allowed rut depth is 30 mm and the maximum width of cracks is 30 mm on minor roads. If ruts depths are measured using a road survey vehicle the measured limit values 28 mm / 20m or 20 mm / 400 m in a section. The maximum dimensions for the potholes are 30 mm in depth and 200 mm in diameter. In longitudinal direction the maximum unevenness is 6 cm in 2 m length (3 %). These rules have been established mainly in the interest of traffic safety.

A new and interesting project for defining the worst allowed condition is the evaluation of the "skamgräns" i.e. the shame value for a 1000 meter section of the road. The road below the shame value is in shameful condition and should be given priority in the maintenance planning. The definition of the shame value is defined based on extra road user cost. Those costs are comprised of increased time cost, increased vehicle expenses, uncomfortable driving and traffic safety cost. The current limit for the shame value has been 1 extra SEK / km (appr. 0,12 euro/km), but there are also discussions that the

shame value should be 1,20 SKr. This shame value is calculated mainly from the IRI value using the price of 1 SEK per vehicle and km to correspond an IRI value of approximately 4,5 mm/m as an average for 1000 meters. According to a preliminary evaluation, the Northern Region has approx. 690 km of roads with IRI values higher than the shame value level. There is also a need to create shame value specifications for gravel roads. SNRA's Western Road Directorate Region is currently making a photo catalogue to help to evaluate the condition of gravel roads.

Troms County, Norway

There are no clear guidelines for evaluating the lowest standard of road condition allowed. The best indicator of poor road service performance has been feedback from drivers and local politicians.

In general, the roads in the Troms region appeared to be in better condition, when compared with other Road partner districts. There are concerns however, that in the future the condition of the low traffic volume roads will deteriorate rapidly, if new measures are not taken.

Due to diminishing funding for road maintenance and rehabilitation, the available resources have been directed to main roads at the expense of medium and low traffic volume roads. The standard of main roads has been improving over the last few years, whilst that of low traffic volume roads, especially county roads, has worsened. The gap in standards between these roads is constantly increasing.

The Highlands, Scotland

There is not an accepted 'lowest standard' in the Highlands. However the maximum allowed rut depth is as low as 10 mm. The Highlands have a range of road types and traffic usage, and the lowest acceptable standard for each will be variable. While roads can be in a 'poor' condition, they must still be 'safe', i.e. regular safety inspections are carried out to prevent hazards developing. On one of the older Trunk roads there are safety inspections carried out twice a week.

There are 'intervention criteria' set out in a Code of Practice for Local Authorities, which gives good guidance on what defects are acceptable.

7. MAINTENANCE AND REHABILITATION MEASURES

7.1. Special maintenance techniques for gravel roads

Lapland, Finland

Pre-winter maintenance

Autumn maintenance, carried out just before the winter season, is very important for gravel roads in Finland. Graders are used to fix the cross slope at a gradient of 4% and road shoulders are graded even, in order to allow water to flow from the road surface into the ditches. Autumn maintenance also includes cleaning out any poorly working ditches and checking culverts.

Spring maintenance

Spring maintenance is carried out in early spring and it mainly consists of de-icing culverts and ditches filled with ice. Once the snow has melted, gravel roads are reshaped using a grader.

Dust binders and other additives

During the spring, dust binding is carried out using approx. 1-2 tn/km of salt (CaCl).

The Northern Region, Sweden

Pre-winter maintenance

There are no special instructions or techniques for the maintenance of gravel roads before the winter period. However maintenance contractors are encouraged to make even slightly too high crossfall (specifications are 3.5 %) on gravel roads than too small crossfall.

Spring maintenance

Spring maintenance in Region Norr includes snow removal from the road shoulders and opening and cleaning the culverts. Gravel road wearing course is also graded in spring but it is not compacted every time. Some graders have a rolling compaction system, unfortunately they are not widely used.

Drainage improvement

A special drainage improvement technique which also increases bearing capacity of the road shoulder has been the replacement of the non-permeable material in road shoulder with macadam. This 0.2 m * 0.2 m macadam replacement technique was tested for the first time in 1990

and the experiences from the technique have been very good. The cost for this shoulder soil replacement using macadam has been 5 -10 SKR (0.6 -1.2 Euro)/ m and material costs have been about 10 (1.2 Euro) SEK / m. Other used techniques have been basic ditch cleanout and deep drainage techniques.

Dust binders, other additives

Both MgCl and CaCl have been used for dust binding purposes in Region Norr. The amount of MgCl use has been approximately 1.2 tn/km and CaCl 1.0 tn/km. Other additives have not been used. If a new wearing course is needed the amount of the wearing course material addition has been normally 3 tn/km.

In the Northern Region bitumen emulsion treatment has also been used to bind the wearing course material. The experiences from this technique have mainly been good, the investments have been repaid within 5 years. As a result of emulsion treatment there has also been better bearing capacity in the road. However there have also been some problems with this technique, the biggest of them has been the inadequate maintenance of the bitumen emulsion treated wearing course. Major mistakes have been made especially when the wearing course has not been irrigated enough before and after the grading. The bitumen treatment of the wearing course requires a well-trained and motivated maintenance crew.

In the Northern Region the use of milled old asphalt or oil gravel material has been tested in gravel road wearing courses but the experiences have not been good.

Troms County, Norway

Pre-Winter Maintenance

No special maintenance techniques are carried out on gravel roads prior to the winter season.

Spring-time maintenance

During the spring season, the wearing course is reshaped using a grader as soon as possible.

Drainage improvement

Drainage is improved during the spring season by removing snow from the road shoulders, before the snow begins to melt.

Dust binders, other additives

Calcium chloride (CaCl) is used for dust binding gravel roads. About 1 tn/km is used each year. Sealing, or other dust binding techniques, have not yet been tested in Troms.

The Highlands, Scotland

Pre-winter maintenance

No particular measures are employed in advance of winter

Spring maintenance

In gravel roads maintained by the forest industry the main maintenance technique is reshaping the wearing course with grader. Gravel road wearing course is normally 50 mm thick (but can be up to 300 mm thick) and is made of local material.

Dust binders and other additives

In practice almost any local material will be used if it is felt the result would be effective.

7.2. Special maintenance techniques for paved roads

Lapland, Finland

Spring maintenance, crack sealing

Private contractors take care of sealing cracks in paved roads during the spring season. Sealing is normally carried out using 200 bitumen, although larger cracks and small potholes are sealed using Ebanol (bituminous cold sealing mass). Cold mix pavement potholes are repaired using a special cold mix stockpile mixture. Finnra's policy is that all hot mix pavements on main roads should be sealed each year, while the need for sealing on low traffic volume roads is assessed case-specifically.



Crack sealing in HW 21 near Tornio, Finnish Lapland

The Northern Region, Sweden

Spring time maintenance, crack sealing

In Region Norr basically all the major cracks on a paved road will be sealed every spring. Sealing begins with the major roads and proceeds to the low traffic volume roads.

Troms County, Norway

Spring time maintenance, crack sealing

During the spring thawing period there is lot of pothole repair work in Norway. Troms is using both cold asphalt mixes and hot asphalt as patching material. A special heated container is used in hot mix asphalt repair on high traffic volume roads.

Before the thawing period starts the frost heave cracks are at their widest. These are sealed using a polymer modified, fine graded asphalt material. This material is called sand asphalt in Norway and it has maximum aggregate size of 4 mm. Polymer-modified bitumen is used for its premium elastic and adhesive properties.

The Highlands, Scotland

Spring time maintenance, crack sealing

The main maintenance techniques in paved roads are crack sealing and pothole repair. Crack sealing is performed during the frost season when the cracks are open, as these close again when the frost front comes out of the road. If the pavement gets worse a new surface dressing is applied in the summer using bitumen spray and chips. Low friction values are also a reason for surface dressing the road. Surface dressing can also include glass fibre reinforcement to aid crack sealing and limit reflective cracking. This proprietary process is called Fibredec. Normally surface dressing is expected to last 7 years in Scotland.

Potholes are repaired as they arise, using cold delayed set bituminous macadam. Areas where distress is widespread will be programmed for more substantial patching, surface dressing or overlay. If an overlay is chosen, it will normally be 40 to 50 mm thick bitumen macadam.

7.3. Rehabilitation Techniques for paved roads

7.3.1. Stabilisation

Lapland, Finland

Stabilisation has been a very popular technique to improve bearing capacity of roads in Lapland and about 300 km of roads in total have been stabilised since 1994.

In-situ / plant stabilising

In-situ stabilisation is the dominant method in Finland, with plant stabilisation being applied only in some special cases. The main stabilisation technique used in Lapland is the Remixer base technique designed by Kalevi Luiro, a pavement engineer from the Lapland Region, and by Rovaniemi based Kalottikone Oy, a company which specialises in asphalt machinery. This remix technique involves firstly pre-heating the old pavement, then milling the pavement and top part of the base and mixing it with additional bitumen and aggregate. The mixture is then laid using the same machinery and compacted with rollers.

Bitumen stabilisation: foam bitumen, emulsion bitumen

Emulsified bitumen is used in the remix technique. The binder content needed for the stabilisation is estimated using a Tube Suction test and normally it varies from 2.8 to 3.8 %. Since 1994, foam bitumen stabilisation has not been used in Lapland.

Cement stabilisation

Cement stabilisation has not been tested in Lapland, but has been used in some sites in the Oulu region.

Lime stabilisation

Lime stabilisation was used in one project in the Ylitorio community. According to measurements taken before and after stabilisation, the bearing capacity increased slightly in lime stabilised road sections.

The Northern Region, Sweden

In-situ / plant stabilising

The stabilisation of the pavement structure in Region Norr is done only using on-site techniques, no plant stabilisation is used. The main problems with the on-site stabilisation have been a base course that is too thin and big boulders, in the base course or sub base, that have caused problems when going into a mixer.

Bitumen stabilisation: foam bitumen, emulsion bitumen

Bitumen stabilisation has been used in Region Norr since 1987 and the experiences have mainly been very positive. The only problems have been in frost susceptible areas with a low grade line and poorly working drainage. Both foam bitumen and emulsion bitumen stabilisation techniques have been applied. The experience has been that the emulsion bitumen Roadmix technique gives more homogenous results compared with foam bitumen. In some cases, after rainy days, some potholes have appeared in foam bitumen stabilised roads. The bitumen content normally used is 3.5 %. The experience has been that foam bitumen binds the fines slightly better and that is why the following rules are now used when choosing the bitumen stabilisation technique:

Fines content	Stabilisation type
< 8 %	emulsion
> 10 %	foam bitumen
8 - 10 %	depends on the price

The experience in Sweden is that 11 cm of Remix base equals 15 cm of foam bitumen base.

Cement stabilisation

Cement stabilisation of the pavement structure has been used in a few sites in Region Norr. In summer 1999 one test road in Älvsby area was built with two different structures. The problems with these sites however have been rapid deformation.

Lime stabilisation

Lime stabilisation has not been used in Northern Region road structures.

Troms County, Norway

In-situ / plant stabilising

Stabilisation is a very popular rehabilitation technique in Region Troms, and in 1999 about 1.5 million m² of road was stabilised. Both in situ and plant stabilisation techniques have been utilised but presently only in-situ stabilisation is being used. Plant stabilisation has been used in cases where poor quality wearing course was recycled. This material is transported to the plant to be mixed with new aggregate and emulsified bitumen.

Bitumen stabilisation: foam bitumen, emulsion bitumen

Both foam bitumen and emulsion stabilising techniques have been used in Troms. The first emulsion stabilisation tests were carried out in 1986, the first tests with foam bitumen in 1996. The foam bitumen technique is cheaper, but general opinion is that emulsion stabilisation provides better stability. Foam bitumen does seem to work better, however, if the fines content is high.

There are four basic pavement rehabilitation procedures used in Troms:

1. Basic procedure (when there is no need for reinforcement)

(a) Old pavement is crushed with a milling machine in order to be able to reshape the road surface.

(b) The road surface is reshaped using a grader

(c) The old wearing course is stabilised using bitumen amount of 1.5-3.0 l/m²

(d) A new wearing course is paved.

2. Frost susceptible base course

(a) Old pavement is crushed with a milling machine and mixed with the old gravel base course material. After that the road surface is reshaped using a grader

(b) The base course and the old wearing course is stabilised using about 3.5 % bitumen content based on mix design.

(c) A new wearing course is paved.

3. Base course has too much sand fraction or the road has bearing capacity problems

(a) Old pavement is mixed with base material and the surface is reshaped using a grader

(b) New coarse grained aggregate (the grading depends on the grading for the old base layer) is added on the top

(c) Top layers are mixed and stabilised

(d) A new wearing course is paved.

4. Unbound base

(a) Old pavement is milled away

(b) New base course is made on the top of old base

(c) Old recycled pavement material is used for new pavement. The old pavement can also be used as an upper base course or as a binder course. In these cases a new wearing course has to be laid.

Cement stabilisation

Experiences with cement stabilised roads have mostly been positive in Troms, with problems only occurring in those areas with frost susceptible subgrade and poorly performing drainage. A special composite type cement-bitumen stabilised structure has also been tested. This technique involved spreading cement over the unbound base layer, which was then stabilised with emulsion bitumen. There was a noticeable improvement in the bearing capacity of these roads, compared with those roads stabilised using only emulsion bitumen. Some problems have arisen with this technique, however, particularly concerning the mixing technique, and drivers have complained about their cars getting dirty. In the future, the goal is to use cement stabilisation on frost-susceptible and hard subgrade soils.

Lime stabilisation

Lime stabilisation has not been used in Region Troms.

The Highlands, Scotland

In-situ / plant stabilisation

In-situ stabilisation is predominantly used.

Bitumen stabilisation: foam bitumen, emulsion bitumen

There are many small examples (trial sections) using foamed bitumen recycling since 1990, but to date this process has not been used generally as a maintenance technique.

Cement stabilisation

As with bitumen, there are many trial sections, but cement is not normally the preferred material.

Lime stabilisation

The road pavement materials used do not lend themselves to lime stabilisation.

Slag

Slag is becoming more popular as a fill material, below the basic pavement layers in new build or full depth reconstruction.

7.3.2. Recycling

Lapland, Finland

Nowadays, almost all the pavements in Lapland are recycled using a similar pavement remix technique as used in Sweden and Norway. Pre-heating is now carried out using a petroleum heater. The amount of pavement remixed each year is generally 40 km for cold mix pavements and about 80 km for hot mix pavements.

The Northern Region, Sweden

The goal of the SNRA has been that, in 2000, more than 90 % of the old asphalt should be recycled as new asphalt layers in the rehabilitation projects. In 1998 that number was about 75%. From year 2000 there is a 250 SEK/ton (29 euro/ton) deposit fee for road material dumped outside the road. This will increase the rate of recycling in maintenance and rehabilitation projects in the future.

Semi-hot remixing of old cold mixes and hot remixing of old hot mix asphalt has been in use for a few years and the experiences are mostly good. Recycling in asphalt plants has been done for many years and the experience has been that the best result is achieved when old hot mix asphalt is recycled using an emulsion technique and old cold mixes are recycled using soft bitumen. This simple rule decreases the risk for plastic deformation and unevenness.

Troms, Norway

The plant recycling technique (cold recycling) was previously, some 10 years ago, used a lot in pavement rehabilitation projects. Mainly due to long distances and expensive transportation the cold recycling technique was given up, but today in-situ recycling is used increasingly. During the years 1997 and 1998 a Finnish contractor (Savatie Oy) did the remixing. The Troms County road administration got its own remixer equipment in 1999. In the first years of using in-situ remixer techniques, Troms County has experienced some problems related to weather conditions, use of untrained personnel, and remixer quality.

Currently there is also pressure to use plant recycling due to large amount of milled asphalt stored in towns that should be recycled, but local asphalt plants do not have recycling equipment and transportation to the road administration's facilities is too expensive. Milled asphalt is instead used to reinforce roads near towns.

The Highlands, Scotland

Recently, old leanmix (weak concrete) road bases have been recycled using a foam bitumen technique on one of the busy Trunk roads.

Recycling has been used to date in village streets, primarily for the speed of the process, and the reduction in disruption to road users. The other benefit of recycling the upper pavement layers is the avoidance of conflict with underground services. There is likely to be an increase in recycling with energy consumption considerations and the increasing landfill tax charges.

7.3.3. Reinforcement techniques

Lapland, Finland

Steel grids

Steel grid reinforcement against longitudinal cracking has increased in popularity in Lapland during the last few years. During the late 1990's, 6-8 km of steel reinforcement was used annually but in 1999 more than 15 km of public road was reinforced with steel grids. Steel grids have also been used in pedestrian and bicycle paths. Steel grids are usually placed in the base course, but in some cases they have been instrumented to asphalt pavement. In practice, this method has mainly been successful and less than 1 % of the projects have failed. One of the main causes of failure has been the installation of steel grids too early in the summer before the frost has completely thawed. Another cause of failure has been the use of steel grids which were too short in a transverse direction.

Geogrids, geotextiles etc.

Geogrids have been mainly used in subgrade strengthening projects. Small scale glassfiber geogrid tests for strengthening asphalt were carried out in 1997 near Rovaniemi and so far they have been functioning well. In the mid-1980's geogrids were tested in H.W.21 near Tornio to prevent reflection cracking, but all the tested materials failed.

The Northern Region, Sweden

Steel grids

Steel grid reinforcement has been used in Region Norr for many years with very positive experiences, only one failure has occurred. General opinion is that steel grid reinforcement works out well every time if only the instructions are followed.

A very interesting new experience has been the use of steel grids for reinforcing the road shoulders. In these cases grids have been installed longitudinally following the road shoulder to prevent shoulder deformation. Test sites have been working very well so far and no deformation has occurred.

Steel grids have also been used for reinforcing very weak road embankments resting on peat and experiences from these sites have also been positive.

Geogrids

Experiences of geogrids have not been as positive as those from steel grids. They have been tested in some locations but they have not worked out well, however there are no written documents from these tests. Glass fiber reinforcement has been working in some places if the reinforcement has been thick enough.

Troms County, Norway

Steel grids

Steel grid reinforcement has not been used in Region Troms. Polymer modified bitumen has, however, been successfully used for sealing frost cracks.

Geogrids, geotextiles etc.

Geogrids have been used to prevent reflection cracking in roads stabilised with cement. Geogrid was placed on top of the old road, beneath the leveling mix and the new pavement. This structure has been working well.

Glassfiber composite pavement was tested as a method of preventing frost heave cracking, but failed completely.

Geotextiles have been used in soil replacements in roads. The replacement depth is normally 50 cm. Geotextile has also been used to reinforce gravel roads with new base course and wearing course. In these cases Troms is using 15-20 cm of base course and 5 cm of wearing course and geotextiles are used to separate non-frost susceptible and frost susceptible materials from each other.

The Highlands, Scotland

Steel grids, polyester grids and glass fiber grids have been used to prevent pavement cracking. Tensar polypropylene grids have also been used as sub-base reinforcement in areas of weak subgrade. The experiences from the reinforcement grids have been mainly positive. Good results are reported of hexagonal road mesh manufactured by Maccaferri of Italy. Rehau geogrids have been used in roads constructed over peat.

Steel grids

Steel grids have been used many times in the last 5 to 10 years, and so far these appear to have been successful

Geogrids, geotextiles etc

Some polypropylene geogrids, bitumen impregnated polyester geogrids, woven and unwoven geotextiles have been used, both at upper and lower levels of the pavement. These installations are being monitored, but it is too early to judge their long term performance as an effective maintenance technique. Glass fibre reinforced (fibres around 15 mm long) surface dressing has also been used effectively as a low cost remedial measure for alligator and centreline cracking.

7.3.4. Insulation techniques

Lapland, Finland

Polystyrene

Due to the cost of polystyrene, it has not been widely used in Lapland. Soil replacement has proved a cheaper option in repairing frost damage.

Peat

Sod peat insulation structures have been tested in TPPT (Finnish Pavement Structure Research Program) test sites. So far, feedback has been mainly positive and these structures can be economically applied in areas where sod peat is available.

Other insulation techniques

Some lightweight gravel insulation structures have been used in Lapland with promising results. However, the high price of lightweight gravel compared with soil replacement is still a major problem.

The Northern Region, Sweden

Polystyrene

Polystyrene frost insulation was applied in the Northern Region in the late 70's but at the moment hardly any road structures in the area are insulated using polystyrene. The only area where the method is used is near the coast in the county of Västerbotten. Polystyrene frost insulation structures work out well if they are properly installed.

Peat insulation

Peat insulation has not been applied, peat has been used only in some special lightweight embankment structures.

Wood chips

In Region Norr wood chip insulation has not been used but some wood bark structures were made during the early 1970's - experiences were not good.

Troms County, Norway

Polystyrene

Polystyrene frost insulation is used in areas where road aggregates for soil replacement are not available nearby. The thickness of the polystyrene layer is usually 40 mm at the coast and 85 mm in coldest areas and the average price for the polystyrene insulation structure is 200 Nkr (24 euro) / m².

Other insulation techniques

A special foam glass insulation technique will be tested in Region Troms in summer 2000.

The Highlands, Scotland

It is not necessary to insulate pavement structures in Scotland.

7.3.5. Other structures

The Northern Region, Sweden

Repair of shoulder deformation using grouted macadam

Using a grouted macadam structure to repair shoulder deformation is a fairly common technique in the Northern Region. The aggregate used is 16-32 or 32-63 depending on the depth of the deformations. The grouted macadam is carefully sealed to prevent water from penetrating into the macadam and causing frost damage.

Widening the roads resting on peat

A special technique in road widening projects where the old road is resting on peat has been tested in Region Norr. In this technique, peat is replaced on both sides of the road to the "hard" bottom soil with aggregate that has been stabilised with cement or replaced with unbound macadam.

7.3.6. New materials, industrial by-products

Lapland, Finland

Slag

Stabilisation using Rautaruukki steel slag has provided very good results in the Oulu area. In the Kemi-Tornio area, Finnra has used Outokumpu steel slag, but this material does not have stabilising properties. However, Outokumpu slag sand has good insulation properties and has been used in insulation layers in the Kemi -Tornio area in South-Western Lapland. The largest project where slag sand has been used is the Kemi -Tornio motorway project, where the slag sand has helped reduce the total thickness of the road structure and thus helped avoid settlements in clay areas.

Fly ash

A fly ash test road has been constructed near the city of Kemi in Southern Lapland. However, the structure is quite new and as of yet there is no feedback concerning its performance.

The Northern Region, Sweden

Slag

Blast furnace slag 0-300 mm has been used in several roads in the sub base course and experiences have been positive. The material has the ability of acting as a binder over a long term. If the structure is thicker than 50 cm transverse cracking has not appeared and if the blast furnace structure is thicker than 90 cm uneven frost heave will not take place.

Other materials

Crushed recycled concrete has been used in the base course and in sub base courses in some locations in Region Norr, the results so far have been encouraging. The stiffness of these layers after one year is three times higher than the normal sub base material.

Troms County, Norway

Slag

Slag has not been used, in Troms, since the material is not available nearby. Slag, however, is used in Nordland.

Fly ash

Fly ash has not been used in roads in the Troms region.

Other materials

Silica has been tested in some roads.

The Highlands, Scotland

New materials and industrial waste products have not been tested in the Highlands of Scotland because aggregates are relatively easily accessible. Light-weight expanded clay aggregates have been used for embankments over weak subgrade.

Slag

Used as a cement replacement in structural concrete, not commonly used in road pavements.

Fly ash

Has been used in road construction as a fill material in UK, but not commonly used in the Highlands.

7.3.7. Drainage improvement techniques

Lapland, Finland

Edge drains. Horizontal drainage

Edge drains have not been used in Finnish Lapland, but horizontal drainage geotextiles have been used in Kemi-järvi and at the Arctic Test Road test site in Kilpisjärvi.

Deep drainage

The first deep drainage structures were installed in Rovaniemi and Tervola during winter 1998-99, but as of yet there has not been any feedback concerning their performance. Slope intercepting ditches have also been used with varying results.

The Northern Region, Sweden

Edge drains

Edge drains have been tested in road 676, where the structure was extremely thin. In this case the structure did not work very well. Hydrodrain drainage structure has been used in Vindeln area in Västerbotten and the results with this structure have been good.

Deep drainage

In Norrbotten area a few kilometers of deep drainage structures, where the drainage pipes were installed at a depth of 1.2 m from the bottom of the ditch, have been constructed. The cost of the structures was 260 - 320 SEK/m (30 - 38 euro/m). These sites have been working very well. However, blockages can become a problem after a few years if they are not cleaned well.

Troms County, Norway

Edge drains

Hydrodrain has been tested on one road, as an edge drain in sloping hill areas, to prevent water flowing under the road. Hydrodrain was placed 60 cm deep and this structure has been functioning well.

Deep drainage

Deep drainage is used in Norway for long road cuts both in soil and rock. It is mainly used for the purpose of draining the subgrade but not to treat frost heave problems. When water flowing under the road causes frost problems, an insulation structure is used instead and water is allowed to flow under it. As it has been observed in Norway that drying the subgrade soil helps frost to penetrate deeper into the ground, possibly to even more frost susceptible layers, the risk of failing to prevent frost heave by deep draining is considered too big compared to insulation.

The Highlands, Scotland

Drainage maintenance is carried out through general drainage improvement. In some new roads vertical drainage has been constructed by using drainage textiles. A major problem in drainage improvements is the fact that the road authority does not own the adjacent land, and this can cause difficulties in building drainage channels away from the road.

Edge drains, Horizontal drainage

New roads, and old roads with particular drainage problems, have edge drains (filter drains 1m to 1.5m deep) but older roads have mostly ditches. The filter drains are constructed using a 15-22 cm diameter perforated pipe, in a trench of single size (20 mm nominal) aggregate, wrapped in a geotextile. The geotextile is designed to suit the D^{85} of the surrounding soil.



8. RESEACH ACTIVITIES IN NP PARTNER ROAD DISTRICTS

8.1. Lapland, Finland

Since the mid 1980's the Lapland Region has sponsored and been involved in numerous research projects concerning the problems in road design, construction and maintenance in sub-arctic areas. A part of the projects are national projects, another part have been managed and sponsored by the Lapland Region alone or together with some other organization or company. The following reviews some of the most important projects that can be related to the low traffic volume road condition management.

1) Pavement structure lifetime and pavement material degradation research projects, (Tierakenteen kestoikä tutkimus)

In co operation with the Lapland Road Region and University of Oulu, Pavement structure lifetime research projects were conducted in the 1980's and early 1990's. The goal was to survey the effect of base course thickness, aggregate type and aggregate grading on pavement structure life time of cold mix (oil gravel) roads and to evaluate reasons for the pavement defects. The results have shown that the base course material has degraded considerably and base course samples taken from the road structure did not meet the grading requirements of base course materials in Finland, especially due to a high fines content. The formation of ruts in pavement structure had two phases: the first phase happened immediately after the construction when rut development and widening of the road was rapid but the second phase following the first year the deformation was not as fast. The highest rutting problems occurred in test sections with open graded base course materials or in sections with high fines content in base materials. Pavement defects also appeared in sections with thin base course and steep inner slope. Low bearing capacity values of subgrade soils increased the permanent deformation of the road structures as well.

Report:

Jouko Belt: Kestoikä tutkimus, loppuraportti. Oulun yliopisto, Tie- ja liikennetekniikan tutkimusselostuksia 2/1999. (In Finnish).

2) Arctic Road Construction, (Arktinen koerakentaminen)

A research project was carried out in 1985-1990 in Finnish Lapland, on the initiative of the Finnra, to study and solve the problems caused by cold climate on roads in

the North. The main problems observed and studied were: 1) pavement damage due to thaw settlement of permafrost, 2) pavement damage due to frost heave, 3) snow accumulation on pavement causing excess maintenance and 4) icing of pavement and drainage structures due to freezing of winter run off. In the project different test sections were designed and constructed and monitored, in HW 21 near Kilpisjärvi in North Western Lapland, in order to find out the best solutions for solving these problems.

Report:

Seppo Saarelainen: Arktinen tierakentaminen, Kilpisjärven hankkeen yhteenveto. Tielaitoksen tutkimuksia 5/1993. English abstract: Arctic road construction - final report of Arctic Road - project at Kilpisjärvi.

3) ASTO Programme (ASTO-projekti)

The Asphalt Pavement Research Programme (ASTO) 1987-92 focused on producing pavements that are more durable against: 1) wear due to studded tires, 2) deformation in asphalt pavement, 3) water susceptibility and 4) temperature cracking. ASTO focused especially on the material properties of the hot mix and cold mix bituminous pavements and the specified fields of interest were: bitumen types, aggregates, additives, pavement types, proportioning, paving techniques etc. The results of the survey showed that the most important factor against pavement wear was aggregate strength and grading. Bitumen viscosity and proportioning had an effect in pavement deformation. Water adsorption value was an important factor when measuring the water susceptibility of bituminous pavements. Lapland Region had two test ASTO road sections: temperature cracking test road on hw 4 near Sodankylä and a test section in road 926 near Rovaniemi to test when and to what degree cold mix pavement should be heated to obtain the best durability against weather changes.

Report:

Asko Saarela: Loppuraportti, ASTO 1987-1992. Pank ry, VTT, Espoo 1993 (In Finnish).

4) TPPT Programme (TPPT-projekti)

TPPT (The Road Foundation and Pavement Structure Programme) 1994-2001 is mainly financed by Finnra and its goal is to develop road structures, so that the present level of service can be achieved in the future for twice as

long and simultaneously to reduce the annual maintenance costs of the road by 5-10 %. TPPT includes research relating to foundation conditions and their characterization, pavement structures, frost structures and foundations. In Lapland Region TPPT has been surveying frost insulation structures made from compressed peat pellets (sod peat).

More info:

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(www.tielaitos.fi)

5) Remixer stabilisation project (Remixer-stabilointiprojekti)

In 1995 a survey project was conducted in Lapland Region by the University of Oulu and Finnra in order to evaluate the effect of the remixer stabilisation technique in the improvement of bearing capacity of road structures. The survey comprised of testing different aged road sections, stabilised with remixer technique, and comparing them with the road sections stabilised using foam bitumen technique. Some laboratory tests were also performed at the University of Oulu. The results showed that the remixer technique produced better bearing capacity than the foam bitumen stabilisation technique. The quality and the bearing capacity was almost as good as roads where asphalt concrete had been used. Remarkable savings can be achieved by using the remixer method, due to reduced bitumen consumption, because thinner stabilisation thickness can be used.

Report:

Belt, Jouko: Remix base course survey. Summary of the final report. Road and Transport Laboratory, University of Oulu, Research Reports 4/1998.

6)GPR in asphalt pavement quality control, (Päällystetutkaprojekti)

During the 1990's a number of laboratory and field tests were performed in Lapland and in Texas, at the Texas Transportation Institute, to develop a Ground Penetrating Radar horn antenna technique in quality control of newly paved asphalt pavements. The Ground Penetrating radar technique enables pavement thickness to be measured rapidly from a moving vehicle and information on variations in pavement voids content to be collected simultaneously on the basis of dielectric value fluctuations. The results can be calibrated against real air content by sampling the material concerned and by the relationship between dielectric value and void content, determined beforehand under laboratory conditions. The field tests performed in 1995-1997 resulted in a good correlation between dielectric value measured in laboratory and measured using GPR reflection technique. The method was

tested in asphalt paving projects in 1997-1998 and in 1999 GPR method was accepted as an official asphalt quality control method in Finland.

Publication:

Timo Saarenketo and Petri Roimela: Ground Penetrating Radar technique in asphalt pavement quality control. Proc. Of the 7th Int. Conf. On GPR, Vol2. May 27-30, 1998. Lawrence, Kansas, pp. 461-466.

7) MISU-project (MISU-projekti)

The main goal of the MISU-project "New methods in road rehabilitation design", sponsored by the Finnish National Road Administration, was to evaluate the suitability of the new and fast survey methods for the road structures and subgrade in light and heavy road rehabilitation design projects. The methods were tested in four different projects in the road districts of Lapland, Vaasa and Uusimaa and the methods tested were: GIS (Geographical Information System), GPS (Global Positioning System), Tachymeter method, Video recording, ground penetrating radar (GPR) technique, falling weight deflectometer, roughness and rutting measurements and dielectric value and electrical conductivity measurements using a frost probe.

The results of the MISU project clearly shows, that the GPR measurements with 500 MHz and 1.0 GHz antennas together with the results of roughness and rutting measurements FWD data and results of sampling and laboratory analysis give excellent data with which to evaluate the condition of road structures. The MISU project also showed that the frost probe technique could be used to evaluate frost susceptibility of the subgrade if frost heave information is not available. GIS technique has great potential in analysing and presenting the results of the surveys.

The MISU project also tested and developed a road analysis technique, where previously mentioned techniques are applied supplementing each other and taking advantage of the strength of each technique. The results of the road analysis enable a precise rehabilitation design for the road, which focuses the repair measures only to the damaged road sections. The renewed road structure can be designed to be as homogenous as possible with respect to its life time.

Publication:

- 1) Uudet mittaus- ja tutkimusmenetelmät rakenteen parantamisen suunnittelussa (MISU-projekti). Tielaitoksen selvityksiä: 23/1999. Oulu 1999. (In Finnish, English abstract).
- 2) Timo Saarenketo: Tieanalyysi - MISU-projektin lopuraportti. Tielaitoksen selvityksiä: 24/1999. Oulu 1999. (In Finnish, English abstract).

8) Using Ground Penetrating Radar in gravel road wearing course surveys (Maatutkan käyttö sora- teiden kulutuskerrostutkimuksissa

During summer 1998 a series of tests were conducted in Lapland Region and in Central Finland Region in order to find out how Ground Penetrating Radar (GPR) technology can be utilized at both the project and network level, when surveying the wearing course thickness of gravel roads. The second objective was to investigate the possibility of applying dielectricity information, obtained using the GPR surface reflection method, when determining the quality of the gravel road wearing course. GPR 1.5 GHz ground-coupled antenna and a 1.0 GHz horn antenna were tested in this study.

The research results show that GPR can be used to measure the thickness of the wearing course, the average measuring error against reference drilling measurements being 25 mm. Of the two GPR antennae tested, the horn antenna proved to be the more effective in measurements. The dielectric value of the wearing course, measured using the horn antenna surface reflection method, represents well the suction properties of the wearing course. High dielectric values reflect water sensitive and frost susceptible wearing course materials where as low values reveal the lack of binder. A quality rating of the wearing course by its dielectrics and layer thickness is also suggested. In presenting results and analysis, GIS-maps proved to be invaluable.

Publication:

Timo Saarenketo and Heikki Vesa: The use of GPR technique in surveying gravel road wearing course. Proc. of the 8th Int. Conf. on GPR, Vol2. May 23-26, 2000. Gold, Coast, pp. 182-187.

9) Tube Suction Test (Imupainekoe ja rengastestit)

A Tube Suction Test (TST) was developed in mid 1990's in co-operation with Lapland Region and Texas Transportation Institute to investigate the moisture and frost susceptibility of unbound base course aggregates and has also been successfully applied in the research of bound aggregates. During the TST, the sample is compacted into a plastic tube, dried and placed in a bath containing 10-20 mm of water. The amount of unbound water absorbed by the sample is then assessed using the dielectric value of its surface. Based on the results of the test, the samples can be divided into three qualitative categories: good, marginal, and poor.

In 1998-99 a co-operative project was carried out between Lapland Region of the Finnish National Road Administration (Finnra), Texas Transport Institute (TTI) and Office of Minnesota Road Research (Mn/ROAD), where

Tube Suction test results taken from the laboratories of the cooperating institutes were compared. Each laboratory studied both good quality and poor quality base course aggregates selected from sites in Finland, Texas, and Minnesota in the United States and Saskatchewan in Canada. The classification of these aggregates were determined from their field performance. The results of the study indicate that despite some disparities, mainly due to sample preparation, the correlation between the test results of each laboratory was positive, with good quality samples proving to be good and problematic samples bad

Publications:

Tom Scullion and Timo Saarenketo. Using suction and dielectric measurements as performance indicators for aggregate base materials. TRB Record 1577. 1997. pp. 37-44.

Timo Saarenketo: Tube Suction Test - Results of the round robin tests of unbound aggregates. Tielaitoksen tutkimuksia, Lapin tiepiiri (in print).

10) Strength and deformation and suction properties of unbound base aggregates (Kantavan kerroksen murskeen imupaine- ja muodonmuutosominaisuudet)

In 1996-2000 a series of research projects, sponsored by Lapland and Vaasa road regions and Finnra central office, were carried out in Lapland Road Region, at the Tampere Technical University and at the University of Oulu in order to study the relationship between electrical properties and strength and deformation properties of base course materials. The test series has been comprised of Tube Suction tests, chemical tests, frost heave tests and dynamic triaxial tests using known, good and poor performing, base aggregates from Lapland and Vaasa regions. The preliminary results have shown that fines content as well as chemical properties have great effect on the suction properties of base materials. Resilient modulus values have major changes depending on if they are dry, wet or if they have gone through a freeze-thaw cycle. The differences increase with increasing fines content. However, regarding the strength and deformation properties of road aggregates the resilient behaviour of the base materials were not as critical as positive pore water pressure in base material under repeated dynamic loads.

Report:

Timo Saarenketo, Pauli Kolisoja, Nuutti Vuorimies, Teija Yliheikkilä ja Seppo Ylitapio: Kantavan kerroksen murskeen imupaine- ja muodonmuutosominaisuudet, Osa I: sitomattomat materiaalit. (In print).

8.2. The Northern Region, Sweden

1) Alternative materials in road construction road 597 and road 597.01 in the Northern Region

In the summer of 1997 the Road Administration in Luleå constructed test sites outside Luleå consisting of crushed concrete, blast furnace slag and granulated slag. The alternative materials are being used as subbase and base course in the road 597 in Luleå. This far the crushed concrete as subbase shows a high increase in bearing capacity. The granulated slag has the lowest calculated stiffness, about 50 % of the stiffness of the blast furnace slag and 25 % of the crushed concrete. There are no differences noticed on the surface between the different materials after two years. The granulated slag shows the best frost insulation properties of all materials and the frost depth has been about 1,10-1,12 meters compared to the blast furnace slag 1,40-1,50 meters and the gravel (reference material) and crushed concrete 1,60-1,80 meters.

2) Cement stabilisation in Visträsk, test site road 648

The purpose of this project is to examine the possibility for reusing the material in the existing road and as such decrease the transportation of new material to the road. Studies of the bearing capacity development due to less flexible constructions in areas with deep frost penetration will also be done. The test site was constructed in August 1998 and is located in Visträsk, about 100 km southwest from Luleå. The three different sections were constructed as follows:

- 1) 90 mm base course (0-32 mm)
80 mm macadam (8-32 mm)
200 mm concrete stabilisation (14 kg/m²)
- 2) 80 mm base course (0-30 mm)
250 mm subbase (0-70 mm)
50-600 sand
200 mm concrete stabilisation (14 kg/m²)
in the formation

3) Road 94 (normal section)

After two years it can be observed that the rut depth is 5-40 mm and that the road is uneven. One explanation can be that there was no shaping of the base course before surfacing with MJOG and that this was done when there still was frost in the road construction. The bearing capacity has not had the anticipated improvement.

Report:

Cement stabilisation in Visträsk, Test site road 648, Report nr 1 - November 1998 (Cementstabilisering i Visträsk, Provsträcka väg 648, Delrapport 1 -November 1998);

Cement stabilisation in Visträsk, Test site road 648, Report nr 2 - February 1998. (Cementstabilisering i Visträsk, Provsträcka väg 648, Delrapport 2 -Februari 2000)

Both reports written in Swedish.

3) Roadmix road (Wearing course) 395 Peräjävaara in the Northern Region

This is a method to perform semi heated rehabilitation of an old wearing course with ruts, and is not suitable for roads that need to be reconstructed. Because of reduced transportation the method saves energy compared with a conventional recycling in an asphalt plant and there is also a reduction of emissions. Roadmix is a fast method and the traffic does not have to drive on the unbound base course. The costs of the Roadmix technique is only 60% of the cost of conventional reuse of a wearing course

This method was used in Pajala on road 395 in August 1998.

Report:

No report has been written.

4) Deep stabilisation road 601 Sundsvägen in the Northern Region

A new method to stabilise the peat subgrade under the road has been examined. Instead of soil replacement, the peat has been stabilised with 150 kg/m³ Lohjamix. Lohjamix is 40 % Portland concrete and the rest is reused products from the steel industry such as slag or fly ash. The stabilisation was a success and the bearing capacity increased even if the stabilisation was not totally homogeneous.

This method was used in May 1995 at Sundsvägen in Råneå as a block stabilisation where the Lohjamix was mixed to a depth of 2 meter into the soil.

Report:

A Geotechnical and Environmental investigation of a block-stabilised road section.

5) Reinforcement road 600 Sundom in the Northern Region

This is one of the full scale test sections and is a part of the REFLEX project (Reinforcement of Flexible Road Structures with steel Fabrics to Prolong Service Life). The test sections are located on road 600 at Sundom and the research project focuses on:

- Increasing the bearing capacity of the road structure
- Counteracting frost cracks in the pavement
- Counteracting settlement cracks in the road shoulder
- Preventing cracks between the existing and widened parts of the road

Report:

In year 2000 a report will be produced in Swedish.

8.3. Troms County, Norway

Troms County does not have many R&D projects of its own. The Norwegian Road Research Laboratory in Oslo administrates most of these projects, but specialists from the counties attend in project groups and involve the counties in this way. Below are some R&D projects carried out in Norway that are important to the road condition management in Troms County.

1) BUAB-project

A four year research project called BUAB (better utilisation of the bearing capacity of roads) was completed in 1994. This project evaluated the economical effects of not using load restriction during the spring thaw period.

The extra cost of lifting the load restrictions for the road owner was calculated to be approx. 145 mill. NOK (17.4 mill. Euro), but the profit to road users was calculated to be 330 mill. NOK (39,6 mill. Euro), provided that the surfacing service life was maintained at its present level. A potential loss of 210 mill NOK (25.2 mill. Euro) was estimated if the extra cost to maintain the roads surfacing service lives were not allocated.

Extra maintenance cost for each county were also calculated both for national- and county roads.

In 1994 50 % of the national highways had load restriction in the NP-area and 96,1 % of the county roads.

Main report:

Publikasjon nr. 75 NRRL. Sluttrapport for etatsatsningsområdet "Bedre utnyttelse av vegens bæreevne". (Publication nr. 75 - NRRL. Final report "Better utilization of the bearings capacity of roads")

Other report:

Publikasjon nr. 70 - NRRL/SINTEF. Vegbrukers reduserte transportkostnad ved opphevelse av telerestriksjoner. (Publication nr. 70 - NRRL/SINTEF. Reduced transportation costs for road user when lifting axle load restrictions during spring thaw period.) Geir Refsdal. BCRA 1998 - Vol. I. "The lifting of axle load restriction during spring thaw - a Norwegian experiment"

2) Use of Polymer modified bitumen in Norway

Polymer modified bitumen (PmB) is used in many countries because of its stability, elasticity, adhesion and ageing properties. However the problem is that the binder cost about twice a normal binder.

Norway has tried for several years to use PmB to reduce wearing from studded tires, but this has not been successful. It appears that the most important material property of PmB in countries where the studded tires are making the ruts, is the adhesion. The elastic properties make the binder suitable for use in cold regions. Stabili-

ty is only a problem on bus-stops/bus terminals and in road intersections.

The project will be reported in 2000.

3) Cold recycling of oil gravel using plant

In the beginning of the 1990's a lot of cold recycling using a cold mix asphalt plant was performed in Troms County. This technique and the pavement performance have been evaluated.

There were some problems when producing the material and some sections had roughness and stability problems in steep rises. The recycled pavement has mostly performed very well in spite of very soft binder in the pavement.

Documentation:

Gudmund Reiertsen. NVF Utvalg 33 "Gjenbruk. Hovedmenne 1997"

4) Effect of different grading in aggregate for foamed and emulsified asphalt

A project was started in 1999 in order to find the effect of different grading in the aggregate for foamed and emulsified asphalt. Both dense graded and open graded aggregates will be tested. The effect will be evaluated from E-modulus values, shear stresses and compaction characteristics using ICT. There will also be an effort made to measure the deformation characteristics.

The project will be reported in 2001.

5) Effect of deep stabilisation

FWD-measurements have been carried out on a section that has been reinforced using deep stabilisation and additional gravel/macadam. In Norway an equation is used to calculate a bearing capacity (in ton) for the road.

The measurements have been performed before and after reinforcement. During the first period (up to 1-2 months) after stabilisation using emulsified bitumen the bearing capacity has decreased. The reason is probably the increase in moisture content when the emulsion reacts on the aggregate surface. After one year the measurements showed that the bearing capacity has been increased 1.5-2 ton. The stabilisation depth was normally 10-12 cm and about 5 cm gravel/macadam was added on these projects.

The binder content, void content and elastic modulus were analysed for the stabilised material.

A final report has not been made, but the measurements are presented in the paper "Erfaringer med bitumenstabiliserte bærelag i Troms" by G. Berntsen.

6) Development of remixing and stabilisation equipment

Troms County has considerable amount of equipment for remixing and stabilisation, and has obtained significant amount of experience by using them. They have made several improvements, especially to the remixer, that others in the NP-area could find beneficial. Both the remixer and the foaming equipment on the deep stabilisation miller are produced in Finland.

The purchase contract for the deep stabilisation miller states that the contractor and the Public Road Administration shall co-operate on developing the equipment, and as such a number of improvements have been implemented.

For more information - contact the Public Road Administration, Production Department, Troms County.

7) Composite stabilisation - emulsified bitumen and cement

In 1995 in Rv-861 in Senja, Troms County tested different kinds of stabilisation techniques: Cement stabilisation, emulsified bitumen stabilisation and a combination of emulsified bitumen and cement. The advantage of using cement is that this reacts with the water in emulsified bitumen and avoids the reduction in shear strength capacity of the stabilised material during the first period after stabilisation. Troms County has experienced low bearing capacity and development of ruts in this first period. Adding cement when stabilising, this problem is reduced.

Measurements of bearing capacity were performed before and after the stabilisation and results confirmed that the stiffness of the road structure increased. The change in rutting and roughness also indicate that this technique results a very strong road structure.

The FWD-measurements and the method are presented in a paper at "Asfaltkonferansen 1995". Geir Berntsen

8) Reduction of the bearing capacity during the spring thaw period

Both the freezing and thawing process in a road structure have been analysed. In analysing the freezing process the frost penetration and formation of ice lenses and frost heave is calculated. Analysis of the thawing process is carried out using models for resilient modulus, stress path analyses, moisture content and pore water pressure, temperature, permeability of the soil and other material property.

In order to illustrate some of the bearing capacity problems during the spring thaw period, some regular pavement structures were analysed. Finite element methods were used to calculate stresses and strains, and different models were used to calculate the changes in the bearing capacity.

Documentation:

Geir Berntsen. Theses for the doctorate - 1993:64 NTH. "Reduksjon av bæreevnen under teleløsningsen" ("Reduction Of Bearing Capacity During The Spring Thaw Period").

8.4. The Highlands, Scotland

The Highlands main problems are associated with peat subgrades, or very silty subgrades beneath evolved roads. With limited funds the 'solution' to a settling road over peat is to add more surfacing and improve the vertical alignment. Lightweight fill has been used, and it would be useful to have other, lower cost, solutions. Similarly a more targeted approach to identifying causes of problems with more effective rehabilitation techniques would be of great benefit.

Below are listed some reports/work carried out by TRL (Transport Research Laboratory), which has been targeted at finding low cost and effective remedial measures to help prolong the life of roads.

1) PA/SCR243 Road Haunches: A guide to maintenance practice (1991)

The increasing width and volume of commercial vehicles, particularly on minor roads, has resulted in extensive edge of carriageway deterioration. This guide outlines the extent of the problem, discusses the various modes of failure (inc. inadequate drainage, edge support, trenching effects, trees and differential road construction) and provides guidance on methods of investigating haunch defects and carrying out repairs.

2) TRL Report 216 Road Haunches: A guide to reusable materials (1996)

This report follows on from the above by providing engineers with methods of repair by re-using road materials or industrial by-products. The guide is based on the in-service performance of 22 test sections.

3) TRL Report 386 Design guide and Spec. for structural maintenance of highway pavements by cold in-situ recycling (1999)

This report promotes the concept of the existing road being used as a 'linear quarry' from which aggregates can be reclaimed. The information contained in this report offer the latest best practice advice on the design, supervision and construction of cold in-situ recycling works, used for structural maintenance of roads.

4) RN39 Design guide for road surface dressing (Fourth Edition, 1996)

Surface dressing provides a cost effective and simple form of maintenance. This revised document provides guidance on the choice and design of an appropriate surface dressing. TRL also have experience of other sealing techniques such as the Otta technique (developed in Scandinavia).

5) PA3134/96 Performance of the crack and seat method for inhibiting reflection cracking

The above 1996 conference paper gives a good overview of the technique of crack and seat, and the results on trials set up in 1991. The crack and seat process can be used on cement-bound road bases (composite pavements) which require maintenance/reconstruction. Information, yet to be published, indicates that the technique is very cost effective. Contracts have been completed in one third of the time and at one third of the cost of totally reconstructing the pavement. As the existing pavement is left in place the technique supports sustainable construction initiatives.

Other TRL Research

In addition to the above much research has been carried out to develop techniques to assess the condition of roads. Automated survey methods have been developed which take surface condition measurements for assessing maintenance requirements, e.g. High-speed surveys and SCRIM. Other techniques have been developed to reflect the structural condition of the pavement in depth. These tend to be based on the measurement of transient deflection under an applied load, e.g. Deflectograph and Falling Weight Deflectometer. Ground probing radar has also been used in trials to assess existing pavement layer thickness.

The use of Pavement Management Systems (PMS) to analyse and display collected data is vital. TRL have developed in conjunction with South Bank Systems (SBS) an integrated PMS called CONFIRM. The system assists pavement engineers in maintaining their road network by collecting condition measurements. Using algorithms, the system will optimise and apply treatment options over multi-year periods, apply budgetary considerations and output the results in a variety of formats appropriate to different levels of decision making.

9. SPECIAL TECHNIQUES TO OVERCOME BEARING CAPACITY PROBLEMS IN THE NP AREA; BEST PRACTICE IDENTIFICATION

The Road Condition Management best practise identification, prior to the phase II tests, has been done in two ways: a) each partner district has made their own lists, where they have selected special techniques with which they have been very satisfied, and b) the work group chairman has made another list after reviewing all the research material and after interviewing every partner district and comparing the practices in each district. Thus chapter 9.2 presents the chairman's own view and is not an official statement of the Roadex project. Many techniques have been selected to several lists and they also have been mentioned earlier in this report.

9.1. Partner Districts' Choices

Lapland, Finland

1) Remixer stabilisation

Remixer stabilisation is a mix-in-place method, which is used in particular to repair paved roads, which are already cracked and have lost their load bearing capacity. This method restores the load bearing capacity, and the life-time of the pavement structure will be extended remarkably. A bitumen stabilised layer is made by mixing heated old pavement with the grinded upper part of the base course, and optional new aggregate. Remixer stabilisation offers remarkable savings. Especially, normal load bearing capacity can be achieved with thinner layers and, thus, with less bitumen, although the same binder content is used. Remixer stabilisation does not disturb traffic flow more than normal pavement rehabilitation.

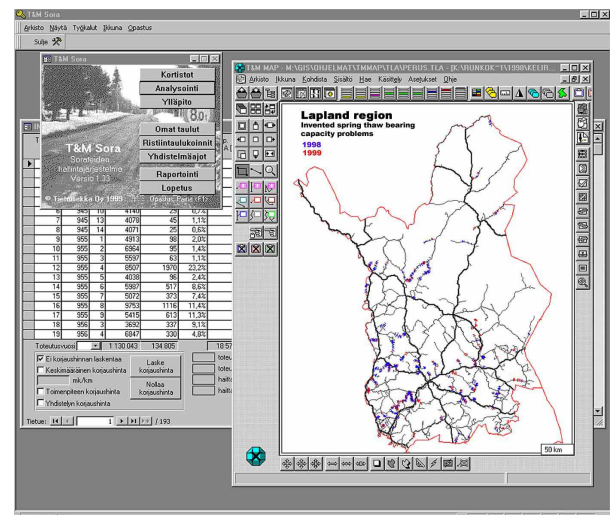


2) Soft bitumen pavements on low traffic volume roads

Oil gravel and other cold mix pavements have proven to be usable pavement types on low traffic volume roads. These roads often suffer from frost heave and freeze-thaw weakening problems which both cause pavement deterioration. On the other hand there are no pavement wear problems due to high traffic volume. Due to the reworkability of the cold mix pavement it is possible to repair this damage, on-site, using simple and cheap methods. The road sections with low bearing capacity can be identified from the deep rut formation and these sections can be repaired by mixing and evening the pavement with a grader and adding a small amount of new cold mix pavement material and evening and compacting the surface. The low price and usefulness of the cold mix pavements allowed Finnra to pave the low traffic volume road network to the present level and in early days also the main roads were paved with oil gravel.

3) T&M software for gravel road spring bearing capacity problem evaluation

T&M software is a GIS-software that allows comparison, on a map background, of the location of bearing capacity problem sections on gravel roads in each year. This method allows easy location of the sections where spring thaw bearing capacity problems are appearing each year and the rehabilitation resources can be focused on these sites.



4) Precise rehabilitation using data provided by T&M software

See previous best practise

5) Frost dimensioning

Both climate factors and subgrade soil conditions are observed in the Finnish frost dimensioning system. The best result is achieved when the road is constructed using non-frost susceptible road materials to the frost line depth. If the frost susceptibility of the subgrade soil is known, a thinner pavement structure can be used. In that case even frost heave is allowed because it does not cause harm to the traffic.



6) Rehabilitation design of paved road with distresses

New road survey techniques such as ground penetrating radar and falling weight deflectometer and their integrated analysis, known as road analysis, have been used in analysing the reasons for the defects causing problems in roads under a rehabilitation programme. By analysing structural defects and determining the current condition of the road, it is possible to select a suitable rehabilitation method for each particular type of road defect on each road section. It also presents the possibility to leave untreated those road sections with reasonable life expectancy. By locating defects and implementing rehabilitation measures based on their causes, unnecessary construction work and incorrect rehabilitation measures can be avoided. Using road analysis it is possible not only to keep down costs but also carry out rehabilitation measures confidently.

7) Using steel mesh reinforcement to prevent longitudinal cracking

Steel mesh reinforcement has been successfully used to repair longitudinal cracking on roads. Steel mesh has been installed either in the pavement or in the unbound base course and this method allows the repair of the problem without any major rehabilitation of the pavement structure. Thanks to steel nets the pavement does not crack even though the road is still moving due to frost heave.

Finnra has not yet had any experience of rehabilitation of the road sections with old steel reinforcement and this may present some problems in the future.



The Northern Region, Sweden

1) Milling of pavement, new unbound base material and on the top reuse of the old pavement - often called "the conventional method"

When the pavement has been removed it is possible to construct the proper crossfall on the base course surface and/or remove the old base course and rebuild with new material to obtain better quality of the material in the road. The granulate can be treated in an asphalt plant and re-used for a cold or semi hot mixture pavement with good results. When making a cold mixture, bitumen emulsion is utilised and for a semi hot mixture soft bitumen.

The benefits of this method are almost 100 % reuse of the old pavement material and lower temperature required when heating the material, which result in reduced use of natural gravel, energy and transportation (the last depending on the distance of the asphalt plant).



Milling machine

2) Roadmix (Pavement and/or base course)

In this method, all stages of paving are performed directly on the road. This is a fast method which allows the

traffic to use the repaved road at once, without temporary re-routing or driving on the base course.

The new pavement is a mixture which consists of old pavement, soft bitumen and a small amount of semi hot mixture (MJOG) - the method is also called semi mixture remixing. The costs of this method are only 60% of the costs of conventional reuse of wearing course. When used to stabilise the old pavement and base course, the mixture consists of old pavement, old base course, emulsion and macadam. In stabilisation projects, the amount of existing base course material has to be examined first to make sure there is enough material for stabilising.



Roadmix of the base course.



Result after roadmix of the base course.

3) Stabilisation (foam bitumen and emulsion)

Stabilisation is performed with either foam bitumen (bitumen B180 170°C + water) or bitumen emulsion. Both these methods have a lot of advantages when it is not possible to raise the grade line. Stabilisation also makes a more stiff and stable base course than unbound layer. Other advantages are reduced transportation costs and decreased consumption of natural resources.

Stabilisation with foam bitumen is used when the fines content in the base course is high. This is because the

foam has a bigger contact surface with the aggregate (especially the fines) and a more homogenous mix is obtained. By experience, when the base course contains a sand fraction emulsion stabilisation seems to give a more homogenous mix.



Stabilisation with emulsion

4) Reinforcement/Steel grids

Reinforcement is an efficient method to prevent longitudinal cracks on the pavement surface caused by frost heave. Many successful field tests have been performed with grids in the pavement or in the unbound base course. The steelgrids are not supposed to be used everywhere to prevent the cracks but where large cracks generate a risk to traffic safety or to the lifetime of the road structure. Steel grids can also be used to prevent cracks when widening an old road. The grids should, if possible, be installed in the unbound layer, because if they are placed in the bituminous layer this will be hard to reuse in the future.



Steelmesh in Sundom road 600 in Norrbotten county.

5) Drainage (ditches)

Drainage is one of the most important factors to affect the lifetime of a road structure. Ditches are always built for drainage (and indirectly to increase the bearing ca-

capacity) when a road is built, or during the maintenance of roads. To prevent undermining of the road structure, the excavation of ditches should be performed one year before rehabilitating a road.

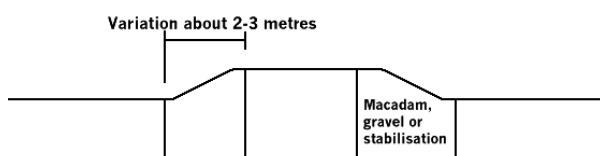
6) Waste materials

The Northern Region has used materials gained from industrial processes since the 1970's, when the first experiments were conducted with blast furnace slag. Today, the preferred waste materials besides blast furnace slag from a SSAB steel works are granulated slag gained from copper extraction, and crushed concrete. The experiences thus far from these materials are listed in the following:

Material	Positive	Negative
Blast furnace slag	<ul style="list-style-type: none"> shows fairly good results in preventing frost heave very good stability 	<ul style="list-style-type: none"> sulphate smell
Granulated slag	<ul style="list-style-type: none"> shows very good results in preventing frost heave 	<ul style="list-style-type: none"> low stability cannot be used directly under the pavement
Crushed concrete	<ul style="list-style-type: none"> shows a high increase in bearing capacity (E-modulus 350 MPa to 900 MPa during three years) can be used directly under the pavement 	

7) Widening of roads resting on peat

To prevent settlements when widening roads resting on peatland, and to be able to use as much of the material existing at the site as possible, the below illustrated strengthening method is used.



When the peat is not too deep (max 5 m), all material is excavated. If the peat layer is deeper than five meters, the excavation is done down to three meters from the surface. The width of the excavation is usually two to three meters, depending on the depth.

Troms County, Norway

1) Deep stabilisation using foam or emulsified bitumen

Troms County has used a lot of stabilisation since 1986, first with emulsified bitumen. According to Norwegian design standards the content of fines ($<75 \mu\text{m}$) should be less than 4-5 % if emulsified bitumen is used for stabilisation. Because of this, coarse aggregate (4-22 mm or 8-22 mm) is added and mixed together with the old base gravel. The experiences have been very good, but it is expensive to produce the emulsion and to transport 30-35 % water long distances.

To reduce the costs, foam bitumen has been used since 1996. This bitumen works better when the content of fines is higher than 6 %. If additional gravel is needed for reinforcement, well-graded aggregates must be used.

The reason for using stabilisation is the same as in other countries: old base gravel and old pavement are recycled as a new base layer. FWD-measurements show an increase in bearing capacity of about 2 tons. Using empirical equation (4th power law) this increase in bearing capacity also increases the lifetime of the pavement.

2) Surface dressing using a special spreader on a lorry

The reason for using this method is to extend the life of existing pavements.

The equipment that is used is mounted back on a lorry. This has a bitumen tank containing 1 ton of emulsified bitumen and has a spreader with 9 hatches of width 30 cm. It is possible to treat up to a width of 2,7 m in steps of 30 cm. Only areas that are distressed are treated.



3) Frost insulation to prevent frost heave and longitudinal cracking

In order to prevent the frost from penetrating into frost susceptible road structures and subgrade soils, frost insulation is the most reliable method.

The old pavement structure is removed to a depth of 50 cm. The surface in the excavated area has to be very

smooth before the insulation plates are placed. The maximum thickness for the insulation depends on the frost and is normally between 4-8.5 cm. At both ends the insulation is made thinner to avoid sudden changes in frost heave. The old pavement structure is carefully replaced. It is important not to damage the insulation plates.

This method works very well, but is a relatively expensive.

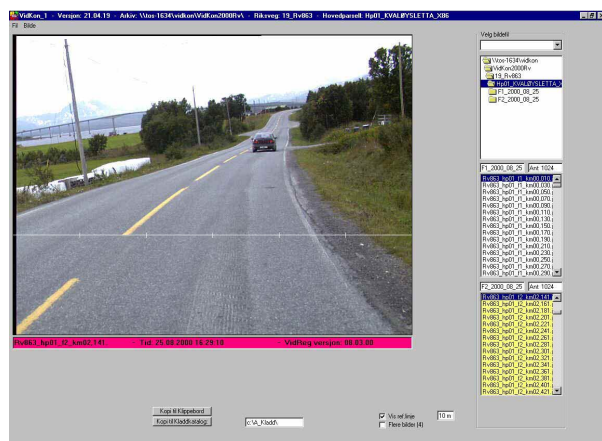
4) Measuring rutting and roughness and cross fall of the road network every year

Performing rutting and roughness measurements every year gives a very good view of how fast the roads deteriorate. When designing a road, the aim is to attain the designed lifetime. Together with other distress information, changes in rutting and roughness values are effectively indicators of defects in the road structure; FWD, core samples, and DCP measurements are used to find out reasons for the defective condition.

5) VidKon system; using digital photos for pavement distress evaluation

Rutting, roughness and FWD measurements are insufficient for the evaluation of the road condition. A complete picture of other distresses in the pavement is obtained by using the VidKon system, which registers digital photos of the road surface at 20 m intervals in both directions.

In the VidKon system the pictures are taken in connection with rutting, roughness, cross slope and horizontal curvature measurements. The pictures are stored on a server and they are available for all road administration personnel. The pictures are used for a number of other purposes as well, e.g. for analysing traffic accidents.



6) FWD measurements to evaluate road structure and bearing capacity of the subgrade

The measurement of rutting and roughness tells that the "patient" is ill, but very little about the diagnosis.

It is possible to do backcalculations on FWD-measurement, but then the layer thickness in the pavement

structure is needed. The backcalculation is very time consuming and is only done in special cases.

It is possible to use regression equation to estimate E-modulus. As an example the deflection 90 cm away from the load centre gives the E-modulus for the subgrade and the surface curve index tells a lot of stiffness of the top layers.

An empirical equation is used to calculate bearing capacity at every testpoint.

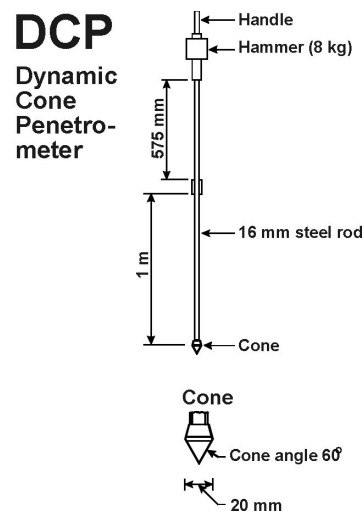
FWD-measurements are done for the whole national road network. These measurements vary depending on weather conditions (temperature and precipitation), but the variations are largest during the spring thaw and from one spring thaw to another. For rehabilitation projects the weakest measured bearing capacity of three measurements are used.

7) Use of DCP for recording shear strength and layer thickness

DCP (Dynamic Cone Penetrometer) is used to register the shear strength and layer thickness in the pavement structure and the subgrade.

The illustrated equipment is hand-operated; an automatic device has also been built for two counties in Norway.

The DCP gives the CBR-value; different equations are used depending on the material.



8) In-situ remixing of pavement course

Troms County uses remixing of the pavement course a lot, as do other counties in Norway.

The experiences made in Norway with this method and equipment imported from Finland have been very good.

9) Transportation of soft asphalt and gravel using boats

Troms is a county with of many fjords and islands. The people are living near the sea and because of this the roads

are also situated here. The largest asphalt plants in Troms County are situated near the sea, which makes transportation of material by boat possible.

Both gravel for reinforcement and soft asphalt is transported in this way. The temperature drop is low when transported by boat and there are no problems having soft asphalt 2-3 days inside the boats. Every transport is about 1000 ton and this is the capacity for a team to pave for one day.

A drop in temperature is not so critical for soft asphalt as it is for hot asphalt mixes. Asphalt types with high content of binder and coarse aggregate have a tendency to separate when transported by boat.



10) Paving only the wheel tracks

Troms County has a special drum for one of the miller that only mills the wheel tracks. After the asphalt is removed, a special paver is used to put new asphalt material in the wheel track. This saves about 60 % of the paving material. Because of the trouble caused to motorcyclists by pavement edges, the method is not used when the permitted speed is more than 60 km/h.



The Highlands, Scotland

1) Surface dressing to prolong the life of the road and to provide friction

This is a low cost method of extending the life of existing pavements. Normally the section of road requiring treatment will have some areas of distress, rutting and cracking, especially at the carriageway edges. Once the worst of the areas have been patched, the surface is sprayed with a K1-70 or K1-80 bitumen at around 1.8 litres/sq metre, with 6mm, 10mm or 14mm crushed rock chippings applied and rolled in. This method seals the road surface against water ingress and restores surface texture.



Surface dressing project in Highland

2) Reinforcement using steelgrids, geogrids and geofabrics

These materials have been used at various depths in road pavement, and have generally been successful. In one case a very badly grazed section of single track road was overlaid with a fine steel mesh (small diameter) and 50mm of dense bituminous macadam. Shortly after the work was completed a fully laden lorry ran off the road edge and sunk into the peat verge/ditch. Subsequent removal of the lorry by crane and other vehicles imposed significant stress onto the road surface, but the surface remained intact and in good condition.





Road section resting on peat reinforced with steel mesh



Edge strengthening project



Pavement reinforcement using Rispond Tensar geotextile

3) Edge Strengthening

Most of the roads in the Highlands have been widened through time from original single track roads. Unfortunately this means the carriageway edges may not have as good a foundation as the central portion of the road. With increasing heavy traffic using the roads, the nearside wheeltrack is prone to high stresses which cause deformation, rutting and cracking. The cracking allows more water ingress and the pavement deteriorates more quickly as a result.

The solution most commonly adopted is to remove a strip of road pavement, normally between 800mm and 1200mm wide (depending on distressed area and width of compaction plant), to a depth of up to 300mm, (deeper

if the subgrade is poor). The area is then infilled with several layers of bituminous materials, and brought back up to finished level. The material used for the top layer will normally be a dense bituminous macadam with a surface dressing applied to the whole carriageway the following year.



Road section after edge strengthening

9.2. Best practices - Work Group chairman's opinion

The following compilation of the road condition management best practices in each Roadex partner district has been based on the work group chairman's information, experience and comparisons that he has gathered and evaluated from questionnaires, interviews and field trips in each Roadex partner district. A large part of the practices are the same as those mentioned in the previous lists presented by partner districts but there are also other techniques that, according to the chairman, deserve attention. In the chairman's list each technique is mentioned only once even though it has been successfully used in other countries.

Lapland, Finland

1) GPR based road analysis and precise design

Today's challenge for the modern transportation agencies is finding resource effective rehabilitation design and maintenance strategies for the existing network. A promising new solution for the network level road condition evaluation and rehabilitation design, road analysis, has been used for several years in Lapland. This method, that applies the advantages of the new non-destructive road survey methods, allows maintenance and rehabilitation measures to be focused only on the road sections where measures are needed. Road Analysis, developed in Finland, is comprised of the examination of 1) pavement condition, 2) unbound pavement structure, 3) subgrade soil related, mainly frost fatigue problems, 4) drainage and 5) local damages of the surveyed road. The analysis is based on measurements conducted with ground penetrating radar (GPR), along with the support of drill core samples, roughness and rutting measurements, falling weight deflectometer (FWD) measurements and visual observation and location measurements using GPS.

2) Remix-stabilisation

The degradation of the base course under the pavement is, along with frost damage, the major reason for road defects in the Lapland Region. Base materials with high fines content are water and especially freeze-thaw susceptible. Permanent deformation due to positive pore water pressure can take place only after a few trucks pass. Remixer stabilisation which treats this problem material by mixing the existing pavement on the top with the base, adding new bitumen and new aggregates, if needed, has proved to be an excellent method to treat the roads with poor quality base course materials.

3) Road condition data bases for paved and gravel roads

Finnra has been collecting, for about 10 years, road condition data information that has been stored in several data bases. The benefits of these data bases for road condition management have become quite apparent. There are several applications of these data bases. Pavement condition data base can be used for prioritising the rehabilitation projects and for preliminary evaluation of the rehabilitation measures needed as well as rehabilitation costs. Road condition data bases are also used in precise rehabilitation design, where they give valuable information as to where the defects are appearing and how fast different pavement distresses are growing in each section. On gravel roads the road condition data base has been invaluable when Region has had to decide where to direct the allotted resources to repair spring bearing capacity problems. When the data is available from the spring thaw problem sites for several years it is easy to focus the rehabilitation measures to the road sections where the problems have been appearing repeatedly.

4) Real time bearing capacity monitoring system

According to forest industry, traffic load restrictions each year cause tens of millions of Finnish marks in extra costs to their operations. Because load restrictions still have to be applied in certain roads, due to their weak structure, the only way to improve this situation is to build a real time bearing capacity monitoring system that measures if the materials are frozen and the moisture content at different depths in the road structure and subgrade soil. As a co-operative project between Lapland Region and Roadscanners a prototype of Percostation was installed near Rovaniemi in 1999. This unit consists of five sensors installed at different depths in the structure and subgrade soil. These sensors measure dielectric value, electrical conductivity and, in the future, temperature at, at preset time intervals. The data is transferred to a traffic information centre via modem connection, where decisions for implementing or lifting the load restriction can be made. With this system it is possible to reduce significantly the duration of load restrictions and preserve road structures without causing unnecessary costs to forest industry. In the future there will be a possibility of evaluating the largest allowed axle loads on the roads depending on the depth that the weak zone is situated in the road structure or subgrade.

Percostation results from early spring 2000: dielectric values (ϵ_r) and electrical conductivity values show that the top part of the base thawed over two days in march 30-31, then re-froze and began finally to thaw on April 09. The alarm value for high risk of permanent deformation (ϵ_r 16) was measured once late in the night of April

11. After that the moisture content in the upper part of the pavement structure decreased.

5) Laboratory testing in stabilisation design

Bitumen stabilisation has proved to be a very useful tool in strengthening the roads with high fines content in the base course. The main factor that effects the final costs of the stabilisation is the bitumen content. Research work carried out in the laboratory of the Finnra Lapland Region and Technical University of Tampere has shown that the bitumen content needed for stabilisation can vary significantly: some problem aggregate types need 3,5 - 3,8 % bitumen while the other base material gain the optimum properties with only 1,8 - 2,2 % bitumen content. To study the optimum bitumen content, Lapland Region has started to use the Tube Suction test, which shows the bitumen content when water can no longer penetrate to the stabilised base course. This method has enabled money to be saved in stabilisation projects and it has also helped to use more bitumen in road sections where it is needed.

The Northern Region, Sweden

1) Steel grids

The Northern Region has been very broadminded in using steel grids in pavement structure reinforcement. The steel reinforcement technique has been used in most of cases to a) prevent longitudinal cracking but there are also two other applications that have given positive results: b) road shoulder reinforcement, where steel grids are installed longitudinally about 25 cm in road should to prevent shoulder deformation and c) reinforcement of weak road sections resting on peat. Northern Region has been also a very active participant of the EU Reflex project which focuses on steel reinforcement techniques. A test road has been constructed in 1999 in road 600 near Luleå where different kinds of steel reinforcement structures are being tested.

2) Bitumen stabilisation design - selecting between emulsion and foam bitumen

Northern Region has been using a bitumen stabilisation technique since the late 1980's with mainly positive experiences. The fact that the only problems have been in areas with frost susceptible subgrade and poorly performing drainage reminds that stabilisation does not solve frost heave related problems. In selecting which stabilisation technique should be used: emulsion bitumen or foam bitumen Northern Region has developed a working rule: a) if fines content is <8 % emulsion bitumen is used, b) if fines content is >12 %, foam bitumen is used and c) with fines content between 8 and 12 % the method depends on price.

3) Shame value

The Northern Road District has, for two years, tried to prioritise how to allocate the resources for maintenance and rehabilitation of surfaced roads by using c/b-calculations. The benefits are lower road user costs due to a better road surface. The road user costs calculated in the Swedish PMS are not the total cost, but the extra cost due to a bad road surface. These extra road user costs consist of travel time cost, vehicle operating cost, (dis)comfort cost and accident cost. They are calculated from IRI and rut depth. New models for road user costs and c/b-calculations are currently being developed and will hopefully be in use next year.

Northern Region has used a road user cost of 1 SEK (0,18 euro) /(km,vehicle) as a definition of the worst allowed road condition. It is equal to IRI = 4,5 and a rut depth 20-30 mm (mean value/km). Within the RD area there is about 700 km of public roads that has a worse condition than the shame value at the moment.



A road section in worse condition than shame value.

4) Widening technique of road resting on peat

A special method that has been used to prevent settlements when widening roads resting on peat. When peat thickness is less than five metres (<5 m) excavation has been done to the hard bottom, but if the peat thickness is deeper than five metres the excavation is performed down to three metres from the surface. The width of the excavation depends on the peat thickness, normally it is 2-3 meters. The material used for the excavation is normally gravel or macadam and it has sometimes been stabilised with a small amount of cement. After the excavation is finished the road is widened.

The method is good when there are long material transportation distances and it also conserves natural resources. Traffic can use the old road during the construction which is also an important benefit compared with the total soil replacement method (see also Norway).

5) Gravel road wearing course treatments

Region Norr is the only road region of NP partner districts that has seriously attempted different kinds of treatment techniques for gravel road wearing course. Even though not all the tests have been successful and there

may be some environmental problems in treatment of the gravel roads the results have shown that very good results can be achieved when the work is carried out by a professional and devoted maintenance crew. This r&d work should be continued with new materials and maintenance techniques.

Troms County, Norway

1) Rutting and roughness measurement system

The benefits of the rutting and roughness measurements of the entire road network and of using the Arthur system in Troms County will soon be utilised in the form of extremely precise and valuable road data that can be used for road structure lifetime evaluations. When this data is compared to the pavement distress data, collected at the same time with the rutting and roughness measurements and road structure data, it is possible to evaluate precisely what kind of structures and pavement materials are working in various environments in Troms Region. This information can then be used for future road and rehabilitation design in the area.

2) Pavement design procedures

The pavement design procedures, that combine theoretical knowledge of the road structure together with empirical data and data collected from the road structures and subgrade soil, seem to work especially well in Norway. These design procedures are easy to adopt and different dimensioning methods can be used depending on the road standard and what kind of information is available. The rutting data collected from the Troms road network during the late 1980's also shows that the system is working well.

3) Frost design procedure

When driving on recently constructed or rehabilitated Norwegian roads one can see that the frost design procedure is working quite well in the area. This can be observed, when driving from Finland, or Sweden, to Norway and then comparing the quality of the roads with a similar age. In older roads the only problems seem to be related to culverts with poorly working transition wedges and poorly working drainage.

4) Insulation techniques

Troms Region is the only region in Scandinavian partner districts that routinely uses polystyrene frost insulation structures. In other countries they are thought to be too expensive and not even comparative calculations are carried out. Frost insulation, when properly designed and installed can have several advantages compared with soil replacement that is normally used, for instance if the road is located on a sloping hill with heterogenous subgrade conditions and bedrock close to surface frost insulation

allows ground water to flow under the road without causing frost heave problems and the environment around the road does not suffer from the lower ground water level.

5) Cement stabilisation and composite structures

Troms Region has been testing more rigid pavement structures in its roads with non-frost susceptible subgrade soils. Even though there has been some problems with the technique, in the future there will be road sections in each NP districts where cement stabilisation or composite structures will provide a better and cheaper solution in road rehabilitation projects.

The Highlands, Scotland

1) Pavement structure design against transverse cracking

The amount of transverse cracks in roads in Highland is amazingly small compared with the roads in Scandinavia. The only types of transverse cracks seem to appear on road over peat subgrade where the cracks are clearly tensile cracks. The reason for the low amount of cracks is most likely that the pavement design protocol has been successful and deals extremely well with transverse cracking.

2) Edge drains

Due to problems with adjacent land ownership there has been major problems in constructing a proper drainage system for the road by using open ditches. That is why in several places Highlands has been using edge drains (drainage pipes installed to a certain depth at the edge of the road). Highland Council has many years of experience with these systems and the feedback has been mainly positive. However there are several procedures that need to be followed when designing, installing and maintaining these pipes. It would be highly beneficial that this experience were published to be available to other Roadex partner districts, who also have roads where this drainage structure could be used.

3) Sealing techniques, Surface Dressing

The Highland Council has successfully used the surface dressing method to protect the pavement structure from water, which is the main factor causing damage in roads. Thanks to this method the roads in Highlands area show very few signs of distress. Surface dressing is normally carried out when the pavement starts to show signs of distress, such as alligator cracking and deformation. The worst section will be repaired before the surface dressing. Surface dressing has also been done also using glass fiber reinforcement; this pavement is called fiber deck. Normally surface dressing lasts 7 years in Scotland. If the road requires a new pavement 40 to 50 mm thick bitumen macadam layers is mainly used.

10. GENERAL OBSERVATIONS ABOUT THE NP PARTNER DISTRICTS

Lapland, Finland

The stresses and strains on the low traffic volume road structures are highest of the NP partner districts, this is because Finland allows maximum axle loads and 60 tn trucks and has relatively small amount of spring load restrictions applied in its network. In spite of that fact the roads in Lapland Region are in relatively good shape compared with the other partner districts, only the low traffic volume roads are becoming worse. The quality of gravel roads and old gravel roads paved with thin cold mix pavement has especially become worse during recent years.

Lapland has an effective road condition evaluation system for both gravel and paved roads and rehabilitation measures have been addressed on the basis of this objective information. Lapland has also a modern and effective pavement rehabilitation design system, which offers cheap and practical solutions - unfortunately it is not thoroughly adopted by all the personnel working in this field for Finnra, consulting companies or contrac-

tors. There is also a tendency in Lapland for “patent solutions” ie. once a successful method has been invented it will be used without another thought in almost every project and the results are not always the best possible.

Lapland Region has for years had a very positive attitude towards research and development work for both in-house or in co-operation with universities and other research organisations. These r&d investments have produced many new techniques and innovations that have turned out to be very cost effective. These techniques have also been widely used in other areas. The positive attitude towards r&d is one of the major reasons for the effective road management in the area.

The big problem for Lapland in the next few years will be the break-up of the Finnra organisation and how the in-house know-how can be transferred to the consultants and contractors. To do that a lot of work will be required especially when preparing the tender documents.



The Northern Region, Sweden

With regard to the low traffic volume road network, Sweden will have, in the near future, the greatest problems. A majority of the low traffic volume roads are in extremely bad shape and these roads will present major difficulties especially for the forest industry, which has a significant role in the economy of this area. The poor condition of these roads has been noticed not only by industry but also local politicians and private road users. All have reacted and there are increasing public discussion in Sweden as to what to do with the bad quality roads. The Northern Region has a slightly awkward position: on the one hand there are claims about bad quality roads and on the other hand industry is arguing against load restrictions.

The Northern Region differs from the other NP partners districts in its size. The Northern Region area 160 000 km² and its road network length 18.080 km is about two times larger than the second largest partner district, Lapland. This fact creates special problems for the low traffic volume road management due to widely scattered roads and long distances. As in Finland SNRA is also reorganizing its organizations which generates additional problems before the new working practices have been adopted.

When comparing the practices in load restrictions the Northern Region has the most protective attitude towards its road network. When Lapland Region has applied temporary load restrictions in about 6-12 % of its road network in 1990's the corresponding value has varied from 25 % to 37 % in the Northern Region. The reason for this is that the roads are already in bad shape and without restrictions they would become even worse. When comparing the low traffic volume roads with the correspond-

ing roads in Finland the structure thickness in the Northern Region is thinner than in Lapland. The current road design standards in Sweden call for thicker structures but the Northern Region does not have many roads constructed following these specifications.

The Northern Region has developed very interesting techniques and policies to combat the problems of the low traffic volume roads. One of them is the introduction of the term "shame value", which is new, innovative, and an easy-to-adopt parameter that road officials can use to describe the condition of the road network. The Northern Region recognises the importance of keeping lower class roads in reasonable shape - even though the cost benefit value calculations for higher class roads give much better results. The idea of minimum allowable road condition in every public road should also be introduced in other public road administrations. In the technical field the Northern Region has carried out promising tests especially with different kinds the reinforcing and stabilisation methods. These methods succeed in dealing with the bad quality road materials and permanent deformation and cracking problems but not with the uneven frost heave problems of which Northern Region has more than the other partner districts.

The road condition data base in the Northern Region is based mainly on roughness and rutting measurements which do not provide any information about the causes for the problems. Improving this data bases with the addition of pavement distress data and/or structural data Northern Region would have the potential for more cost effective investments for rehabilitation projects.



Troms County, Norway

While the other NP partner district heavy transportation consists increasingly of forest industry transportations, the low traffic volume roads in the Troms County roads office have increasing stresses due to the rapidly expanding fish farming industry. When discussing transportation of Norwegian fish to the European markets everybody understands the importance of logistics.

In general, the roads in Troms county are in the best condition of the NP partner districts. This fact can be explained in many ways, the roads in Troms area are generally the youngest and have been designed and constructed following modern standards. However the low traffic volume roads condition is becoming worse, for example even though the frost dimensioning works quite well in Troms roads there are many culverts that do not have proper transition wedges and in the spring time have sharp frost bumps. Major shoulder deformation problems can be found in the roads located on sloping hills and where

the drainage on the upper side of the road is not working properly.

The Troms Region has some problems with allocation of the road maintenance and rehabilitation money to the low traffic volume network because main funding for the county and municipal roads comes from Troms County and not from Norwegian Public Roads Administration. Due to limited resources Local administration is not able to invest enough funding to rehabilitate these roads.

The road condition monitoring system in Troms region is well organized and in the long term this data base will provide extremely useful information regarding the durability and service length of different kinds of road structures in the area. Due to better resources, the rehabilitation structures used in Troms region are on the whole far superior, but also more expensive, when compared with respective structures in Finland and Sweden. The long term performance is predicted to be better.



The Highlands, Scotland

The biggest difference of the low traffic volume roads in The Highland Council area compared with the other NP partner district roads is the width of the roads. There is still a remarkably high amount of 3 m wide one-lane public roads in Highland area and this must have an effect on the transportation costs and the livelihood of these areas.

One remarkable difference in Highland Council roads compared with the other NP partner district roads is the quality of the pavement surface: if shoulder deformation problems are ignored the road surface is in extraordinarily good shape. The main reason for this is the surface dressing technique used for protecting the road structure and to improve the skidding resistance in the road. This technique requires skilled maintenance crews and is a good example how by using relatively inexpensive maintenance techniques roads can be kept in good shape for a surprisingly long time. In Northern Scandinavia transverse cracking is a very common pavement distress type but that defect can be seen in Highland roads only on narrow peat roads. The reason for that can be explained through the pavement design procedure and/or good quality materials used for the road construction.

Even though the pavement structures show surprisingly few defects and The Highland Council roads do not have the same problems with the frost heave and ice lens formation there are major threats for the road condition in the Highland area. Until now there has not been large stresses on roads due to heavy trucks, but during the last few years the forest industry and fish farming have been growing in the area and axle loads, total truck weights as

well as tire pressures have been increasing. These changes must have a long term effect on the road condition, especially the roads on peat areas which will be at great risk. So far The Highland Council have been able to protect the roads by co-operating with the transportation companies and by applying load restrictions on the roads where major logging is planned. However this policy is not sustainable in the longer term.

The biggest problem in The Highland Council road network is poorly performing drainage. It is the main reason for the increasing amount of severe shoulder deformation in the roads. Due to high grass verges beside the road, rain water is ponding on the road and is infiltrating into the road structure and making it water and freeze-thaw susceptible. However improving the drainage in Highlands is much more difficult than it is in Scandinavia because the road area in Highlands is limited, in most cases, to the carriageway and narrow verge. Solving this problem somehow would result however in millions of pounds savings for the Highland Council in road network maintenance and rehabilitation costs.

Another problem in the management of low traffic volume roads is that Highland Council does not have a road condition data base. As such it is impossible to perform any objective comparisons of the road network performance and the reasons for their defects. If and when Highland Council receives more resources for the rehabilitation of the low traffic volume roads it would be more difficult to prioritise the investments without any measured data.



11. SUMMARY AND CONCLUSIONS

The phase I state-of-the-art study results of the Roadex subproject “Road Condition management” shows that in spite of similar basic problems in each partner district, each country has emphasized different strategies and techniques when trying to resolve bearing capacity problems in their low traffic volume road network.

A significant problem for low traffic condition management, shared by all partner districts, is that almost all the structural maintenance funds and resources are allocated to main roads at the expense of medium and low traffic volume roads. As a result, the performance of main roads has been improving over the last few years, while the state of low traffic volume roads has become worse. Another aspect gaining more publicity and placing pressure on road districts has been that due to increasing logistical demands of the industry, using the lower class network for their transportation routes, have started to complain about load restrictions and bad quality road network.

With the history mentioned above this state-of-the-art study has provided very interesting and valuable information about the possibility of solving these problems either by applying load restrictions, or by improving the bearing capacity of the road network. In the following a short summary is made of current practices of load restrictions, road condition monitoring systems and maintenance and rehabilitation techniques in NP partner districts.

Load restrictions

It is generally recognised across the project region that load restrictions should be minimised because of their detrimental effects on local livelihoods, especially for timber transports. Yet the policies of the national road authorities on the issue vary a great deal, as do the practices in each Roadex partner road district. Finland and Sweden allow the heaviest normal transport weights on almost all the public roads, 60 tn, and appoint temporary load restrictions especially during the spring thaw periods. Whereas in Norway many roads have permanent load restrictions throughout the year for 40 - 50 tonnes and the maximum total weight in Scotland is 41 - 44 tonnes. In the future an interesting research topic would be to make comparative calculations to determine which policy in a long term would be the most economical. Both policies have their pros and cons. The greatest part of the structural damages appear on roads during the spring thaw period. During the other seasons road structures do not have problems carrying the load, a fact which supports temporary load restrictions. On the other hand the main

reason for reduced axle loads on certain roads in every NP partner district is that there are weak bridges along the road.

The maximum allowed tire pressures are basically the same in each country and there is general agreement that these pressures are too high and that modern super single tires are especially causing problems for the pavement materials.

Sweden and Scotland have more protective policies towards road structures, Northern Region uses temporary load restrictions if there are indications for pavement structure defects and Scotland sets permanent load restrictions if there is a fear that increasing heavy traffic might break the road.

There are also some new solutions for dealing with the problem. Modern information technology has provided a possibility for new methods of minimizing the additional costs for the heavy traffic due to temporary load restrictions. Real time road structure monitoring stations, one prototype is currently being tested in Lapland, can give real time information as to when and what level of load restrictions should be applied in each area. This technique is based on scientific research and objective measurements and is more easily accepted by the transportation industry.

The control of the load restrictions also vary in each country: while Troms county road office can order fines or other sanctions for over-loaded trucks the Highland Council and Lapland can only report the offenders to the police.

Road condition monitoring systems

In order to effectively utilise the resources addressed to the low traffic volume road network, road districts need a road condition information system. Troms County and Northern Region are evaluating their road network performance mainly through roughness and rutting information data collection system and use pavement distress information and bearing capacity data only in project level surveys. Both countries do not have a routine system for the gravel road condition evaluation. Lapland has the most complete (and expensive?) road condition evaluation system where along with the roughness and rutting information, pavement structure condition data is also collected using FWD and GPR techniques. Lapland also has a thorough system for gravel road condition evaluation. The Highland Council faces the biggest challenge in this field: at the moment there are no routine objective measurement systems to evaluate and compare road network condition and performance in different parts of the Highland area.

Road condition evaluation systems are in the long term very cost-effective, because they allow long term planning of rehabilitation measures and without this data it is not possible to invest in precise design and rehabilitation projects for the roads. Experience of the road analysis projects carried out in Finland and Sweden have shown that the roads, that are claimed to be totally damaged and requiring a total reconstruction, have severe defects only on about 30 % of the road length. This can be interpreted on the other hand that 70 % of the road is in relatively good shape and might need only some light repair. Thus the savings in rehabilitation projects gained through these pavement condition data bases are multiple when compared with the annual cost to collect the data.

Maintenance and rehabilitation techniques

This State-of-the-art study did not reveal any major new maintenance techniques but there were numerous special rehabilitation and repair techniques and materials that were successfully used in some districts and could be easily transferred to the other partner districts and other countries.

In rehabilitation techniques there are several unique techniques, materials and practices especially in stabilising the pavement and base course, in reinforcing and insulating the road structure and in road structure drainage improvement. In discussions with the district staff and in questionnaire answers especially road mix or remix stabilisation and steel mesh reinforcement techniques were mentioned frequently. Road Mix / Remix has been used in Norway, Sweden and Finland and steel reinforcement in Scotland, Sweden and Finland. Northern Region has tested a very interesting reinforcement method where steel nets are installed longitudinally into the base course to prevent shoulder deformation. An economical method to protect pavement structure and at the same time add friction is the surface dressing technique that especially Scotland and Norway are using successfully. One problem for implementing this technique in Sweden and in Finland is that surface dressing can be done only in dry weather and these countries no longer have permanent employees who can do other maintenance work during the rainy days. Due to slightly better resources Troms Region has been testing and using several more advanced, stronger but also highly expensive rehabilitation methods, that have also better long term performance.

The state-of-the-art study did not find any superior drainage improvement techniques even though drainage was a major problem in each country. Especially Highland Council has major problems with poorly performing drainage that is most likely the main reason for the shoulder deformation. The problems in other districts are mainly located on roads located in sloping hills.

Shared problems and need for the future research

The state-of-the art study clearly showed a few major problems that all the partner districts are sharing: drainage of roads located on transverse sloping ground, permanent deformation due to freeze-thaw cycles, bad quality road materials and their treatment, and road sections resting on peat.

The first three problems are more or less related to the water content and freeze thaw cycles and the research and development work should focus on these two subjects. Peat roads are clearly another kind of problem which require a different approach.

In the future research should also focus on the following topics:

- 1) how much road closures and load restrictions effect on the road structure deterioration,

- 2) what is the lowest allowed road standard and what are the social benefits and costs for road users and roads owner to have an adequate road performance and

- 3) how much funding is needed for the low traffic volume roads to keep the low traffic volume road network on a sufficient service level.

Roadex partners should continue actively seeking and researching transport-friendly alternatives that would not cause the deterioration of existing secondary roads.

One example could be new and smarter types of restrictions like the following:

- 1) optimising (& shortening) the period of load restrictions,

- 2) defining time and distance between heavy load vehicles,

- 3) defining vehicle speed and

- 4) defining truck tire pressure.

Roadex work group A, Road Condition Management, will focus on the phase II field tests in 2000-2001 with the purpose of collecting information on the existing road structures and road test sections in each partner district and then comparing more precisely the performance of the different road structures. The results of these comparison tests together with this state-of-the art report will be then produce substantial benefits in the development of more resource effective practises to reduce traffic load restrictions and in the development of road rehabilitation methods needed on low traffic volume roads with bearing capacity problems.

