INFRASTRUCTURE NOTES

TRANSPORTATION, WATER AND URBAN DEVELOPMENT DEPARTMENT
THE WORLD BANK

March 1993
Transport No. RD-14

SEASONAL TRUCK-LOAD RESTRICTIONS AND ROAD MAINTENANCE IN COUNTRIES WITH COLD CLIMATE

Jukka Isotalo

Some new member countries of the Bank are in regions where road structures are subject to seasonal freezing and thawing. Roads in these countries used to carry light vehicles during the spring thaw period without causing major pavement or structural damages. However, thin road overlays on frost-susceptible soils are subject to severe structural damage as vehicle weights increase. Vehicle weight restrictions can limit this damage.

A sustainable solution to this problem is road rehabilitation using frost-resistant structural layers with high bearing capacity. This solution is, however, so expensive that even wealthy Scandinavian countries have not implemented it for the lower functional class roads. An alternative is the application of vehicle weight restrictions during the spring thaw period. Estimates of the benefits vary from 1.5 to 10-fold when combined road maintenance and transport costs are compared with and without restrictions. This note also discusses current policies in France, the United States and the Nordic countries pertaining to thaw restriction guidelines.

FROST IN SOIL

All soils freeze and change their physical properties when exposed to temperatures below 0°C. The freezing may be harmful only if the type of soil is susceptible to frost (high capillarity) and enough water is present. In road structures the main damages caused by frost are:

- Uneven frost heave, which may cause traffic accidents and damage cargo;
- longitudinal cracking due to deeper frost penetration in the middle of the road than along the edges covered by removed snow; and
- loss of bearing capacity during the thawing period.

The formation of frost in soil, and the damage it causes to the pavement vary from year to year. If soil is saturated with water, it has more thermal capacity than dry soil, and the frost does not penetrate as deep as in dry soil. If the temperature stays for a long period between 0°C and -5°C, the risk of ice formation in road structure is high, because of accumulation of water due to vacuum under the frozen layer and capillarity. If the temperature remains far bellow 0°C for longer periods, the road base freezes fast and the accumulation of water is minimal. A rainy autumn may increase the risk of frost damage on roads. Variation of the content of water in the soil, the height of the groundwater table, the periods of time below 0°C and the

heterogeneity of subsoil cause great annual variations in the behavior of any section of a road.

LOSS OF STRENGTH DURING THAW

The variation of strength of a road in a northern climate between a dry summer and a Spring thaw period may be small if the road has sufficient sand and/or gravel sub-bases to cut water capillarity and to increase the distance between frost-susceptible soils and the road surface. Paved roads with thin overlays on top of frost-susceptible soils may lose more than 50 percent of their bearing capacity in Spring. A gravel road, built without sufficient base course thickness, may have only 30 percent of its original strength during the thaw period.

The thawing starts in spring from above and below the frozen layer. If there is a surplus of water immediately under the thawed road surface due to poor drainage, the majority of the damage will take place in the road pavement. More damage may occur to the pavement and the whole road structure when the thawing has progressed to the surface of the frost-susceptible subsoil. If the road is exposed to heavy traffic, the dynamic forces will pump up the saturated fine graded subsoil, and mix it with the structural layers. Consequently the whole road structure will be damaged.

FINANCIAL IMPLICATIONS

Finland, Norway and Sweden are exposed annually to frost damage, and it is estimated that the annual costs of road repair amount to an average of $10 million per country under present policies of spring load restrictions. Costs for road repair would be $35 million per country without restrictions. Road user costs due to traffic restrictions were estimated to be $15 million to $20 million per year. Practically all main roads in the Nordic countries are built to a frost-proof condition, and road damage occurs only in the secondary road network. The consequences of one occasional severe winter, in a country of normally moderate climate, may be devastating. For example in France the severe winter of 1962-63 caused $850 million in reconstruction costs. It was estimated that after another severe winter in France, the costs of road rehabilitation without truck load restrictions, would have been $8,000 million, and the estimated delay costs from load restrictions amounted to $4,800 million, or 0.8 percent of GNP.

In order to establish an order of magnitude of the benefits to be gained, either from strengthening roads that are sensitive to frost damage or from applying traffic restrictions, an initial analysis was carried out in Central and Eastern European countries (Reference 1), to estimate the economic benefits based on the French experience with severe winters. Based on the French data, assumptions were made about the extent of damage to pavements in normal freezing conditions and in a severe winter (assumed to occur every 20 years) and the resulting costs. These costs include repair of pavements, incremental costs of operating vehicles on roads suffering from frost damage, and the costs resulting from restricting trucks on roads during thaw periods.

The savings calculations in Table 1 are based on the occurrence of a severe winter once every 20 years and are discounted at 12 percent (Reference 1). Table 2 shows the US Federal Highway Administration's (FHA) estimated benefits from using spring load restrictions (Reference 2).

The costs of a severe winter and frost sensitive roads can be categorized as follows (Reference 3):

- Additional costs to maintain and rehabilitate roads. A main part of these costs is related to the volume and weight of traffic. A minor part is related to the physical damage of freezing and thawing of road structures.
- Direct costs to road users are related to reduction of speeds (in Finland 10 to 20 km/h) and higher vehicle operating costs due to increased unevenness, soft surface etc. and to vehicle damage.
- Indirect costs to the economy in terms of lower utilization of vehicle capacity and reduced loads, extended routes to bypass weak or restricted roads, re-loading and storage of goods to reduce weight, and the amount of canceled transports.

The economic consequences are in direct relation to the length of restrictions and the volume of restricted traffic.

THE SCANDINAVIAN EXPERIENCE

Social costs can be reduced by active information. The main source of information in Norway is "Veglist", the booklet of all highways, with axle load limits, total weights, vehicle widths and lengths as well as anticipated axle-load during spring thaw. Finland and Sweden have meetings with road user groups, especially the forest industry, and use advertising in local radios, newsprint, and text-TV.

The Scandinavian experience (References 4 and 5) show that it may be profitable to introduce low-pressure truck tires as well as of various other tire types, in order to decrease the contact pressure on the road surface. Particularly roads with a thin overlay may benefit from the lowered tire pressure in addition to the axle load limitations. Investigations are warning that introduction of wide-thread (supersingle) tires would dramatically increase the damaging effect and could reduce the structural life of roads by a factor of 5. The interest of truckers, however, is the opposite because high pressure increases tire life.

In Finland it is considered more feasible to shift the restrictions from total weight to axle load, as is applied already in Norway. Sweden which is applying a mixed system, is conducting a study to standardize the weight limit application system.

The complexity of the thaw phenomenon, and the need for fast decisions at the lowest possible administrative level during the peak thaw period, is creating pressure to develop a fast and cheap method to measure bearing capacity. The knowledge of seasonal variation of structural strength of roads should be developed to the same extent as has been done for daily and annual variations in the amount of traffic. In particular, the following should be considered:

- Frost and spring thaw defects should be included in the road data base and maintenance management system, as is already the case in Finland;
- regular measurement of frost depth and FWD measurements along the road network (see Annex 1), in conditions similar to the actual roads, and comprising sufficient variety of soil and moisture conditions are of importance;
- portable weigh bridges should be available to assist police and maintenance staff to enforce weight limit restrictions. The overweight penalties should be in right proportion to damage caused by overweight;
- meteorological institutes should provide sufficient regional statistics on temperatures below zero. The Road Administration in Finland receives its frost information as a sum of hours below zero times actual temperature during each hour (h°C);
- the weight restriction system applied in a country should be uniform, understandable for the road user, enforceable and easy to measure on the spot; and
- the economic consequences of weight restrictions can be partly mitigated by allowing additional loading of vehicles during the peak winter period, as is done presently in Finland and Sweden.

As a general conclusion, the Bank should help its member countries introduce guidelines for winter road conditions and calculations of economic consequences of winter to the road traffic, for example, via the HDM III model.

TO LEARN MORE

1. Ray, Michel, Melody Mason, Sydney Thriscutt and Michel Guerin. 1992. "Road Rehabilitation and Maintenance in Central and Eastern Europe." The ECA and MENA Technical Department, World Bank.

2. USDOT Federal Highway Administration. 1990. "Spring Use Restrictions." Pavement Newsletter No. 17/1990.

3. Chenevez, Bernard. 1992. "Strategies for the Implementation of Truck Load Restrictions during Spring Thaw." OECD, Discussion paper for the Road Technology Transfer and Diffusion for Central and East European Countries meeting in Budapest, October 12-14, 1992.

4. Saarela et al.. 1986. "Traffic Regulation during Frost Thawing Period." Nordic Road Association, Section 31, Report No 1:1986. Summary in English.

5. Nordic Road Association. 1990. "Tunge koretojer's nedbrydning af vejbefaestelser" (Damaging effect to road pavements by heavy vehicles-a pilot project). Section 34, Report No 1: 1990. Chairman of the Section, Gunnar Dinesen. Summary in English.

Table 1: Cost Savings from Traffic Restrictions

Country	Percent of main road network sensitive to frost and thaw restrictions	Average annual daily traffic	Cost of a severe winter w/truck restrictions (US$ million)	Cost of a severe winter w/o truck restrictions (US$ millions)	Cost w/o truck restrictions as percent of GNP	Discounted cost savings w/truck restrictions (US$ millions)
Bulgaria	25	2,250	200	2,500	11.9	800
CSFR	30	2,700	300	2,300	4.3	700
Hungary	40	2,900	300	3,100	14.8	1,000
Poland	15	2,240	400	1,800	2.3	500
Romania	50	2,700	600	4,400	10.0	1,400
Yugoslavia	45	2,100	900	5,400	11.2	1,700
France (1985)	20	4,900	4,800	8,000	1.8	1,200

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Table 2: Benefits from Spring Load Restrictions

Pavement Load Reduction (Percent)	Pavement Life Increase (Percent)
20	62
30	78
40	88
50	95

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Table 3: Application of Load Restrictions TI in oF-Days

Pavement Structure	Should Level	Must Level
Thin	10	40
Thick	25	50

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Table 4: Allowed Deflection in Finland

Type of Road	Deflection S5, in mm
Asphalt paved main road	1.2
Other asphalt roads	1.4
Secondary gravel roads	1.8
Tertiary gravel roads	2.0

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ANNEX 1: DESIGN AND MANAGEMENT OF WEIGHT REGULATIONS

To reform the existing policy of dealing with road strength variations in spring, France is going to address the following issues (Reference 3):

- Improve the knowledge of the road characteristics and conditions;
- reduce the number of thresholds and adopt a nationally uniform method of establishing thresholds;
- give the fullest possible information to the road users; and
- apply stricter controls on dispensations.

France strives to have simple indicators and cursory monitoring methods to determine the frost sensitivity of roads. Trial sections of different categories of roads will be established in different regions to help determine the dates for applying and lifting weight restrictions. There is a need for a single method of determining thresholds taking into consideration (a) the harshness of winter, (b) road structure, (c) knowledge of thermal and other properties of the underground, (d) permeability of wearing course, (e) drainage system, and (f) pre-winter conditions. The weight limits have been raised to 7.5 and 12 tons (5 and 8 tons respective weights per twin wheel axles. Improved cooperation is developed with the main road users to explain the regulations and to warn affected firms and user groups on possible restrictions in advance. Clearer rules will improve the motivation of the police to enforce the restrictions and will reduce the work load of the local road management staff.

In the **United States** a FHA study (Reference 2) recommends the calculation of "Freezing and Thawing Indices" as guidelines for the application and removal of load restrictions. These guidelines include classifications of pavement as thin for a surface thickness of 2 inches or less and a base course thickness of 6 inches or less. The pavement structure is classified as thick for a surface thickness of more than 2 inches and a base course thickness of more than 6 inches.

The Freezing Index (FI) and Thawing Index (TI) are calculated based on the daily high and low temperatures in the season as a sum of days multiplied by degrees bellow zero for the FI index and above zero for the TI index. The FI calculation starts

from 0°C (32°F) and TI from -2°C (29°F), since asphalt surface temperature is above 0°C when air is still bellow zero. Table 3 gives guidelines when weight restrictions should and must be applied (in Fahrenheit days).

The length of the load restriction period should approximate the time required to achieve complete thawing in pavement structure, which depends on the relation between the Freezing and Thawing indices. The restriction period for FI 400°F-days is about two to four weeks and for FI 2000°F-days about six to eight weeks.

In **Finland** using the Benkelman beam measurements, the applicable weight restriction of either 4, 8 or 12 tons is determined from a graph. Use of Falling Weight Deflectometers (FWDs) has recently ousted the use of Benkelman beams. The aim in principle is to place weight restrictions based on objective measurements (see Table 4). Spring bearing capacity multipliers appear in the Road Data Base for most road sections. FWDs and other measurements are not done every year but according to a program. However, a visual inspection, and the institutional memory of road maintenance units, of the behavior of various road sections over decades, still play a key role in decision making. Every road maintenance unit also has one or more frost depth measurement points.

In **Iceland** the thawing of frost is measured, and when the thawing has reached a depth of 30 cm and the traffic is causing deformations, maintenance crews will impose a weight restriction.

In **Norway** the Benkelman beam measurement is also fading out as a standard procedure because of its labor intensity and because it does not sufficiently simulate the traffic-road surface interaction (does not give the angle of deflection of road surface under wheel load). Most measurements are made with FWDs. Frost depth is measured starting from January to the end of the thawing period. Restrictions are imposed when the surface has thawed to 5 to 15 cm and continue until 90 percent of the normal summer bearing capacity has been achieved, which on average takes eight weeks.

In **Sweden** the decision on restrictions is based on long experience of behavior of different road sections and the results of frost depth measurements. No quantitative criterion, for example rut depth, is measured. However, the increased demand to restrict traffic on surface dressed roads is leading to an increased measurement of bearing capacity with FWDs. Back to text.

ANNEX 2: CURRENT WEIGHT REDUCTION POLICIES

In **France** weight restriction policy (Reference 4) is based on (a) frost prevention on primary roads and (b) application of weight restrictions during frost thaw on the secondary road network. Before 1989 poor uniformity in setting restrictions and tonnage thresholds and exemptions in different regions undermined the efficiency of restrictions and increased costs to the road users and the economy. It is difficult to achieve a coherent system for the whole of France because of the large number of decision makers, haphazard approach to meteorological information, and insufficient inter-country and inter-regional cooperation. The weight thresholds are based on total weights of 3.5 and 9 tons, which correspond to 2.5, 4, 6- and 8-ton single twin-wheel axles, but these axle load limits have not followed the recent heavy vehicle development and leave the use of a number of new vehicles under dispensations.

In the **United States** 19 states have spring use restrictions (Reference 2). Due to shortage of rehabilitation funds, the restrictions are for many road agencies the only viable option to prevent pavement deterioration during the thaw period. However, there have been no uniform formulae on how to apply load restrictions, where and when to use them and how much to restrict loads.

In **Scandinavia** weight limitation policies are based on the following standards (Reference 4): damage to the roads should be avoided in order to reduce annual road maintenance and rehabilitation costs (Finland, Norway, Sweden); the life span of the road should be extended and damage avoided to keep the road passable outside the spring thaw period (Iceland); the roads should be passable year round for cars and emergency vehicles (Finland and Iceland); the roads should be secured for dairy

and food transports, school busses and daily commuting traffic (Finland); and the life span of thin overlays and surface dressings should be safeguarded (Norway and Sweden).

Finland is presently applying vehicle total weight restrictions. A 4 tons limit will allow transportation using cars, vans and agricultural tractors with a reasonable load. A 8 tons limit will normally allow empty trucks and smaller buses. The limit of 12 tons, which allows normal buses and 2-axle trucks is aimed to prohibit heavy timber and earth moving transports. The local road maintenance supervisor has an authority to grant dispensations to critical transports. In practice the dispensation practice has been liberal.

In **Iceland,** where 10/16 ton weights are applied (one axle with 2 wheels = 7 tons, one axle with four wheels = 10 tons and twin axle with eight wheels = 16 tons), the thaw limitations occurring there not only in spring, have the following six alternatives. Within each group there are several sub-alternatives that depend on the form of the truck or tractor-trailer combination, and on the number of driving wheels, such as 7/11 tons (single/twin), 7/11 tons (reduced), 5/8 tons, 5/8 tons (reduced, no trailers), 2 tons total weight, and closed. All these alternatives can be applied successively at the same road section, during the same thaw period, depending on the road condition.

Norway has classified all public roads according to the maximum allowed total weight, which then depends on the allowed axle loads and the axle distances in the vehicle combination. The classification is published annually in a booklet called Road List (Veglisten), distributed to all road users. Norwegian classification originated from the capacity of bridges. Since 1979 there has been a new road class, 10 tons with spring thaw restrictions. Outside spring thaw period, the users may apply the full 10 tons axle weight. However, spring thaw limitations may be applied along these roads. Due to increased studies and knowledge on the bearing capacity of roads, the number of road kilometers in this category has actually increased during recent years. Exemptions are usually granted only for route buses and dairy transports.

Sweden applies a variety of weight restrictions. An axle load of 10 tons may be reduced to 8, 6 or 4 tons. The total weight may be limited to 12, 9, 7 or 4 tons. An average of 150 km is closed annually. Restrictions are imposed by the local road maintenance supervisor (the lowest administrative level of decision making) who may also grant dispensations. The exempted "necessary" transports may include dairy and food deliveries.

Cooperation between the road authorities and the traffic police in Scandinavian countries is good, and weight restrictions are controlled using portable scales. However, only Iceland uses special police/highway staff teams to supervise weight restrictions. It is also important that trucking companies and the highway administration cooperate closely to help minimize losses due to restrictions.

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