

Operation and maintenance of gravel roads

A literature study

Hossein Alzubaidi




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| Abstract Gravel roads form a large percentage of the road network in Sweden. The public road network under the jurisdiction of the Swedish National Road Administration has a total length of some 98,000 kilometres. About 22,000 km of this network consist of gravel roads. In addition, there are about 74,000 kilometres of private road and 210,000 kilometres of forest roads. The report describes the present position in the operation and maintenance of gravel roads. It presents a comprehensive literature survey of current and recent national and international research. It deals only with summer maintenance and focuses primarily on roads surfaced with aggregate. The following areas are treated in the report: 1-Definitions and terms regarding the operation and maintenance of gravel roads. 2-General description of the Swedish road network. 3-Major factors causing deterioration of gravel roads. 4-Technical requirements for Swedish gravel roads. 5-Factors, which influence the operation and maintenance of gravel roads. 6-Operation and maintenance methods. 7-Condition assessment of gravel roads. 8-Planning and evaluation of operation and maintenance measures. | | |
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Foreword

This study of the literature forms the first part of a PhD project "Efficient production methods in the operation and maintenance of gravel roads". The project is carried out in the Centre for Research and Education in the Operation and Maintenance of Infrastructure (CDU), with financial assistance from the Swedish National Road Administration (SNRA), Management of State Roads.

The project is carried out at the Swedish National Road and Transport Research Institute (VTI). My principal supervisor and examiner is Professor Rolf Magnusson, Royal Institute of Technology (KTH). Project manager at VTI is Lars Bäckman, and the SNRA representative is Ulf Pålsson. A combined steering and reference group has been formed for the project, comprising the following members:

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Linköping, May 1999

Hossein Alzubaidi

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Summary

Gravel roads form a large percentage of the road network in Sweden. The public road network under the jurisdiction of the Swedish National Road Administration (SNRA) has a total length of some 98,015 km. About 22% (22,136 km) of this network consists of gravel roads. In addition, there are about 74,000 km of private roads and 210,000 km of forest roads. The Swedish National Road Administration has recognised the need for more research concerning gravel roads. The need to optimise the costs of maintaining optimum quality has been of great concern to SNRA.

This report describes the present position in the operation and maintenance of gravel roads. It presents a comprehensive **literature survey** of current and recent national and international research, and deals only with summer maintenance. Summer in Sweden extends from May to October. The report focuses primarily on roads surfaced with aggregate, and forms the first part of a PhD project, "Efficient production methods in the operation and maintenance of gravel roads". The project will be carried out in collaboration between the Swedish National Road and Transport Research Institute (VTI) and the Department of Infrastructure and Planning, Highway Engineering, Royal Institute of Technology (KTH).

The report consists of eleven chapters. A brief description of the content of each chapter is given below.

Chapter 1 discusses the background to the PhD project, the aim of the current report. This chapter also presents the limitations this literature study is subject to and how the search of information is performed.

Chapter 2 gives a review of several definitions and terms regarding the operation and maintenance of gravel roads. These include maintenance, operation, stabilisation, unsealed roads, different wearing courses and different layers in the road structure.

Chapter 3 provides general information on the Swedish road network. The extent of gravel roads is described in tabular form. The chapter also contains details such as length, traffic volume, speed limits, road width and maintenance costs. Corresponding information on other types of wearing course is given for comparison.

Chapter 4 briefly describes the major factors which cause deterioration of gravel roads. These include routine maintenance activities, traffic and climatic factors. The chapter also discusses surface damage and problems associated with gravel roads and their development in connection with the above factors. The major problems are dust, corrugations, potholes, insufficient drainage, loose aggregate and frost damage.

Chapter 5 sets out the technical requirements for gravel roads in Sweden which are applied by the Swedish National Road Administration. These requirements mainly relate to materials and workmanship concerning gravel wearing course,

roadbase, sub-base and protection course. Requirements relating to operation and maintenance are also covered.

Chapter 6 deals with factors which affect the frequency and cost of the maintenance of gravel roads. These include road standard, traffic, aggregate characteristics, and geometric and climatic factors. Traffic is one of the man made factors that affect gravel roads, and the types and speeds of vehicles and the annual average daily traffic (AADT) on the roads all constitute variables in this context. The effect of geometric factors is seen in terms of road width, cross section and alignment. Aggregate characteristics comprise proportioning, shape and type of aggregate.

Chapter 7 describes maintenance methods for gravel layers. These are dust control, grading, regravelling, ditching, watering and dragging. The chapter also examines different materials used in dust control such as calcium chloride CaCl_2 , magnesium chloride MgCl_2 , lignosulphonate and bitumen emulsion. The selection of a suitable dust control agent, total cost, dust control procedures, frequency, environmental impacts and evaluation of a dust control programme are discussed here.

Chapter 8 reviews methods for assessing the condition of gravel roads. Methods of subjective assessment applied or proposed in Sweden, Finland, USA, Canada, Australia and New Zealand are described. These subjective assessments have been correlated with objectively measured condition factors such as surface roughness. Objective measurement methods used in Sweden are described.

Chapter 9 covers planning and economic evaluation of road improvements. It describes the relationship between improvements achieved by operation and maintenance activities, and discusses the benefits resulting from savings in road user costs such as vehicle operating costs, and from greater traffic safety and trafficability.

Chapter 10 lists the literature quoted in the report.

Chapter 11 lists the figures and tables.

1

Introduction

Gravel roads constitute more than 22% of the Swedish road network managed by Swedish National Road Administration (SNRA) for whom maintenance represents 17% of the total maintenance budget. This chapter discusses the background to the PhD project and presents the aim of the current report. This chapter also describes the limitations this literature study is subject to and how the search of information is performed.

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1.1 Background

Gravel roads make up a considerable proportion of the Swedish road network. The State maintained road network comprises 98,015 km roads, of which 22,136 km (22%) are gravel roads (1997). Apart from the State gravel roads there are also about 74,214 km private gravel roads and about 210,000 km forest roads.

Maintenance costs for gravel roads constitutes about 17.3%, a significant proportion, of the total maintenance expenditure. Maintenance costs relates to paved roads, gravel roads, bridges, tunnels and ferries.

The performance of gravel roads is important for rural areas, recreation and forestry. Gravel roads have societal rather than traffic policy significance. They represent the end points of the road network and must be kept in a state acceptable to society and the road user. In certain cases, gravel roads also have a cultural and historic value.

Should gravel roads be paved? This is a question that is often posed by road users. In recent years some gravel roads have been given a simple type of surfacing. For two reasons, however, all gravel roads will not be paved. The first reason is low road traffic flow, and the second lack of funds.

A large proportion of gravel roads have such a low traffic flow that, from the standpoints of both business economic (road management authority) and societal considerations, there is little chance of these being paved. The aim of the Swedish National Road Administration is to pave gravel roads carrying more than 250 AADT.

However, owing to lack of funds, all gravel roads that have a high traffic flow will not be replaced by paved roads in the next few years. The roads are in such a poor state that they cannot be simply given a surfacing. The wearing course, roadbase and sub-base must all be reconstructed.

Gravel road research was intensive during the 1930s and 1940s, but has been at a low level since then. Attention was instead directed towards permanent carriageways.

Much of the earlier gravel road research consisted of small investigations of limited scope which were seldom described in reports, which means that there is a need for investigations of a more systematic nature.

At present there is thus a lack of knowledge and research in this field. Greater competence in the field of gravel road management is therefore desirable if a transport system of greater long-term sustainability is to be achieved.

1.2 The aim

The aim of this study of the literature has been to collate knowledge and previous experience within or closely related to the subject of this PhD project, "Operation and maintenance of gravel roads". It also serves as a knowledge base for the postgraduate student in his further studies. The study of the literature is intended to cover most of the problem area that is the operation and maintenance of gravel roads.

1.3 Limitations

The study of the literature is subject to the following limitations:

- The report mainly deals with Nordic conditions.
- The methods for operation and maintenance of gravel roads mainly relate to measures during the period when roads are free of snow and ice. Winter maintenance of gravel roads is not dealt with in this report.
- Technical requirements for gravel roads, operation and maintenance methods and condition assessment refer primarily to the requirements and methods applied in Sweden.
- The study of the literature does not cover strengthening or improvement measures. In some cases it has however been difficult to distinguish between maintenance and strengthening measures.
- Measures, which have the aim of providing gravel roads with a surfacing, are not included in this literature study.
- The literature study mainly deals with State maintained roads.

1.4 Information search

The search for information has been performed at the VTI Library and Information Centre and comprised the following databases: ROADLINE (VTI library catalogue), accessible via TRANSGUIDE [URL: <http://transguide.vti.se>], SNRA library catalogue, and the two international databases IRRD (International Road Research Documentation), produced by OECD [URL: <http://www.oecd.org>] and TRIS (Transportation Research Information Services) produced by TRB [URL: <http://www.nas.edu/trb>].

Information retrieval is based on keywords coupled together in blocks. Everything connected with gravel roads has been correlated with various construction, operation and maintenance aspects. Retrieval has no limitations regarding geography, language or time. In order to facilitate processing of the material, the different aspects are brought out in order. Search can be described as $A * (B + C + D)$, where the blocks comprise the following terms:

- A) Gravel road? + Low cost road? Unsurfaced road? + Unpaved road? + Grusväg?(Gravel road) + Skogsväg?(Forest road) + Skogsbilväg?(Forest road)
- B) Dust + Damm(Dust)
- C) Ditch + Drainage + Dikning(Ditch)
- D) Construction + Production + Maintenance + Grading + Surfacing + (Recycling * Aggregate) + Produktion(Production) + Konstruktion(Design) + Hyvling(Grading) + Grusåtervinn? (Aggregate recycling) + Tillståndsmätning(Condition rating)

The wildcat [?] character indicates that there may be any number of characters after the word, e.g. road? means roads, road construction, road maintenance.... etc.

2

Definitions

The fundamental concepts used in the report are defined in this chapter. These concepts are operation and maintenance, maintenance, operation, stabilisation, strengthening, State, municipal, forest roads and private roads, types of wearing course and the different courses of a road. Terms such as maintenance and operation will be described in greater detail.

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2.1 Operation and maintenance

Operation and maintenance are often used as one expression or concept. This concept covers all activity relating to the upkeep of gravel roads so that the road is kept in a trafficable state. In this literature study, operation and maintenance are used as one concept.

2.2 Maintenance

The **Swedish National Road Administration** defines the term maintenance as a measure whose object is to restore the properties of structures, facilities and devices to the level intended at the time of original construction or a later improvement (Regulations for Maintenance and Operation, 1990, in Swedish).

According to the **Swedish Association of Local Authorities**, maintenance is defined as measures after which the function of the facility remains unchanged but which have a residual value at the end of the year (Bäckman et al., 1998).

In the course "Operation and Maintenance of Traffic Facilities-KTH" (1997), in Swedish, Olsson defines maintenance as the measures needed in order that the

desired properties of a building or facility should be preserved or restored and which result in economic values with a duration longer than one year. He gives some examples of maintenance activities such as enlargement of drainage systems. According to this definition, ditching along gravel roads is assigned to the concept maintenance since ditches last longer than one year. Olsson also assigns repaving works of asphalt concrete roads to the concept maintenance because they have a duration longer than one year.

He himself thinks that his interpretation of what is comprised in the term paved road maintenance and gravel road maintenance does not fully agree with the terminology at present applied by professionals in civil engineering.

Bäckman et al. (1998) give a schematic picture of the way maintenance can be subdivided; see figure 2.1.

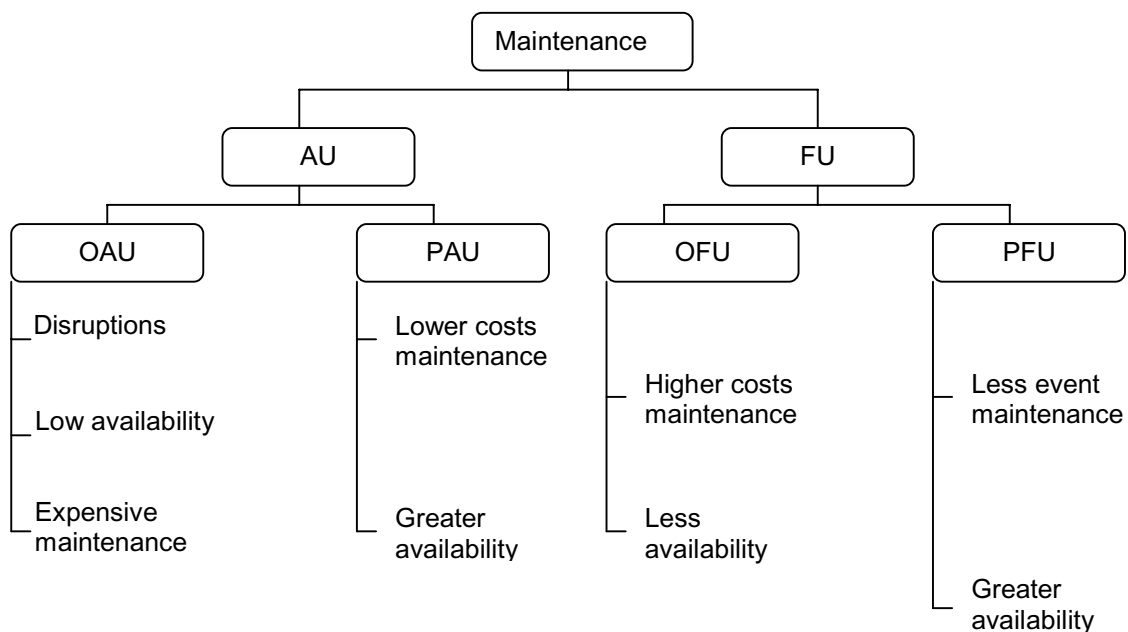


Figure 2.1 Schematic representation of the subdivision of maintenance (Bäckman et al., 1998).

AU Event maintenance
FU Preventive maintenance
OAU Unplanned event maintenance
PAU Planned event maintenance
OFU Unplanned preventive maintenance
PFU Planned preventive maintenance

In the course "Operation and Maintenance of Traffic Facilities-KTH" (1997), Sundquist (1997) shows a similar schematic relationship between different types of maintenance; see figure 2.2.

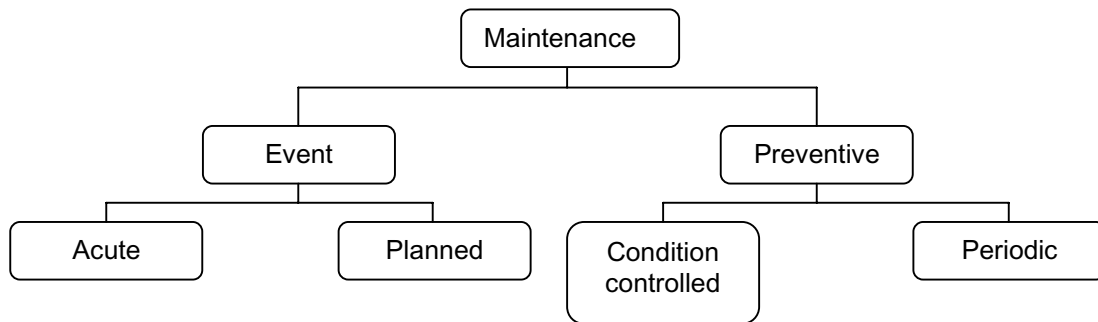


Figure 2.2. Relationship between different types of maintenance (Sundquist, 1997).

Preventive maintenance (FU) is defined by Sundquist (1997) as measures whose object is to prevent the occurrence of defects (direct FU) or to detect defects before these result in breakdown (indirect FU).

Event maintenance (AU) is defined as measures whose object is to remedy defects, which have occurred. Such maintenance may be unplanned, resulting in acute repair work, or it may be planned and controlled. In most cases the greatest proportion of event maintenance is unplanned, while the proportion of planned event maintenance is small (Sundquist, 1997).

The term **condition controlled maintenance** implies that the condition of the object concerned is checked at regular intervals. It is not until gradual deterioration causes the object to approach an unacceptable condition that appropriate measures are taken.

Condition assessment is assigned to preventive maintenance. The resulting measures may be assigned to either preventive or event maintenance. As a rule, condition controlled maintenance can be planned in good time as regards both its extent and its timing and costs (Sundquist, 1997).

It is worth noting that Sundquist's definitions agree quite well with the operation and maintenance of bridges, but are often less appropriate for gravel roads.

Periodic maintenance denotes action of greater extent that is taken at intervals of several years. Examples of periodic maintenance are ditching and recycling of aggregate. (Olsson, "Operation and Maintenance of Traffic Facilities-KTH" (1997).

Routine maintenance is activity that is carried out every season on a section of road; this necessitates continuous surveillance of the condition of the road. Examples of routine maintenance are dust control, grading etc which are performed by the contractor himself.

Service activity and **actual maintenance** are expressions that are used in some old literature, but are seldom used now. **Service activity** is work that is closely related to keeping the road trafficable and safe in the short term. Examples of this

are dust control, grading, patching and repair of damage such as frost damage (Bergfalk and Åkeson, 1969).

Actual maintenance denotes work to prevent deterioration of the road through wear, such as regravelling, ditching and maintenance of culverts (Bergfalk and Åkeson, 1969).

2.3 Operation

The National Swedish Road Administration defines operation as the measures necessary to ensure that roads, bridges and traffic facilities at all times have the functional properties they are designed for (Regulations for Maintenance and Operation, 1990).

According to the **Swedish Association of Local Authorities**, operation denotes the upkeep needed to ensure that a facility is at all times available and can be used by the users, such as snow clearance and skid-control. Operation measures have no permanent value at the end of the financial year (Silborn, 1997, in the course "Operation and Maintenance of Traffic Facilities-KTH" (1997).

In the course "Operation and Maintenance of Traffic Facilities-KTH", Olsson (1997) defines operation as activity to keep a building or facility in function, which results in economic values of a duration shorter than one year. He quotes dust control and grading of gravel roads as examples of operation activities. At times, however, grading and dust control has duration longer than one year, for instance on forest roads and when emulsion is used for dust control. He writes that the first part of this definition is practically identical with that given by the Swedish Centre for Technical Terminology (TNC) 1989:

"Activity to maintain the function of a building, installation and similar, or to use such function". Olsson justifies the addition concerning economic duration by saying that monitoring and prediction of life time costs are made easier if operation is distinguished from maintenance in this way. Others think that Olsson's definition of operation and maintenance is contrary to older and established definitions, and some people in this field consider that the definition of operation and maintenance by the Swedish National Road Administration is in actual fact a clarification of the TNC definition.

2.4 Stabilisation and strengthening

Stabilisation and strengthening are terms that are often used in a maintenance context.

Stabilisation is defined in ROAD 94, 1996 as improvement of the properties of an unbound material, for instance by the admixture of hydraulic or bituminous binders.

According to the definition of the Swedish National Road Administration, the term **strengthening** implies upgrading of the bearing capacity of the road. Bergfalk and Åkeson (1969) define this word as work entailing improvements and minor reconstruction in order to adapt the standard of the road to the traffic it

carries. However, it is not clear how adaptation of the standard of the road to traffic can be determined for a gravel road.

Sundquist (1997) defines strengthening as "Improvement over and above the original standard of the serviceability of an undamaged or damaged construction". It is not likely, however, that it is possible in practice to determine the original standard of a gravel road.

2.5 Different types of road

Terms such as state, municipal and private roads, forest roads, lightly trafficked roads, secondary and tertiary county roads, will be defined here.

State roads are roads where the Swedish National Road Administration is responsible for road planning, construction, operation and maintenance.

Municipal roads are streets and roads in local development plan areas in towns and built-up areas, which are maintained by the municipality.

Private roads are roads maintained by private property owners and other partnership owners. Private roads may or may not receive a State grant (Private Roads, 1996, in Swedish). The Swedish National Road Administration is the authority that administers the allocation of grants for private roads. The generic term private road has three subdivisions depending on the legal status of the road: easement roads, agreement roads and privately owned roads.

Forest roads are defined as roads, which predominantly serve forestry interests. Forest roads are often classified as private roads without a State grant (Forest road service, 1992, in Swedish).

Lightly trafficked roads are defined as roads with traffic below 1000 AADT or 100 heavy vehicles per day (Bäckman et al., 1998). There are however many different limits for this definition.

Secondary county roads are normally

- Roads along which there are built-up areas with at least 200 inhabitants
- Roads with a traffic volume greater than 500 AADT_t or a traffic volume per summer or winter day that is greater than 1000 AADT_t
- Roads which have or maybe expected to carry an average volume of goods traffic greater than ca 100,000 tonnes per year over the next 5 years (Regulations for Maintenance and Operation, 1990)

Tertiary county roads are normally

- Roads with a traffic volume less than 500 AADT_t and less than 1000 AADT_t per summer or winter day
- Roads with an average volume of goods-traffic less than ca 100,000 tonnes per year

According to Regulations for Maintenance and Operation (1990), gravel roads are classified as secondary and tertiary county roads. In Sweden they have road classification numbers of 500 and above.

Average annual daily traffic AADT is a mean value which refers to a mean day during a certain year for a certain road. If AADT refers to both carriageways of a two-way road, AADT refers to the total two-way flow and is denoted AADT_t (ROAD 94, 1996).

2.6 The structure of the road

Terms such as subgrade, road structure, pavement and embankment are defined below.

The **road structure** consists of embankment and pavement; see figure 2.3.

The **pavement** is the part of the road construction that is above the formation level. The pavement consists of wearing course, base course and sub-base and protection course if any. The pavement has the function of distributing pressure on the underlying material; see figure 2.3.

The **subgrade** is defined as that part of the soil to which load is transmitted by a building, bridge, road structure or similar; see figure 2.3.

The **embankment** is the part of the road construction between the subgrade and the formation level. The embankment mainly consists of imported soil and rock masses; see figure 2.3.

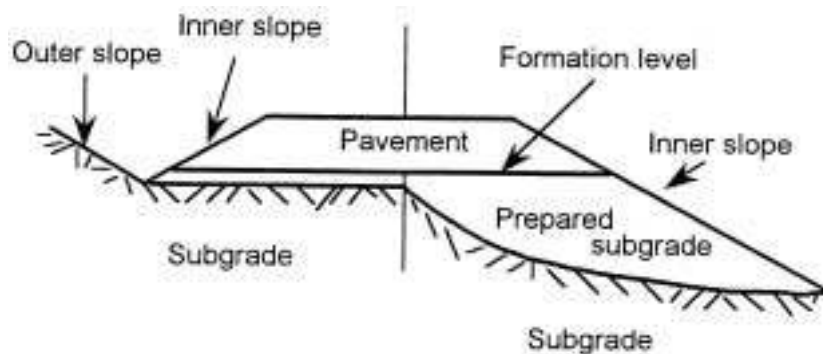


Figure 2.3 *Subgrade, embankment, formation level, pavement and slopes (ROAD 94, 1996).*

2.7 Types of wearing course

Terms such as paved road and gravel road are discussed in this clause. The terms oil gravel, sealed gravel and single course gravel surface dressing Y1G have been used in the report, and a brief description of each of these terms is therefore given below.

A **paved road** is defined in ROAD 94 as "A road with a cement or bitumen bound wearing course or base course. However, a gravel wearing course treated with emulsion to control dust is not classified as a bitumen bound wearing course".

A **gravel road** is defined according to Glossary for Bituminous Surfacing (1976), in Swedish, as a road with a gravel wearing course.

There is some confusion regarding the designations for aggregate. These designations vary to a certain extent depending on the activity in which the aggregate is used. In road construction, gravel is naturally occurring aggregate that passes a 60 mm sieve and is predominantly of 6-60 mm particle size. Crushed gravel is aggregate obtained by crushing gravel, larger stones and rock (Memo for highway engineering, 1995, in Swedish). It is worth noting that gravel wearing courses consist of particles of different sizes. The maximum stone size for a gravel wearing course is 20 mm.

Up to 1986-87, the following fraction limits were applied in highway engineering; see table 2.1.

Table 2.1 *Fraction limits (mm) previously used in highway engineering (Glossary for Bituminous Surfacing, 1976).*

| | | 0,002 | 0,006 | 0,02 | 0,06 | 0,2 | 0,6 | 2 | 6 | 20 | 60 | 200 | 600 | 20000 |
|-------------|--|-------------|--------|------------------|--------|-------------|--------|---------------|--------|--------------|----|--------------|-----|-------|
| Clay | | | | | | | | | | | | | | |
| | | Silt | | Fine sand | | Sand | | Gravel | | Stone | | Block | | |
| | | fine | Coarse | fin | Coarse | Interm | Coarse | Fin | Coarse | | | | | |

At present the fraction limits applied in highway engineering are the same as those in soil mechanics. See table 2.2.

Table 2.2 *Fraction limits at present applied in highway engineering (Karlsson & Hansbo, 1984).*

| Main groups | | Subgroups | |
|----------------------------|-------------------|---------------|-------------------|
| Designation | Particle size, mm | Designation | Particle size, mm |
| Boulders and stones | | | |
| Boulders | ≥600 | Rock | ≥2000 |
| | | Stone block | 2000-600 |
| Stone | 600-60 | Large stone | 600-200 |
| | | Medium stone | 200-60 |
| Coarse soil | | | |
| Gravel | 60-2 | Coarse gravel | 60-20 |
| | | Medium gravel | 20-6 |
| | | Fine gravel | 6-2 |
| Sand | 2-0,06 | Coarse sand | 2-0,6 |
| | | Medium sand | 0,6-0,2 |
| | | Fine sand | 0,2-0,06 |
| Fine soil | | | |
| Silt | 0,06-0,002 | Coarse silt | 0,06-0,02 |
| | | Medium silt | 0,02-0,006 |
| | | Fine silt | 0,006-0,002 |
| Clay | ≤0.002 | Fine clay* | ≤0.0006 |

* This classification is mainly used in a research context

Gravel roads are classified as unpaved roads. Depending on the material in the wearing course, unpaved roads may be gravel or earth roads. Unpaved roads often carry little traffic. In foreign literature, unpaved roads are called unpaved, untreated, unsurfaced, unsealed or unimproved roads. Gravel roads are often referred to as dirt roads, a name that reflects the state of these roads in some countries.

Oil gravel is a plant mix surfacing in which the binder is road oil and adhesion between the aggregate and binder is improved by the admixture of an adhesion agent (Glossary for Bituminous Surfacing, 1976).

Sealed gravel roads have been treated with bitumen emulsion according to the hard method in order to control dust. See chapter 7.

Single course surface dressing Y1G is usually carried out as maintenance on existing bituminous surfacings, and also on oil gravel. The wearing course consists of a bituminous binder layer into which chippings are rolled. (Glossary for bituminous surfacings, 1976).

3

General description of the Swedish road network

The aim of this chapter is to illustrate the role played by gravel roads as part of the Swedish road network. In the following, information concerning the length and composition of the road network and the proportion of maintenance costs and traffic volume accounted for by gravel roads will be tabulated. Data for these tables were obtained from the databank of the Swedish National Road Administration (VDB), with the exception of tables 3.1 and 3.14 where the data were obtained from "Statistics from the Swedish National Road Administration", 1997, in Swedish. The data were downloaded in April 1998.

| | | |
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3.1 Administrative classification of Swedish roads (km)

Table 3.1 *Administrative classification of Swedish roads (km), breakdown by road management authority (Statistics from Swedish National Road Administration, 1997).*

| Type of road | 1992 ¹ | 1993 ¹ | 1994 ¹ | 1995 ¹ | 1996 ¹ |
|--|-------------------|-------------------|-------------------|-------------------|---------------------|
| National trunk roads | - | - | - | 8,029 | 8,000 |
| Other national roads ² | 14,610 | 14,587 | 14,637 | 6,616 | 6,647 |
| Motorways | 1,005 | 1,061 | 1,141 | 1,262 | 1,350 |
| Expressways | 478 | 493 | 466 | 395 | 380 |
| County roads | 83,252 | 83,233 | 83,249 | 83,263 | 83,368 |
| All State roads | 99,345 | 99,374 | 99,493 | 99,565 | 99,745 |
| Municipal roads | 37,925 | 38,618 | 38,300 | 38,900 | 38,900 ³ |
| Private roads with State grants | 73,071 | 73,562 | 73,914 | 74,119 | 74,214 |
| Other roads, round numbers | 210,000 | 210,000 | 210,000 | 210,000 | 210,000 |
| Total length of road network, round numbers | 420,341 | 421,554 | 421,707 | 422,584 | 422,859 |

¹ until 31 December.

² 1992-1994 all national roads, from 1995 national roads which are not national trunk roads.

³ 31 December 1995, according to survey performed by Swedish Association of Local Authorities in 1996.

3.2 Breakdown by type of wearing course (km)

Table 3.2 *Breakdown by type of wearing course (km) of State roads in Sweden over the period 1990-1997.*

| Year | Total length | Gravel | | Y1G | | Sealed gravel | | Oil gravel | | Bituminous | |
|------|--------------|--------|------|-------|------|---------------|-----|------------|------|------------|------|
| | | km | Km | % | km | % | km | % | km | % | Km |
| 1990 | 99390 | 27145 | 27.3 | 10153 | 10.2 | 148 | 0.1 | 14590 | 14.7 | 47286 | 47.6 |
| 1991 | 99345 | 26543 | 26.7 | 10264 | 10.3 | 187 | 0.2 | 14484 | 14.6 | 47804 | 48.1 |
| 1992 | 99491 | 25704 | 25.8 | 10570 | 10.6 | 239 | 0.2 | 14358 | 14.4 | 48560 | 48.8 |
| 1993 | 99686 | 24143 | 24.2 | 11558 | 11.6 | 252 | 0.3 | 14288 | 14.3 | 49371 | 49.5 |
| 1994 | 99893 | 23354 | 23.4 | 11780 | 11.8 | 258 | 0.3 | 14248 | 14.3 | 50165 | 50.2 |
| 1995 | 100166 | 22619 | 22.6 | 11920 | 11.9 | 257 | 0.3 | 14244 | 14.2 | 51039 | 51.0 |
| 1996 | 100348 | 22267 | 22.2 | 11936 | 11.9 | 257 | 0.3 | 14317 | 14.3 | 51463 | 51.3 |
| 1997 | 100429 | 22136 | 22.0 | 11900 | 11.8 | 257 | 0.3 | 14344 | 14.3 | 51684 | 51.5 |

According to Table 3.2, the length of gravel roads decreased by 5009 km between 1990 and 1997, from 27,145 km to 22,136 km. This is a reduction by 5.3 percentage points in the total State road length, from 27.3% to 22%. Roads with single course surface dressing, Y1G, increased by 1747 km during the same period, from 10,153 km to 11,900 km. This is an increase by 1.6 percentage points in the State road network, from 10.2% to 11.8%. Figure 3.1 summarises the total length of gravel roads, Y1G, oil gravel and bituminous roads over the period 1990-1997.

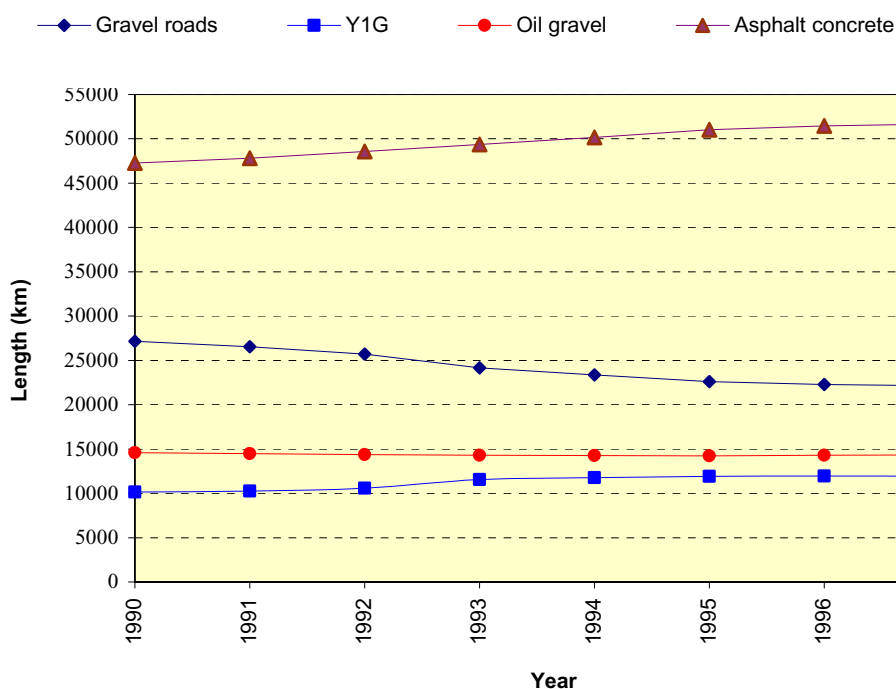


Figure 3.1 Total length of the four wearing course types over the period 1990-1997.

3.3 Breakdown by type of wearing course in different counties

Table 3.3 sets out the lengths of different wearing course types on the State road network in the different counties in 1997, and the percentages of the total State road network that these types represent.

As will be seen from the table, there is considerable variation in the percentages of gravel roads in different counties. The county which has the most gravel roads in relation to the total State length is Västerbotten county which has 3682 km gravel roads. It is the four most northerly counties, Västernorrland, Jämtland, Västerbotten and Norrbotten, in which the proportion of gravel roads exceeds 30%. The county of Gotland has the lowest percentage, 0.07%. It is worth noting that dust control of gravel roads on Gotland with bitumen emulsion (BE) began in 1990. (0) in the tables often denotes a length less than 500 m, but may also signify nothing (0 km), while (:) always denotes nothing.

Table 3.3 Breakdown by type of wearing course of State roads in different counties in 1997.

| County letter | Total length km | Gravel | | Y1G | | Sealed gravel | | Oil gravel | | Bituminous | |
|---------------|--------------------|--------------|----|--------------|----|---------------|---|--------------|----|--------------|----|
| | | km | % | km | % | km | % | km | % | km | % |
| AB | 3138 | 85 | 3 | 26 | 1 | : | 0 | 1 | 0 | 3024 | 96 |
| C | 3013 | 524 | 17 | 302 | 10 | : | 0 | 40 | 1 | 2147 | 71 |
| D | 2832 | 512 | 18 | 205 | 7 | : | 0 | 3 | 0 | 2112 | 75 |
| E | 4731 | 981 | 21 | 705 | 15 | : | 0 | 2 | 0 | 3043 | 64 |
| F | 4567 | 735 | 16 | 861 | 19 | 0 | 0 | 223 | 5 | 2748 | 60 |
| G | 3664 | 647 | 18 | 636 | 17 | 114 | 3 | 326 | 9 | 1941 | 53 |
| H | 4030 | 339 | 8 | 742 | 18 | : | 0 | 74 | 2 | 2875 | 71 |
| I | 1486 | 1 | 0 | 317 | 21 | : | 0 | 15 | 1 | 1146 | 77 |
| K | 1552 | 46 | 3 | 242 | 16 | 129 | 8 | 151 | 10 | 984 | 63 |
| M | 7977 | 718 | 9 | 1149 | 14 | : | 0 | 181 | 2 | 5881 | 74 |
| N | 3093 | 197 | 6 | 549 | 18 | 14 | 0 | 962 | 31 | 1320 | 43 |
| O | 2926 | 183 | 6 | 137 | 5 | : | 0 | 246 | 8 | 2360 | 81 |
| P | 5254 | 1264 | 24 | 736 | 14 | : | 0 | 375 | 7 | 2879 | 55 |
| R | 4093 | 632 | 15 | 476 | 12 | : | 0 | 282 | 7 | 2703 | 66 |
| S | 4816 | 1372 | 28 | 537 | 11 | : | 0 | 768 | 16 | 2139 | 44 |
| T | 2984 | 761 | 26 | 398 | 13 | : | 0 | 106 | 4 | 1719 | 58 |
| U | 2574 | 485 | 19 | 492 | 19 | : | 0 | 24 | 1 | 1573 | 61 |
| W | 5001 | 1030 | 21 | 668 | 13 | : | 0 | 1196 | 24 | 2107 | 42 |
| X | 3596 | 426 | 12 | 307 | 9 | : | 0 | 1039 | 29 | 1824 | 51 |
| Y | 5134 | 1969 | 38 | 238 | 5 | : | 0 | 1335 | 26 | 1592 | 31 |
| Z | 5994 | 2322 | 39 | 377 | 6 | : | 0 | 677 | 11 | 2618 | 44 |
| AC | 9251 | 3682 | 40 | 852 | 9 | : | 0 | 3058 | 33 | 1659 | 18 |
| BD | 8723 | 3225 | 37 | 948 | 11 | : | 0 | 3260 | 37 | 1290 | 15 |
| Totals | 100429 | 22136 | | 11900 | | 257 | | 14344 | | 51684 | |

3.4 Length of gravel roads in different counties

The length of the gravel road network (km) in 1997 on the State road network in the different counties, as well as the percentages of the total length of State gravel roads, 22,136 km, accounted for by gravel roads in the different counties, are set out in table 3.4.

Västerbotten county has both the greatest length and the highest percentage of gravel roads. The length of gravel roads in this county is 3682 km which is 16.6% of the total length of 22,136 km in Sweden.

Table 3.4 Length of State gravel roads (km) in the different counties in 1997.

| County and county letter | | Gravel roads | |
|--------------------------|---------------|--------------|-----------------------------|
| County | County letter | Length (km) | Percentage of whole country |
| Stockholm | AB | 85 | 0.4 |
| Uppsala | C | 524 | 2.4 |
| Södermanland | D | 512 | 2.3 |
| Östergötland | E | 981 | 4.4 |
| Jönköping | F | 735 | 3.3 |
| Kronoberg | G | 647 | 2.9 |
| Kalmar | H | 339 | 1.5 |
| Gotland | I | 1 | 0.0 |
| Blekinge | K | 46 | 0.2 |
| Skåne | M | 718 | 3.2 |
| Halland | N | 197 | 0.9 |
| V.Götaland | O | 183 | 0.8 |
| Älvsborg | P | 1264 | 5.7 |
| Skaraborg | R | 632 | 2.9 |
| Värmland | S | 1372 | 6.2 |
| Örebro | T | 761 | 3.4 |
| Västmanland | U | 485 | 2.2 |
| Dalarna (Kopparberg) | W | 1030 | 4.7 |
| Gävleborg | X | 426 | 1.9 |
| Västernorrland | Y | 1969 | 8.9 |
| Jämtland | Z | 2322 | 10.5 |
| Västerbotten | AC | 3682 | 16.6 |
| Norrbotten | BD | 3225 | 14.6 |
| Totals | | 22136 | 100.0 |

Appendix No 1 shows the lengths of different wearing course types on the State road network in the different counties over the period 1990-1997, as well as the percentages of the total length of State roads accounted for by the different types of wearing course. Figure 3.2 shows the lengths of State gravel roads in different counties in 1997.

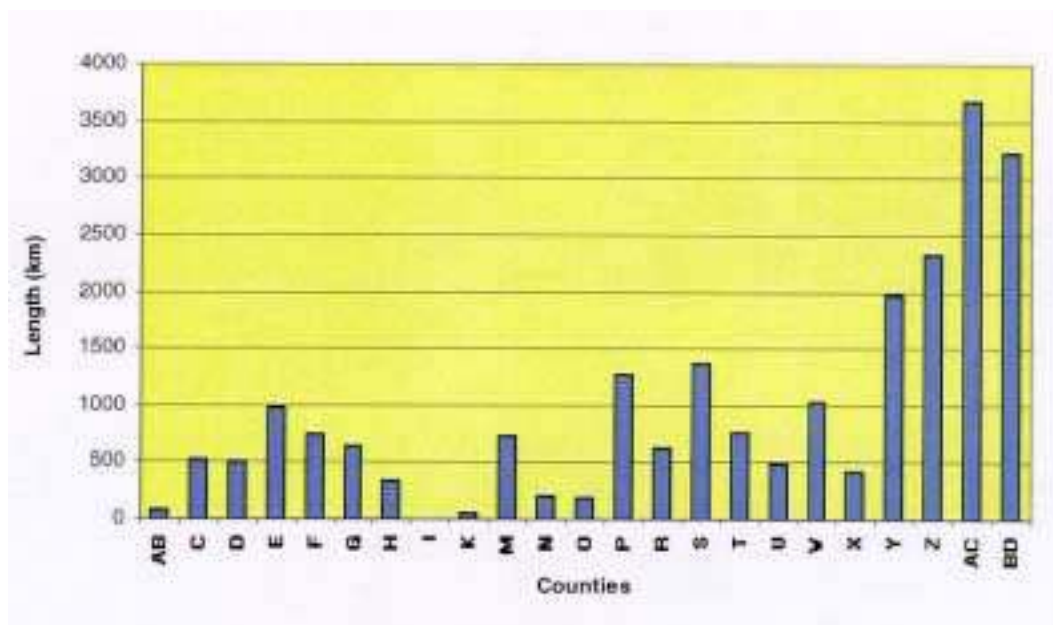


Figure 3.2 Lengths of State gravel roads in different counties in 1997.

3.5 Breakdown of type of wearing course by vehicle mileage

Table 3.5 Vehicle mileage (VM) (two axle unit km x 10³) on different types of wearing course, and percentages of total vehicle mileage on State road network accounted for by the different types of wearing course.

| Year | Total TA | Gravel | | Y1G | | Sealed gravel | | Oil gravel | | Bituminous | |
|------|----------|--------|------|------|------|---------------|------|------------|------|------------|-------|
| | | VM | % | VM | % | VM | % | VM | % | VM | % |
| 1990 | 123966 | 2405 | 1.94 | 1982 | 1.60 | 9 | 0.01 | 6960 | 5.61 | 112162 | 90.48 |
| 1991 | 129678 | 2327 | 1.79 | 1973 | 1.52 | 13 | 0.01 | 6947 | 5.36 | 117968 | 90.97 |
| 1992 | 131064 | 2220 | 1.69 | 2025 | 1.55 | 19 | 0.01 | 6822 | 5.21 | 119541 | 91.21 |
| 1993 | 130982 | 2008 | 1.53 | 2142 | 1.64 | 20 | 0.02 | 6661 | 5.09 | 119631 | 91.33 |
| 1994 | 131727 | 1892 | 1.44 | 2193 | 1.66 | 21 | 0.02 | 6990 | 5.08 | 120324 | 91.34 |
| 1995 | 132716 | 1816 | 1.37 | 2322 | 1.75 | 23 | 0.02 | 6766 | 5.10 | 121185 | 91.31 |
| 1996 | 134258 | 1789 | 1.33 | 2372 | 1.77 | 24 | 0.02 | 6816 | 5.08 | 122455 | 91.21 |
| 1997 | 133739 | 1761 | 1.32 | 2392 | 1.79 | 24 | 0.02 | 6834 | 5.11 | 121924 | 91.17 |

It is worth noting that in 1997 only 1.32% of the total vehicle mileage takes place on gravel roads.

3.6 Breakdown by AADT on different types of wearing course in 1997

Table 3.6 sets out the breakdown of the lengths of the different types of wearing course by average annual daily traffic (two axle units) and the percentages of the total length of State roads with a certain AADT accounted for by the different wearing courses.

Table 3.6 Breakdown of different types of wearing course by AADT in 1997 (km).

| AADT | Total length | Gravel | | Y1G | | Sealed gravel | | Oil gravel | | Bituminous | |
|---------------|--------------|--------------|------|--------------|------|---------------|-----|--------------|------|--------------|------|
| | km | km | % | km | % | km | % | km | % | Km | % |
| -99 | 20906 | 15700 | 75.1 | 2297 | 11.0 | 156 | 0.7 | 1085 | 5.2 | 1667 | 8.0 |
| -124 | 6436 | 2855 | 44.4 | 1534 | 23.8 | 53 | 0.8 | 715 | 11.1 | 1278 | 19.9 |
| -250 | 16779 | 3173 | 18.9 | 5130 | 30.6 | 48 | 0.3 | 3121 | 18.6 | 5306 | 31.6 |
| -300 | 4355 | 264 | 6.1 | 1041 | 23.9 | : | 0.0 | 1162 | 26.7 | 1887 | 43.3 |
| -350 | 2977 | 58 | 1.9 | 625 | 21.0 | : | 0.0 | 811 | 27.2 | 1483 | 49.8 |
| -400 | 2841 | 36 | 1.3 | 393 | 13.8 | : | 0.0 | 783 | 27.6 | 1629 | 57.3 |
| -450 | 2586 | 25 | 1.0 | 287 | 11.1 | : | 0.0 | 925 | 35.8 | 1349 | 52.2 |
| -500 | 2235 | 22 | 1.0 | 198 | 8.9 | : | 0.0 | 710 | 31.8 | 1305 | 58.4 |
| -550 | 2043 | 0 | 0.0 | 135 | 6.6 | : | 0.0 | 643 | 31.5 | 1265 | 61.9 |
| -600 | 1925 | 0 | 0.0 | 58 | 3.0 | : | 0.0 | 746 | 38.8 | 1121 | 58.2 |
| -1000 | 9463 | 2 | 0.0 | 186 | 2.0 | : | 0.0 | 2290 | 24.2 | 6983 | 73.8 |
| Totals | 72546 | 22135 | | 11884 | | 257 | | 12991 | | 25273 | |

Table 3.7 Breakdown of gravel roads by AADT (two axle units) in 1997 (km) and the percentages of the total length of State gravel roads – 22,136 km – with a certain AADT.

| AADT 2 axle units | Gravel roads | |
|-------------------|--------------|------|
| | km | % |
| -99 | 15700 | 70.9 |
| -124 | 2855 | 12.9 |
| -250 | 3173 | 14.3 |
| -300 | 264 | 1.2 |
| -350 | 58 | 0.3 |
| -400 | 36 | 0.2 |
| -450 | 25 | 0.1 |
| -500 | 22 | 0.1 |
| -550 | 0 | 0.0 |
| -600 | 0 | 0.0 |
| -1000 | 0 | 0.0 |

According to table 3.7, ca 71% of the total State gravel road network has AADT below 100.

3.7 Breakdown of road width by different types of wearing course in 1997

Table 3.8 Breakdown of different types of wearing course by road width (m) and the percentages of the total length of State roads of a certain width accounted for by the different types of wearing course.

| Width m | Length km | Gravel | | Y1G | | Sealed gravel | | Oil gravel | | Bituminous | |
|------------|--------------|--------|------|------|------|---------------|------|------------|-------|------------|------|
| | | km | % | km | % | km | % | km | % | km | % |
| 0-3.5 | 12546 | 11141 | 88.8 | 453 | 3.6 | 103 | 0.82 | 247 | 1.97 | 602 | 4.8 |
| 3.6-4.5 | 14189 | 7709 | 54.3 | 2604 | 18.4 | 148 | 1.04 | 772 | 5.44 | 2956 | 20.8 |
| 4.6-5.5 | 15038 | 2530 | 16.8 | 4617 | 30.7 | 29 | 0.19 | 1846 | 12.28 | 6015 | 40.0 |
| 5.6-6.5 | 25953 | 675 | 2.6 | 4055 | 15.6 | 0 | 0.00 | 9147 | 35.24 | 12073 | 46.5 |
| 6.6-7.5 | 3008 | 34 | 1.1 | 141 | 4.7 | : | 0.00 | 668 | 22.21 | 2165 | 72.0 |
| 7.6-8.5 | 1348 | 2 | 0.1 | 0 | 0.0 | : | 0.00 | 264 | 19.58 | 1074 | 79.7 |
| 8.6-9.5 | 317 | : | 0.0 | 1 | 0.3 | : | 0.00 | 37 | 11.67 | 279 | 88.0 |
| 9.6-12.5 | 63 | 0 | 0.0 | 1 | 1.6 | : | 0.00 | 4 | 6.35 | 58 | 92.1 |
| 12.6-40.0 | 41 | 0 | 0.0 | 0 | 0.0 | 0 | 0.00 | 2 | 4.88 | 39 | 95.1 |

Table 3.9 Lengths of gravel roads (km) on State road network in 1997 and the percentages of the total length of State gravel roads of a certain width accounted for by gravel roads.

| Width m | Length km | Percentages in 1997 of total length of State gravel roads of a certain width |
|------------|--------------|--|
| 0-3.5 | 11141 | 50.3 |
| 3.6-4.5 | 7709 | 34.8 |
| 4.6-5.5 | 2530 | 11.4 |
| 5.6-6.5 | 675 | 3.0 |
| 6.6-7.5 | 34 | 0.2 |
| 7.6-8.5 | 2 | 0.0 |
| 8.6-9.5 | : | 0.0 |
| 9.6-12.5 | 0 | 0.0 |
| 12.6-40.0 | 0 | 0.0 |

It is seen from table 3.9 that 50.3% of State gravel roads have a width up to 3.5 m, and 34.8% have a width between 3.6 and 4.5 m.

The road width that is sometimes measured is the loadbearing width, i.e. the width which can normally be used by vehicles with the permissible axle pressure. Usually about 0.5 m near each ditch must be deducted from the total width. Since road width varies along a long stretch of road, the tabulated width is the mean width.

3.8 Breakdown by speed limit on different types of wearing course in 1997

Table 3.10 Lengths of different types of wearing course by speed limit (km/h) and the percentages of the total length with a certain speed limit on the State road network accounted for by these lengths.

| Speed km/h | Total length km | Gravel | | Y1G | | Sealed gravel | | Oil gravel | | Bituminous | |
|---------------|-----------------------|--------|------|-------|------|---------------|------|------------|-------|------------|------|
| | | km | % | km | % | km | % | km | % | km | % |
| -30 | 68 | 3 | 4.4 | 4 | 5.9 | 0 | 0.00 | 16 | 23.53 | 45 | 66.2 |
| 31-50 | 4244 | 191 | 4.5 | 456 | 10.7 | 2 | 0.05 | 964 | 22.71 | 2628 | 61.9 |
| 51-70 | 52757 | 20502 | 38.9 | 10366 | 19.6 | 278 | 0.53 | 5889 | 11.16 | 15720 | 29.8 |
| 71-90 | 12920 | 1377 | 10.7 | 973 | 7.5 | - | 0.00 | 4622 | 35.77 | 5948 | 46.0 |
| 91-110 | 2471 | 0 | 0.0 | 80 | 3.2 | - | 0.00 | 1492 | 60.38 | 899 | 36.4 |

Table 3.11 Lengths of gravel roads (km) with a certain speed limit in 1997 and the percentages of the total length, 22,136 km, of State gravel roads with a certain speed limit accounted for by these lengths.

| Speed (km/h) | Length (km) | Percentage of total length of State gravel roads in Sweden in 1997 with a certain speed |
|-----------------|----------------|--|
| -30 | 3 | 0.01 |
| 31-50 | 191 | 0.86 |
| 51-70 | 20502 | 92.62 |
| 71-90 | 1377 | 6.22 |
| 91-110 | 0 | 0.00 |

According to table 3.11, gravel roads with a speed limit of 51-70 km/h represent 93% of the total length of State gravel roads.

3.9 Lengths and proportions of paved and unpaved roads

Table 3.12 *Lengths of paved and unpaved roads and the percentages of the total length, 422,667 km, of the State road network on 31 December 1997 accounted for by these lengths.*

| Road types | | Length (km) | Percentage of total length |
|------------|--|----------------|----------------------------|
| Paved | Bituminous (Bi) | 51,684 | 12.230 |
| | Y1G | 11,900 | 2.820 |
| | Concrete (Be) | 101 | 0.024 |
| | Stone (St) | 7 | 0.002 |
| | Municipal roads | 38,325 | 9.070 |
| | Total | 102,017 | 24.140 |
| Unpaved | Gravel (Gr) | 22,136 | 5.240 |
| | Oil gravel (Ol) | 14,344 | 3.390 |
| | Sealed gravel (Fö) | 257 | 0.060 |
| | Forest roads with gravel wearing course | 210,000 | 49.680 |
| | Private roads with State grants, gravel wearing course ¹⁾ | 73,913 | 17.490 |
| | Total ²⁾ | 320,650 | 75.860 |

¹⁾ A small proportion of private roads with State grants may be paved

²⁾ Roads that can be graded may perhaps be classified as unpaved roads or roads that are not properly paved

Table 3.12 shows that about 76% of the total length of the State road network is unpaved.

3.10 Swedish gravel road network in 1997

Table 3.13 Summary of Swedish gravel road network in 1997.

| | |
|---|---|
| Length of State gravel road network | 22,136 km |
| Percentage of State road network (100,429 km) accounted for by State gravel road network | 22% |
| Percentage of total road network (422,667 km) accounted for by State gravel road network | 5.24% |
| Reduction of State gravel road network from 1990 until 1997 | 5,009 km (from 27,145 to 22,136 km) |
| Percentage reduction of State gravel road network from 1990 until 1997 | 18.4% |
| Vehicle mileage on gravel road network (thousands of two axle units) | 1761 |
| Percentage of vehicle mileage on State road network (133,739) accounted for by gravel road network | 1.32% |
| Percentage of State gravel road network (22,136 km) accounted for by gravel roads up to 3.5 m wide | 50.3% (11,100 km) |
| Percentage of State gravel road network (22,136 km) accounted for by gravel roads 3.6-4.5 m wide | 34.8% (7,700 km) |
| Percentage of State gravel road network (22,136 km) accounted for by gravel roads 4.6-5.5 m wide | 11.4% (2,500 km) |
| Percentage of total gravel road network (22,136 km) accounted for by gravel roads with speed limit of 51-71 km/h | 92.62% (20,500 km) |
| Counties where length of gravel road network remained unchanged between 1996 and 1997 | Stockholm, Södermanland, Värmland, Blekinge, Västmanland, Gävleborg |
| Percentage of State gravel road network (22,136 km) accounted for by State gravel roads with AADT up to 99 two axle units | 72% |
| County with most State gravel roads in relation to total length of State roads in the county | Västerbotten county (39.80% gravel roads) |
| Counties where the proportion of State gravel roads exceeds 35% of the total length of State roads in the county | Västerbotten (40%), Jämtland (39%), Västernorrland (38.5%) and Norrbotten (37%) |
| County where gravel roads account for the smallest percentage of the total length of State roads | Gotland county (0.07%) |

3.11 Maintenance costs

Table 3.14 Total budget of Swedish National Road Administration in 1994-1996 for different maintenance services (Statistics from SNRA, 1997).

| Maintenance services | Maintenance costs, SEK million | | | | | |
|----------------------|--------------------------------|------------|----------------|------------|----------------|------------|
| | 1994 | | 1995 | | 1996 | |
| | SEK m | % | SEK m | % | SEK m | % |
| Paved roads | 1,691.0 | 66.4 | 1,866.2 | 65.7 | 1,294.0 | 65.4 |
| Gravel roads | 387.6 | 15.2 | 495.2 | 17.4 | 343.6 | 17.3 |
| Bridges | 439.1 | 17.2 | 427.1 | 15.0 | 313.4 | 15.8 |
| Tunnels | 19.1 | 0.75 | 24.7 | 0.86 | 16.5 | 0.83 |
| Ferries | 9.3 | 0.3 | 26.0 | 0.9 | 8.9 | 0.45 |
| Others | 0 | 0 | 0.5 | 0.017 | 0.3 | 0.015 |
| Totals | 2,546.2 | 100 | 2,839.8 | 100 | 1,976.9 | 100 |

4

Deterioration of gravel roads

The deterioration of gravel roads is governed by the behaviours of the road material and the drainage capacity under the combined actions of traffic and climate and the absent of sufficient maintenance activities. Generally problems begin slowly and progressively become more serious. Slight defects will grow into moderate faults and severe conditions. At first, the distress might be found in only a few isolated places. As the condition worsens more and more, the distress will show up on the surface. This chapter discusses the causes of deterioration of gravel roads, for instance traffic, precipitation and grading. Damage such as incorrect shape, insufficient drainage, dust, potholes, corrugation, rutting, loose gravel on the road and frost damage, are also dealt with in this chapter.

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4.1 The causes of deterioration

The road gradually deteriorates due to the action of traffic, rain, wind and grading. Sultan (1974) in his literature study gives a detailed description of the way the carriageway is abraded by wind, precipitation and traffic. In Sweden, wear due to the action of wind is mostly of relatively small extent compared with wear caused by traffic, rain and grading.

4.1.1 Traffic

Hubendick (1969) confirms that traffic is the greatest cause of wear of the road.

Soil erosion caused by traffic comprises two active mechanisms, the slipstream and mechanical abrasion due to the torque developed by the driving wheel (Lindh, 1981).

When the wheels of a vehicle roll along the road, the particles of aggregate in the surface are subjected to considerable forces. Underneath the wheel load, the carriageway deflects to some extent. This gives rise to a certain movement between the particles a little lower down in the wearing course. The particles grind against one another and are abraded. Gradually, large particles become smaller. As the vehicles rush along the road, some aggregate particles are inevitably thrown to the sides and vanish. They are carried along by the tailwind and are also spread out by the wheels as they are thrown into the air. As regards loss of material, however, dusting is much more serious (Hubendick, 1969).

Persson (1993) states that the wearing course is continuously broken down by the vehicle wheels crushing the larger particles. The result is a shortage of aggregate and an excess of sand. The road easily becomes corrugated. Figure 4.1 shows how the particle size distribution curve changes.

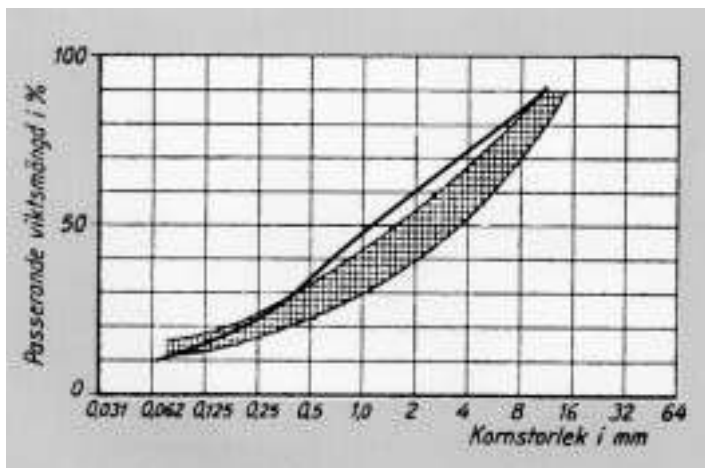


Figure 4.1 *Change in the wearing course due to crushing, dusting and rain action (Road maintenance-roads free from snow and ice, 1992, in Swedish).*

*Vertical axis- Percentage passing in %
Horizontal axis- Particle size in mm*

4.1.2 Precipitation and climate

During a heavy fall of rain, fine particles are dislodged, are suspended in the water and are carried by the water into the ditch. The condition of gravel roads varies greatly from season to season. In the spring and autumn the carriageway is generally softened by water. During the summer gravel roads are often corrugated, potholed and dusty.

Beskow (1934) says that gravel carriageways are subjected to the greatest stress on two occasions, when the water ratio is high and when the moisture content is very low. The water ratio is elevated during long rains and especially when the soil thaws out, while the moisture content becomes very low during dry periods in the summer.

A high water ratio reduces bearing capacity. When water ratio is very low, cohesion decreases and material in the surface of the road is easily dislodged by traffic. One of the consequences of this is the formation of corrugations across the gravel wearing course.

4.1.3 Grading

Each time the road is graded, some abrasion occurs. The grader blade abrades, crushes and cuts into the aggregate. The wetter the carriageway, the smaller the abrasion. But this abrasion is in most cases relatively small compared with that caused by traffic.

4.2 Distresses of gravel roads

The distresses of which will be dealt with is incorrect shape, insufficient drainage, dusting, potholes, corrugation, loose aggregate on the road and frost damage.

4.2.1 Incorrect shape

In the context of operation and maintenance, it is primarily the transverse shape of the carriageway that is of interest. There is no other measure in gravel road maintenance that is so critical for condition and cost as correction of the shape of the road in the transverse direction, i.e. cambering and superelevation. All other measures such as aggregate recycling, regravelling, ditch clearing etc are of little use if, after being graded, the road becomes flat without sufficient camber and superelevation (Road maintenance-roads free from snow and ice, 1992). Camber and superelevation are corrected by deep grading. A gravel road of the wrong shape easily becomes potholed by rain. A well shaped road from which the rain is quickly drained often stands up to several falls of rain before grading is needed. The shape of road on straight sections and through curves will be dealt with in the following.

4.2.1.1 Shape of road on straight sections

On straight sections it is chiefly the endeavour to prevent ponding of water on the road that determines the shape. The sideways slope on straight sections is called camber or crown. The appropriate camber on gravel roads is between 4% and 5% (Hubendick, 1969).

If the road on straight sections is flat as a floor, rain falling on the road is not drained properly. It collects in pools. In such conditions it does not take long for the road to be destroyed. The road is therefore constructed roughly as a roof, with the ridge along the centre line and the roofs sloping down towards the edges of the road. Water then drains into the ditches.

Water must take the shortest route to the sides. The more the road slopes sideways, the more quickly water drains away. A proper sideways slope is therefore desirable. But, on the other hand, the road must not have such a steep sideways slope that a vehicle may overturn or slide off the road, or it becomes difficult to keep the vehicle on the road; see figure 4.2.

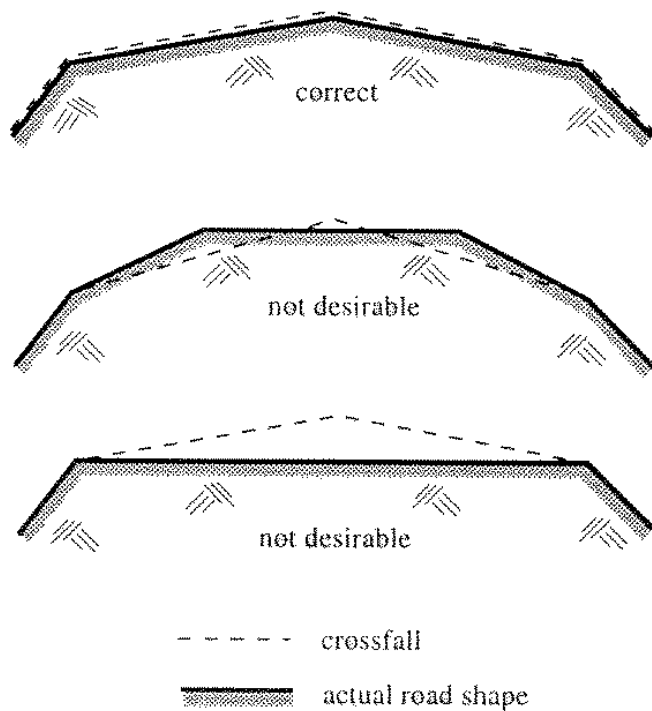


Figure 4.2 *Examples of correct and wrong camber (Unsealed Roads Manual-Guidelines to Good Practice, 1993).*

The more uneven the road, the more slowly water will drain. The cambers on a gravel road must therefore be slightly steeper than on a paved road. Hubendick (1969) says that the shape of a road will deteriorate due to wear and overload.

A. Incorrect shape due to wear

Wear reduces camber. To some extent, wear is due to the fact that the finest material, in particular, turns to dust and is blown away. Some of the coarser material is also displaced by the wheels of vehicles and is spread to the sides. When the wheel rolls along the road, it draws material towards itself. This material is lifted off the surface to some extent. When the material returns to the sloping surface, it falls a little to the side. This process is illustrated in figure 4.3.

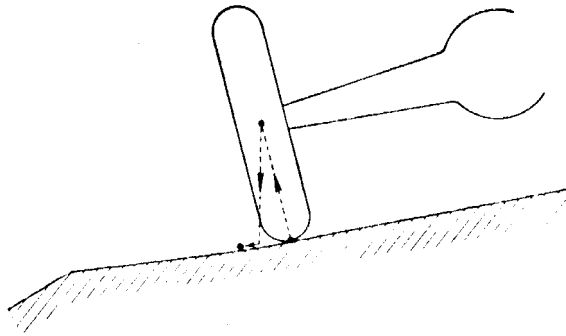


Figure 4.3 Owing to the camber of the road, material tends to be displaced towards the sides (Hubendick, 1969).

In this way, the road gradually becomes flatter while the edges are raised up. Figure 4.4 gives some examples of how the camber is worn down.

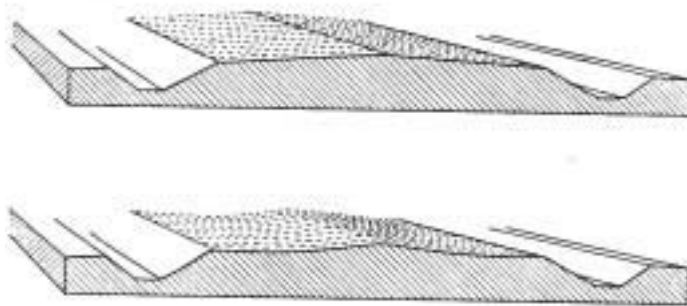


Figure 4.4 The camber is gradually worn down, the edges are raised up, and ruts are formed in the carriageway if this is not graded (Hubendick, 1969).

If camber is greatly reduced, water will not drain satisfactorily and the road will therefore be exposed to other types of damage. The road must therefore be reshaped in time before wear has gone too far. Deep grading does this. If the road is not reshaped in time, a reverse camber is formed; see figure 4.5.

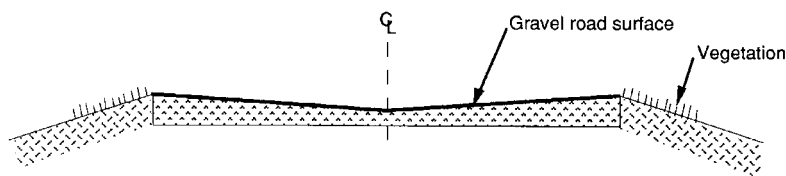


Figure 4.5 Reverse camber (Unsealed Roads Manual-Guidelines to Good Practice, 1993).

B. Incorrect shape caused by overloading

The road can also be deformed by overloading. If the road has not sufficient bearing capacity, traffic consisting of too heavy vehicles may flatten the camber. In such a case it is not certain that the camber can be restored by grading. On simpler roads the layer of gravel is often relatively thin. If an attempt is made to restore the camber by grading material from the sides towards the centre, the gravel layer will become too thin at the sides. This process is illustrated in figure 4.6.

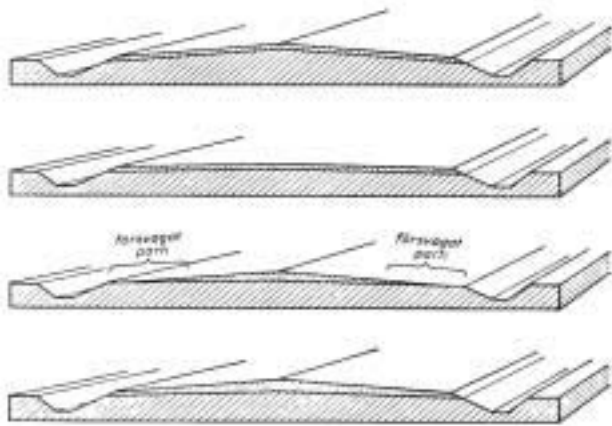


Figure 4.6 *If the road structure is too weak, camber may be flattened in the middle (Hubendick, 1969).*

försvagat parti=weakened part

4.2.1.2 Shape of road through curves

Through curves it is chiefly traffic engineering factors which determine the shape of the road. If the road is inclined transversely towards the inside of the curve, road users will find it easier to negotiate the curve. This slope is called superelevation.

The more vehicles there are, the higher their speed and the sharper the curve, the greater wear will be. The inside of the curve, in particular, is subject to heavy abrasion. The material in the carriageway is dislodged by the wheels and is thrown towards the outside of the curve. The road along the inside of the curve therefore loses material and becomes lower. The thrown out material, on the other hand, raises the road along the outside of the curve. In this way, superelevation gradually becomes too steep.

The thrown-out material does not usually end up at the outer edge, but approximately in the middle of the outer half of the road. The superelevation along the outermost part of the road is therefore too flat. Sometimes it becomes horizontal or even slopes the wrong way. Such a road is a danger to traffic. See figure 4.7.

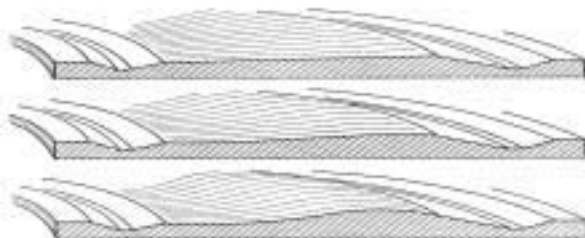


Figure 4.7 *The wheels of a vehicle abrade the material on the inside of the curve and throw it towards the outer edge of the curve (Hubendick, 1969).*

In sharper curves where vehicles must make larger changes in their direction and speed in order to negotiate the curve, the road often becomes heavily worn at the entrance to the curve. It is here that vehicles begin to turn and brakes are usually

applied the hardest. The surface therefore easily becomes uneven at the entrance to the curve.

Even over transition sections between superelevation and camber along the outside of a curve, the road may become uneven. The normal camber and superelevation on gravel roads is illustrated in figure 4.8.

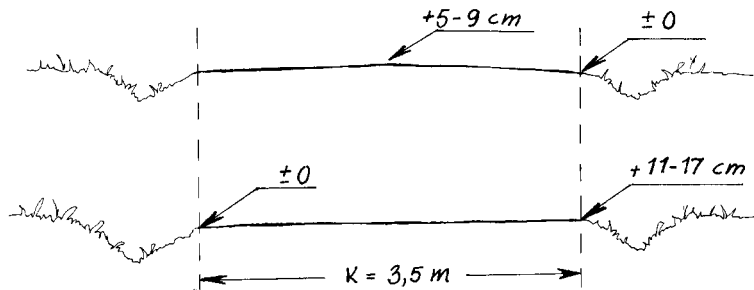


Figure 4.8 Normal camber on straight sections and superelevation in curves on gravel roads (Persson, 1993).

4.2.2 Insufficient drainage

Water or moisture is certainly an important ingredient of a gravel road. The road surface should be slightly moist for correct cohesion. Too much water on the road is however destructive. Water can damage a road in many ways, and the road must therefore have a functioning drainage system. The different parts of a drainage system are discussed below.

4.2.2.1 Crossfall

Crossfall has been discussed in Subclause 4.2.1.

4.2.2.2 Road edge

Banks consisting of worn out or displaced aggregate, dirt and clumps of grass may sometimes form along the edges of the road. If this happens, water is prevented from draining into the ditch, and runs along the road instead. On inclines the water gathers speed and may wash away the road surface. If water is kept back by the banks on horizontal sections, it remains on the surface of the road. These pools obstruct traffic. Potholes form, and the material in the road structure may finally be softened by moisture to such an extent that the bearing capacity of the road is reduced.

4.2.2.3 Slopes

The inner slope must not be too steep since it serves as support for the road structure. If the slope is too steep, the edge of the road will collapse. On steep slopes water has a high speed. The faster water drains away, the more soil and sand it carries with it, so that the slope is washed away.

4.2.2.4 Ditches

According to Hubendick (1969), ditches are the most important part of the road. If there are no ditches, there is nowhere for water to go; the result is that water builds up in the road structure so that its bearing capacity is reduced. Ditching is

therefore important work. Jansson (1985) and Hubendick (1969) say that a ditch has several functions:

- To take away water that runs off the road. This does not require either a particularly wide or deep ditch. Water is drained from the surface of the road due to its crossfall.
- To remove water from the surroundings of the road which would otherwise run on to the road. In most cases, more water comes from the surrounding terrain than from the road itself. The ditch must therefore have a certain size. If water must be carried over a long distance along the road, the ditch must be made larger. Water from the surrounding terrain and from the carriageway is in most cases removed through an open ditch.
- To drain the road structure. This can be achieved with an open or covered ditch. The deeper the bottom of the ditch, the better the road structure will be drained. In terrain that is susceptible to frost action, it is extremely important for the road structure to be properly drained. If ditches are allowed to deteriorate, this may be the direct cause of very serious frost damage to the road during the thaw; see Subclause 4.2.8. Water is present in the road structure in many forms, and all water cannot be drained by ditches. Water that is bound around the particles of material, for instance, is not affected. Two experiments performed by Jansson (1985), however, show that there is no relationship between depth of ditch and the bearing capacity of gravel roads. A Finnish study shows that, in a normal road construction, very little water is drained sideways into the ditch (Jansson, 1985).
- To act as a storage place for snow (Jansson, 1985).

4.2.2.5 Culverts

Culverts have an important role in ensuring that the road is drained. Culverts, especially at their inlets and outlets, can silt up or be blocked when snow melts or when ditches are cleared, bushes are trimmed or trees are felled. In the worst case the road structure can be completely washed away (Forest roads, 1992, in Swedish).

4.2.3 Dust

The finest particle fractions in the gravel wearing course are swirled up by the slipstream of passing vehicles into clouds of dust that are driven to the sides and vanish from the road. A speed of 100 km/h corresponds to a wind speed of ca 28 m/s. This is almost the wind speed in a hurricane. The movement of air is sufficiently high to dislodge and remove a quantity of fine material from the carriageway. If traffic is heavy, the quantity of material that disappears in this way will in time be considerable. Ordinary wind also removes fine material in the same way. This is usual in coastal areas and flat country.

4.2.3.1 Definition of dust

Foley and Cropely (1995) define dust as fine particles (smaller than 0.075 mm) that have been transmitted to the atmosphere. Dust normally represents 10-15% of the total material in the wearing course. Foley and Cropely (1995) quote Coppin and Armstrong regarding dust classification by particle size. According to Sultan (1974), the dusting phenomenon may be classified as a kind of soil erosion.

4.2.3.2 The quantity of dust

The quantity of dust emitted to air from gravel roads depends on the following factors, which are briefly described below.

- A. Air velocity near the road surface
- B. Number of vehicles
- C. Composition of wearing course
- D. Cohesion
- E. Climate

A. Air velocity near the road surface

Air velocity near the road surface is proportional to vehicle speed and is also a function of vehicle type.

Vehicle speed influences both the quantity of dust and its dispersal from the road. Relationships between vehicle speed, vehicle type and quantity of dust are illustrated in figure 4.9. Three vehicle types are covered by the figure, small car, large car and lorry. The vehicle type has the influence that e.g. a low vehicle with several wheels raises more dust. Foley and Cropely (1995) quote one of the Transit New Zealand Research reports. The results of this report suggest that heavy vehicles at high speed cause more dust.

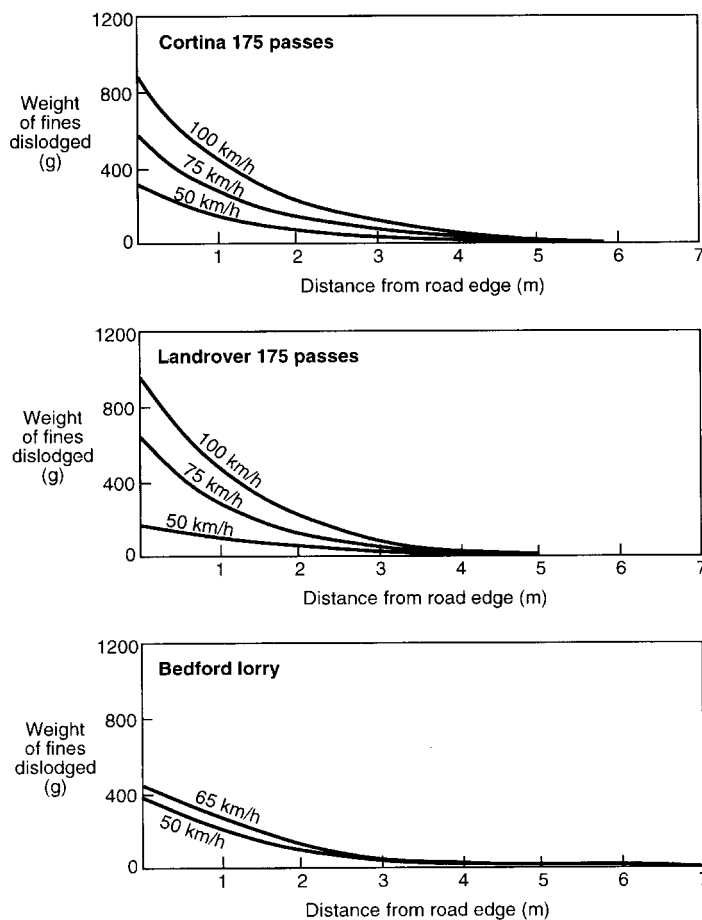


Figure 4.9 Relationship between vehicle speed, vehicle type, vehicle size and quantity of dust (Jones, 1984, in Foley and Cropely, 1995).

Lindh (1981) quotes Roberts and Walter (1975) and gives a relationship between vehicle speed and dust formation. Figure 4.10 shows the relationship between vehicle speed and dust formation on a gravel road in terms of weight per vehicle per mile, for particles smaller than 0.01 mm and 0.002 mm.

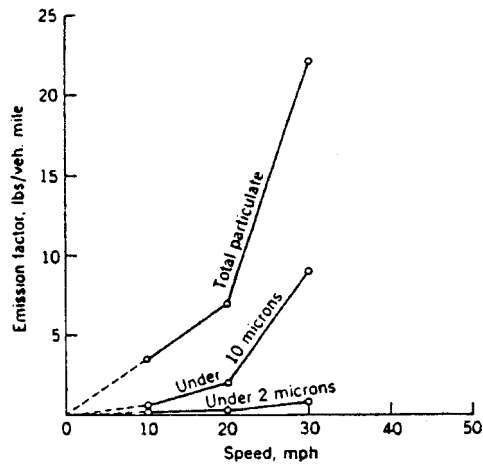


Figure 4.10 Relationship between vehicle speed and dust formation (Lindh, 1981).

Foley (1996) quotes Addo and Sanders (1995) and gives a relationship between speed and quantity of dust; see figure 4.11.

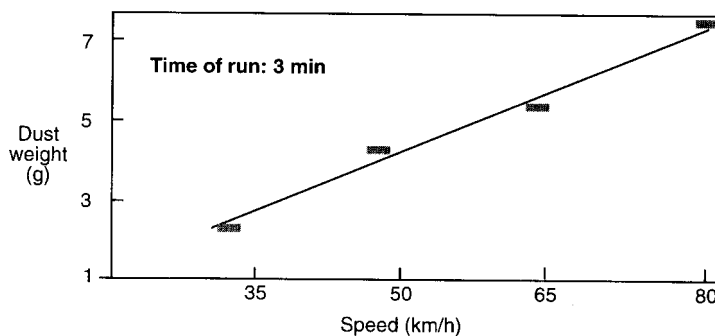


Figure 4.11 Relationship between speed and quantity of dust (Foley, 1996).

B. Number of vehicles

The greater the number of vehicles, the greater the quantity of dust.

C. Composition of wearing course

The influence of the composition of the wearing course is that it is more difficult for heavy particles than lighter particles to be transported, i.e. a fine grained wearing course dusts more, and that cohesion depends on composition.

D. Cohesion

Cohesion depends on how well the wearing course is compacted, the cohesion between particles in the wearing course, and the durability of the material in the wearing course.

E. Climate

The climate has an influence because a number of the effects of dust control agents, e.g. hygroscopic salts, are greatly dependent on moisture. Moisture varies as a function of rain and evaporation. With regard to net rainfall and temperature, a classification into climatic zones can be made.

4.2.3.3 Measurement of quantities of dust

Few experiments have been made to measure and characterise dust from unpaved roads. This is pointed out by Handy in Lindh (1981). Lindh considers this rather surprising in view of the fundamental significance that these properties may have for the development of methods of dust control.

Investigations concerning the significance of gravel roads as a source of dust particles in air have been made by Handy (1975), Roberts and Walter (1975) in Lindh (1981) and Jones (1984) in Foley and Cropely (1995). Investigations have also been made to create a basis for theoretical calculations of the quantity of dust particles that may be expected to be emitted from a gravel road when the factors that cause dusting are known (Lindh, 1981).

Some measurements have been made to determine the quantity of dust emitted to air from gravel roads when a vehicle is driven along the road at different speeds. The publication "Guidelines for cost effective use and application of dust palliatives" (1987) shows an equipment, a Dustfall Station, that is used to analyse and measure the quantity of emitted dust; see figure 4.12.

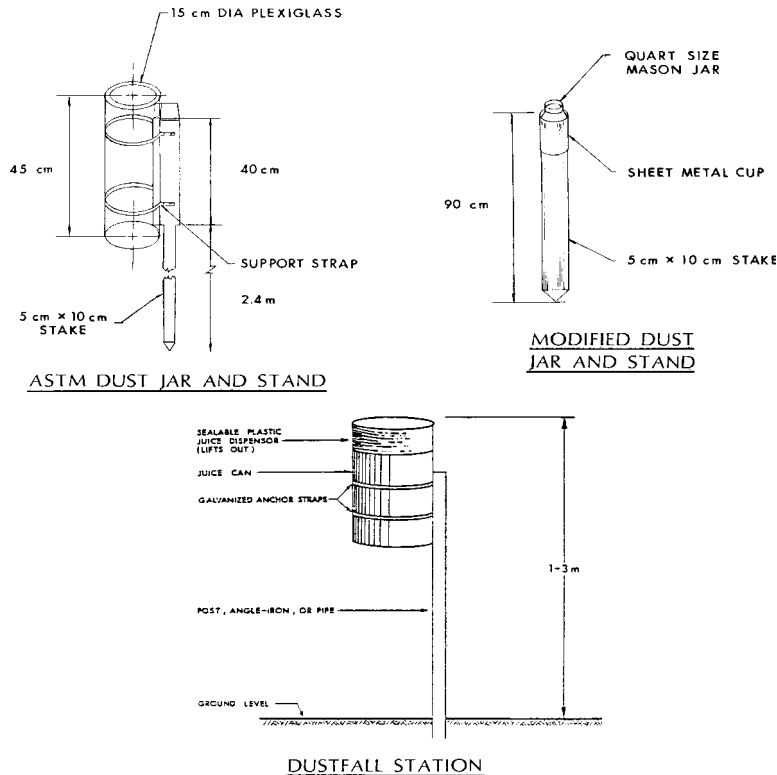


Figure 4.12 Equipment used to measure the quantity of emitted dust.

The purpose of dust analysis was to chart the proportions of particles smaller than 0.01 mm and 0.002 mm, respirable dust, i.e. particles that can penetrate into the lungs, to find how far from the road the dust fallout is measurable, and finally to determine its content of carbonates, quartz, clay, organic substances and other materials (Lindh, 1981).

In their report, Foley and Cropely (1995) give equations or models for calculating the quantities of material removed as dust from gravel roads.

Most states in the USA have drawn up regulations for the maximum permissible quantity of "fugitive dust". The term fugitive dust refers to particles smaller than 30 μm in the atmosphere. In Sweden there are no rules for the maximum permissible quantity of dust in air, and perhaps this is not so important here because of e.g. climatic factors (Lindh, 1981).

4.2.4 Corrugation

The term corrugation denotes a wavy surface. The road surface consists of a series of waves, with ridges and troughs. The pitch of such a wave is the distance between two consecutive ridges or troughs. The difference in height between trough and ridge is the wave height. There is very little connection between pitch and height. Ridges ranging from a few millimetres to 10-20 centimetres can be seen on the same stretch of corrugated road where the pitch is approximately the same.

A gravel road must consist of both coarse and fine material and must on no account be sandy. The aggregate is gradually broken down by wear and sand is formed. When the road contains a lot of sand it is susceptible to corrugation.

Beskow (1932) quotes two factors for the formation of corrugations, vehicles which are the active factor, and the carriageway itself which is the passive factor.

4.2.4.1 Types of corrugation

Beskow (1932) says that three types of corrugation can be distinguished:

Type 1: Dislodgement of loose aggregate, "Ordinary, normal corrugation"

Type 2: Water splash, "Potholing". Stirred-up water contains suspended fines

Type 3: Plastic undulating deformation

The first type of corrugation, dislodgement of loose aggregate, is discussed below.

Ordinary or normal corrugation is the most important type of corrugation. It is caused by dislodgement of loose aggregate. It is this type of corrugation that dominates on Swedish roads during the dry part of the year; see figure 4.13 and 4.14.



Figure 4.13 Corrugation (Chong and Wrong, 1989).

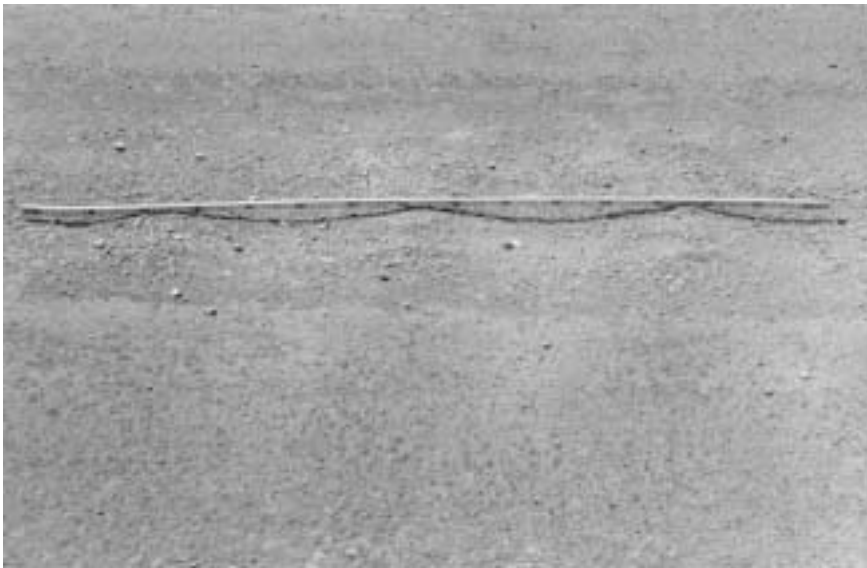


Figure 4.14 Corrugation (Chong and Wrong, 1989).

Beskow (1932) says that part of the unbound material is thrown up by the wheels and is carried along by the slipstream, and part is caught up on the wheels. This results in a sorting of the material. The **finest** particles are entrained by the slipstream in the form of a dust cloud. The **intermediate** particles are too large to be entrained but too small to roll along the carriageway on their own. They accumulate in the corrugation ridges which thus attain a clearly graded, sometimes very well graded, sandy composition. The **coarse** aggregate particles and stones roll easily if they have a rounded shape, and cannot remain on the ridges. In its purest form, this type of corrugation arises where there is a thin cover of aggregate on a hard and firm surface, for instance a carriageway treated with sulphite lye and well compacted.

The ridges do not usually consist completely of loose aggregate but have a core of more or less hard compacted material. These cores are formed by deepening of the troughs due to dislodgement of material, so that the bases of the ridges are slightly

elevated above the original surface. On the whole, however, the firm ridges are formed by loose aggregate that has been thrown up and gradually compacted. See figure 4.15.



Figure 4.15 *Schematic profile through a normally corrugated road surfaced with fine sandy aggregate (Beskow, 1932).*

- a. Loose material on ridges, often fine sand, coarser in troughs.*
- b. Compacted but very easily dug material of approximately the same composition.*
- c. Firm, often stone bound, base level.*

Hubendick (1969) distinguishes between two types of corrugation, dry corrugation and wet corrugation.

Dry or summer corrugation occurs on a dry carriageway with a corrugation susceptible gravel wearing course. This affects only the wearing course itself.

Wet corrugation occurs on a wet or moist road where the road structure has insufficient bearing capacity. In such a case it is not the top layer that is abraded, but the substructure is deformed in depth. Wet corrugation normally occurs during or as a consequence of thaw.

4.2.4.2 Practical measures to counteract corrugation

These practical measures relate to both the vehicle and the carriageway.

Corrugation is reduced by the use of suspension dampers. Modern vehicles may be said to have well complied with this requirement. The second group relates to the carriageway itself.

Beskow (1932) collates information from a number of books and reports. These are based on either experimental investigations or direct observations and general experience. The results indicate that

- Corrugation occurs especially on carriageways that have a considerable thickness of unbound fine aggregate.
- An increase in the moisture content or soil binder content of the carriageway reduces its susceptibility to corrugation.
- Properly executed grading is the best way of preventing corrugation.

Beskow (1932) summarises the most important measures that can be taken against corrugation as follows:

1. Appropriate adjustment of aggregate composition by avoidance of fine sandy aggregate, at least on roads not treated with salt, and primarily by avoidance of

stony aggregate. The ideal appears to be intermediate aggregate up to ca 1 cm in size that is free of stone and has a sufficient sand and soil binder content.

2. Avoidance of a base course construction that dries out the surface, especially a porous compacted stone base.
3. Grading and dragging must be carried out in a way that not only makes the surface appear smooth but also makes the surface layers really homogeneous, i.e. in such a way that corrugations formed in the firm carriageway are removed completely. Such deep grading is particularly important in the spring after thaw, and in other cases after long wet periods when it is easiest to reshape the carriageway.
4. Treatment with hygroscopic salt. This binds the aggregate and grading need not therefore be carried out so often. Once an even and well bound road surface has been achieved, the conditions are favourable for future use of some other binder, e.g. sulphite lye.

Glänneskog and Skog (1994) say that corrugation can be remedied by spreading additional aggregate of e.g. 4-16 mm fraction.

4.2.5 Potholes

Potholes are usually between 30 and 80 cm long, but shorter and longer ones also occur. Their depth is usually between 3 and 7 cm.

Potholes are most common on horizontal sections, in depressions and where the camber is insufficient, and where the road is highly susceptible to corrugation. Potholes often penetrate some way into the roadbase and it is therefore very difficult or impossible to eliminate them by ordinary grading. They form a permanent base for corrugation, a base system through which, in spite of full surface treatment by grading or aggregate spreading, corrugation soon recurs (Beskow, 1932).

4.2.5.1 Formation of potholes

Beskow (1932) describes potholes as a form of corrugation that is caused by splashing. This process cannot however on its own cause any corrugation; the depressions already existing in the carriageway in which rainwater collects are the primary cause. In these depressions, water softens the carriageway, causing finer material to be dissolved and removed when traffic throws water out of the potholes.

4.2.5.2 Classification of potholes

Beskow (1932) classifies potholes in three groups, potholes in a regular pattern, transitional form, and potholes in an irregular pattern.

Potholes are said to form a **regular pattern** where several potholes occur in a row at constant intervals approximately corresponding to the pitch of normal corrugations. These clearly regular potholes occur on roads with moderate traffic where deep ruts are formed in the single lane. All the corrugation troughs therefore assume the shape of elongated potholes that are filled with water. See figure 4.16.



Figure 4.16 *Potholes in a regular pattern (Beskow, 1932).*

The **transitional form** is intermediate between regular and irregular potholes. Multiple rows of these occur on heavily trafficked roads. See figure 4.17 (Beskow, 1932).



Figure 4.17 *Transitional form between regular and irregular potholes (Beskow, 1932).*

Potholes in an **irregular pattern** are the third group. If these potholes are compared to the regular normal corrugations, it is seen that the distribution of potholes across the carriageway is quite irregular, with different distances between potholes along the road. Potholes are unevenly distributed across the carriageway. Beskow (1932) explains the irregularity of potholes as follows:

In order that water should collect in the corrugation troughs, it is necessary for these troughs to have the shape of enclosed holes. If the carriageway has a sufficient crossfall, no water will collect in the corrugation troughs. In this respect, the individual corrugation troughs on the same section of road are usually quite different. The result is that only certain of these depressions will become potholes. See figure 4.18.



Figure 4.18 Potholes in an irregular pattern.

4.2.6 Ruts

Ruts are described as transverse irregularities caused by vehicular traffic. The shapes and character of ruts vary depending on what has given rise to rutting. Rutting is due to deformation of the road structure. It is seen from Unsealed Roads Manual (1993) and Memorandum for Traffic Engineering (1995, in Swedish) that deformations may occur in the subgrade, wearing course or base course.

If the **subgrade** has inadequate bearing strength, permanent deformation occurs in the road structure; see figure 4.19.

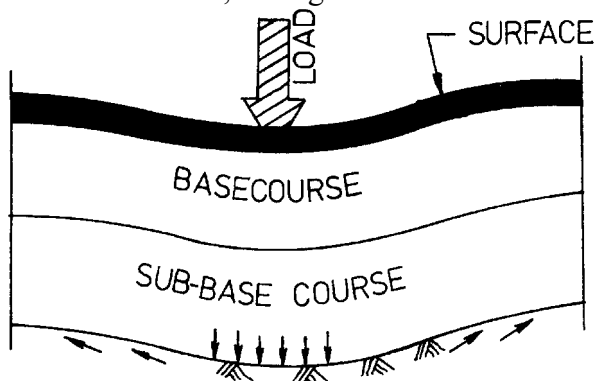


Figure 4.19 Deformations due to inadequate bearing strength (Ferry, 1986).

If plastic deformations occur, the **base course** and wearing course may be displaced to the side. As a result, these courses are raised up on each side of the rut; see figure 4.20.

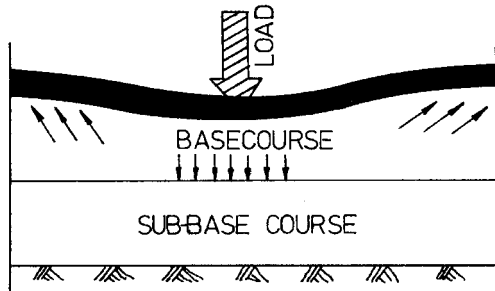


Figure 4.20 Plastic deformations (Ferry, 1986).

Traffic load may give rise to compaction and displacement of aggregate in the wearing course; see figure 4.21.

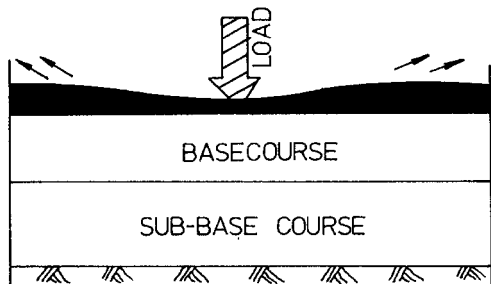


Figure 4.21 Inadequate wearing course (Ferry, 1986).

Problems Associated with Gravel Roads (1998) describes development of ruts on gravel roads due to plastic deformations in the base course and wearing course; see figure 4.22.

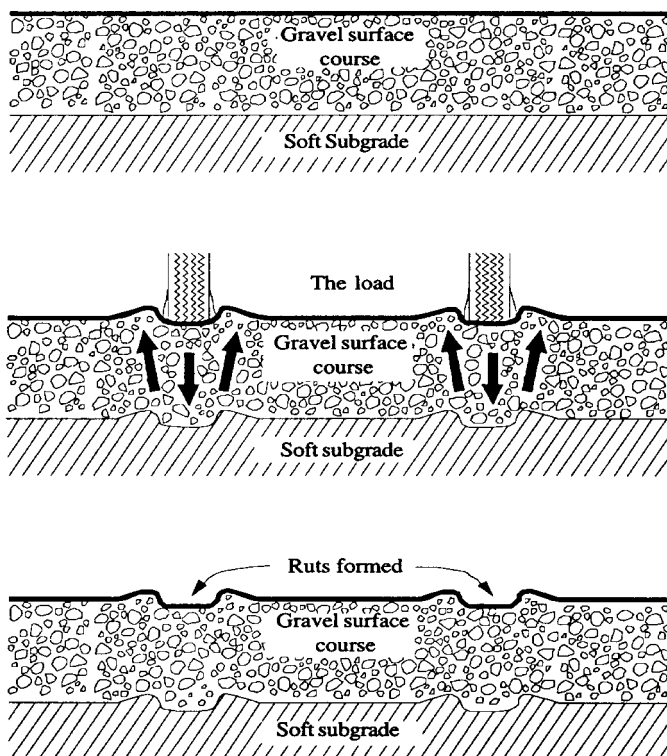


Figure 4.22 Rutting on gravel roads.

Unsealed Road Manual (1993) states that the following are the causes of deformations:

- Inappropriate aggregate composition
- Wearing course of insufficient thickness
- Inadequate compaction
- Insufficient drainage
- High fines content

Hubendick (1969) says that ruts make driving unpleasant because the tyres are forced to follow the ruts. Ruts also collect water which gives rise to other damage.

4.2.7 Loose aggregate on the road

Aggregate may collect on the road in different ways. One of these that is described by Glänneskog and Skog (1994) is that aggregate on the carriageway is abraded or thrown to the edge of the road by traffic. In order to improve the carriageway, it is necessary in this case to deposit a new gravel wearing course on the road. See figure 4.23.



Figure 4.23 Loose aggregate on the road.

4.2.8 Frost damage

The harmful effects of frost may be classified as frost heave, softening, frost boil and stone migration (Guidelines for the Construction and Maintenance of Forest Roads, 1946, in Swedish) and (Persson, 1993).

4.2.8.1 Frost heave

The main cause of frost heave is that water is drawn up to the frost zone and freezes to ice. Thin layers of ice are formed one below the other as the frost boundary moves downwards. These ice layers may be of highly variable thickness, from the barely visible to layers several centimetres or even tens of centimetres thick. The higher the groundwater level, the shorter the time taken for

water to be drawn up, and the quicker the growth of the ice layers and the greater the frost heave. This emphasises the importance of a well drained road structure.

When water freezes it expands since ice has a larger volume. Expansion takes place upwards, i.e. the road rises as it thaws; the total rise is often 20 centimetres and at times almost 50 centimetres. Frost heave exerts such force that sometimes even heavy buildings are lifted up and may thus be damaged (Guidelines for Construction and Maintenance of Forest Roads, 1946).

Frost heave varies with the type of soil. The most frost susceptible soils are silt and fine grained moraines.

4.2.8.2 Softening

Typical softening of the surface occurs in the beginning of the thaw period, especially in conjunction with rain or meltwater. Frost prevents drainage of the road structure so that excess water accumulates in the top layers (Persson, 1993). In normal cases this has no serious consequences if ditches and culverts are in good order and heavy traffic can be kept off the road until it has dried. Deep ruts formed by heavy vehicles can further reduce drainage and thus delay drying. The carriageway becomes soft, of low bearing strength and rutted by traffic.

4.2.8.3 Frost boil

In the spring when the soil thaws out, the ice layers in the road melt. If these ice layers are thick, a lot of water is released. The road loses its bearing capacity and cracks open. Frost boil originates deep down in the road structure when heavy traffic "pumps" water and finer material up through the structure where it erupts through the surface. As a rule, frost boil occurs at a late stage of thaw in the most frost susceptible soils.

4.2.8.4 Stone migration

The migration of stones and boulders depends on several factors, such as the presence of stones in the road structure and the subgrade, the frost susceptibility of the subgrade, the groundwater level and temperature alternations in winter. The road pavement is also of importance.

Persson (1993) describes the process which results in migration of stones to the surface layer. When the soil freezes, a layer of ice forms around the stone. The increase in volume which occurs when water freezes pushes the stone upwards. As the ice melts, the hollow around the stone is filled with fine particles and the stone cannot regain its original position.

Persson lists some problems due to the presence of stones in the carriageway. He says that larger stones in the carriageway reduce the efficacy of grading and dragging because it is more difficult to shape the carriageway. There is more wear on the blade. Snow clearance is also hindered. The stones can damage plant and appliances. Large stones jeopardise traffic safety and reduce trafficability.

5

Technical requirements for Swedish gravel roads

The technical requirements specified for gravel roads vary from country to country depending on climatic conditions such as temperature and precipitation, topography, rock and soil conditions, as well as the available economic resources, traffic volumes, mechanical equipment, technical know-how, maintenance traditions, etc.

The technical requirements laid down by the Swedish National Road Administration (SNRA) are determined with reference to:

- ROAD 94, 1996 and previous general technical specifications.
- Regulations for Maintenance and Operation, 1990, in Swedish.
- SNRA Method specifications "Assessment of the condition of gravel roads-functional properties (106:1996)" (supersedes 106:1990), in Swedish.

Technical requirements for new construction and operation and maintenance will be described in this chapter.

| | | |
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| 5.1 | Technical requirements for the construction of new gravel roads in Sweden | 45 |
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5.1 Technical requirements for the construction of new gravel roads in Sweden

Most requirements in ROAD 94 relate to functional properties, materials and workmanship in new construction, but some requirements are also applicable to maintenance. ROAD 94 contains general requirements that apply to all roads, and also specific requirements for gravel roads. These general requirements are:

- The road construction, other road components and roadside facilities shall be designed and constructed in such a way that the road and its near surroundings have satisfactory bearing capacity and stability during both the construction period and over the entire service life, so that it has satisfactory durability and so that the use of adjoining land is not unnecessarily obstructed.
- The pavement shall have adequate bearing capacity and provide adequate safety and comfort for the intended traffic.
- Requirements for safety in use.

This chapter will deal mainly with the requirements which evidently apply to gravel roads. Technical requirements for gravel roads are given in Chapters 1, 3 and 5 of ROAD 94.

5.1.1 Requirements in Chapter 1 of ROAD 94

ROAD 94 states that gravel pavements can be used for roads with AADT < 250 or for simple temporary roads and for roads carrying very low volumes of traffic. It is worth noting that it is not intended that a gravel pavement according to ROAD 94 should later be given a bound surfacing. Chapter 1 "Common Prerequisites" sets out requirements for service life, permitted traffic, permissible surface unevenness in the longitudinal direction, crossfall, and permissible frost heave.

5.1.1.1 Requirements concerning service life

It is evident from ROAD 94 that the construction shall be designed so that the component below the pavement has a service life of not less than 40 years, and culverts in gravel roads a service life of not less than 20 years. See Table 5.1.

Table 5.1 Technical life (ROAD 94, 1996).

| Component | Service life, years | |
|---|----------------------------|------------|
| | National and regional road | Local road |
| Concrete surfacing | 40 | - |
| Bound base course in road pavement which is not a concrete pavement | 20 | - |
| Subgrade: bearing strength and durability | 40 | 40 |
| Reinforced subgrade: bearing strength and durability | 40 | 40 |
| Culverts | 40 | 20 |

5.1.1.2 Requirements concerning permitted traffic

ROAD 94 lays down that paved roads, parking spaces, rest areas and gravel roads shall, irrespective of the time of year, be capable of carrying vehicles of 11.5 tonne axle load and 19 tonne bogie load.

5.1.1.3 Requirements concerning permissible surface unevenness in the longitudinal direction

Roads with an unbound wearing course or a wearing course of YG (surface dressing on a gravel base), as well as pedestrian and cycle roads, shall be designed and constructed so that the requirements concerning surface regularity according to Table 5.2 are complied with when the road is newly constructed and open to traffic. Surface evenness is to be measured with a 3 m straightedge; see figure 5.1.

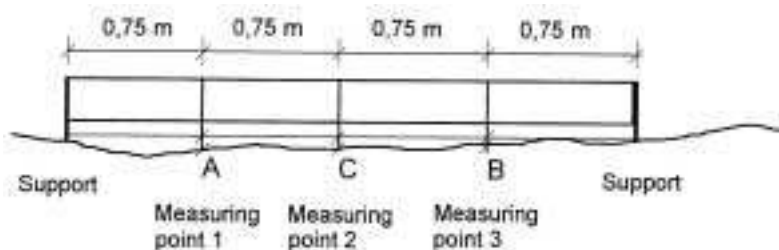


Figure 5.1 Schematic use of 3 m straightedge (ROAD 94, 1996).

Table 5.2 Requirements for longitudinal surface evenness, measured with a 3 m straightedge at the time when the road is opened to traffic, for carriageways on roads with a wearing course of YG or with an unbound wearing course.

| | |
|---|--|
| Section to be checked | Road section 300 m long or traffic lane 600 m long. Section to be selected for investigation with a selection randomness of $\frac{1}{2}$; see VVMB 908 |
| Random sample | $n = 15$, check points to be selected in longitudinal and transverse directions within the check section by the selection model process described in VVMB 107 and VVMB 908 |
| Measurement procedure | 3 m straightedge with 3 measuring points, see figure 5.1. Measurement to be in accordance with VVMB 107 |
| Measurement variables | Deviation (mm) from standard level of straightedge at each measuring point (1, 2, 3) of the straightedge |
| Criterion variables | At each check point: A: Deviation from standard level of straightedge at measuring point 1 B: Deviation from standard level of straightedge at measuring point 3 C: Deviation from standard level of straightedge at measuring point 2 Difference A-C and B-C Total: Proportion of check points with acceptable values of all criterion variables. |
| Acceptance interval, unbound wearing course | At each check point: A and B C A-C, B-C ≤ 5 ≤ 8 ≤ 6 Total: Number of acceptable check points shall be at least 12 out of 15 |

5.1.1.4 Requirements concerning crossfall

The typical value of crossfall shall be not less than 3% for a carriageway with a wearing course of gravel, oil gravel or single course surface dressing of type YG.

The carriageway shall be constructed so that crossfall is not unacceptably different from the specified typical value. The permissible deviation from crossfall, for roads with a wearing course of YG or with an unbound wearing course, shall

comply with the requirement for Crossfall Class No 1 at the time traffic is admitted as set out in table 1.3.9 in ROAD 94. The acceptance interval at the time traffic is admitted is: standard deviation $s \leq 0.45$ and arithmetic mean x within the range $0 \pm (0.55-0.46s)$.

5.1.1.5 Requirements concerning permissible frost heave

Gravel roads and roads with a wearing course of YG should be designed so that frost heave during a mean winter does not exceed 160 mm. Transition zones between road sections with different values of frost heave shall be designed and constructed in such a way that the surface evenness requirements set out in table 5.2 are satisfied for a 10 year winter.

5.1.2 Requirements in Chapter 3 of ROAD 94

In Chapter 3 of ROAD 94, "Pavement Design", gravel roads are classified as roads with a flexible pavement. From the top down, the construction comprises:

- Gravel wearing course
- Unbound base course
- Sub-base and protection course, if any

Design with respect to bearing capacity shall be regulated by varying the thickness of the sub-base, and design with respect to frost heave shall be regulated using a protection course or sub-base.

The pavement shall be designed so that the vertical compressive strain in the formation does not, during any climatic period, exceed the values in table 5.2. A gravel wearing course shall not be included in the calculation of strains and stresses.

Table 5.3 *Maximum permissible vertical compressive strain in the formation for a gravel pavement (ROAD 94, 1996, table 3.3-2).*

| Climatic zone | 1 | 2 | 3 | 4 | 5 | 6 |
|---------------|--------|--------|--------|--------|--------|--------|
| Strain | 0.0090 | 0.0085 | 0.0080 | 0.0075 | 0.0070 | 0.0065 |

Gravel wearing courses used in gravel roads shall be 50 mm thick. The total thickness of the pavement is specified in figure 5.2 and table 5.4.

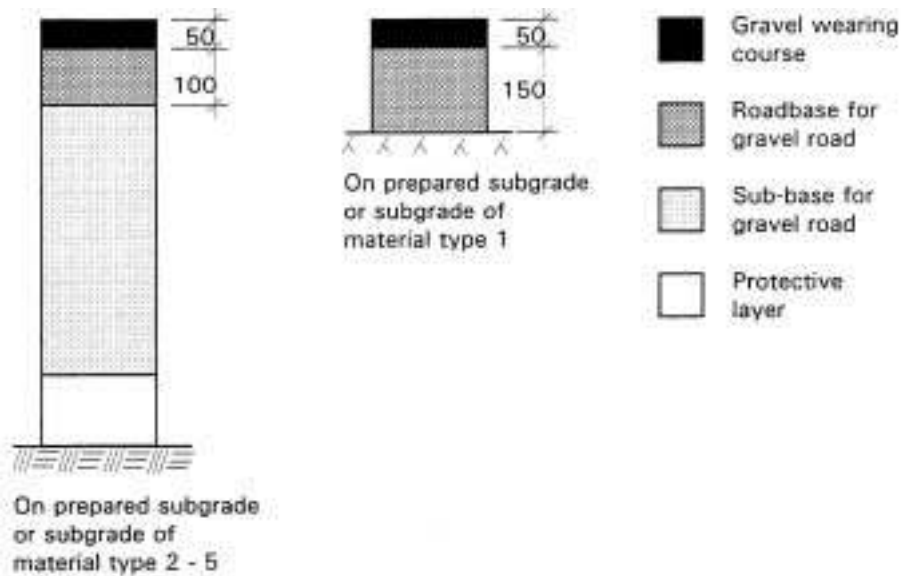


Figure 5.2 Structure of gravel pavement, dimensions in mm (ROAD 94, 1996).

Table 5.4 Gravel pavement, mm (ROAD 94, 1996).

| Total pavement thickness on formation of material of following types | Climatic zone | | | | | |
|--|---------------|-----|-----|-----|-----|-----|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 200 | 200 | 200 | 200 | 200 | 200 |
| 2 | 300 | 300 | 300 | 300 | 300 | 300 |
| 3 | 350 | 350 | 350 | 400 | 400 | 400 |
| 4 | 500 | 500 | 500 | 550 | 550 | 550 |
| 5 | 500 | 500 | 550 | 600 | 600 | 600 |

5.1.3 Requirements in Chapter 5 of ROAD 94

In Chapter 5, "Unbound Pavement Layers", requirements are set out for materials and for the construction of gravel wearing course, base course, sub-base and protection course if any.

5.1.3.1 Requirements for gravel wearing course

ROAD 94 specifies requirements for the gravel wearing course material and for the construction of the gravel wearing course.

Requirements for gravel wearing course material

The material for a gravel wearing course shall have a ball-mill value of 9-30. Organic content shall not exceed 2% by weight. The particle size distribution for a gravel wearing course shall comply with the requirements set out in table 5.5 and figure 5.3. The content (0.002/0.075) shall be 10-30% by weight. The proportion of uncrushed material >8 mm shall be <50% by weight.

Table 5.5 Gravel wearing course, requirement for particle size distribution (ROAD 94, 1996).

| Sieve mm | 0.063* | 0.075 | 0.25 | 1.0 | 4.0 | 8.0 | 16 | 22.4 | 31.5 |
|----------|--------|-------|------|-----|-----|-----|----|------|------|
| Max % | (15) | 16 | 23 | 34 | 57 | 77 | 99 | - | - |
| Min % | (10) | 10 | 13 | 20 | 35 | 55 | 85 | 98 | 100 |

*Sieve 0.063 and its values are alternatives to sieve 0.075 mm

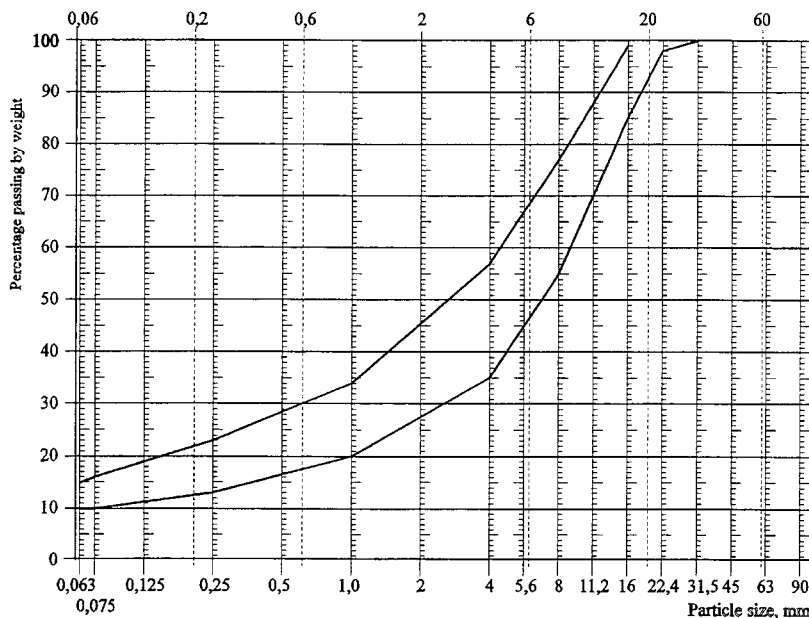


Figure 5.3 Gravel wearing course, requirement for particle size distribution (ROAD 94, 1996).

Requirements for construction of gravel wearing course

The material shall be spread and handled in such a way that a homogeneous layer is obtained.

Dust control of the gravel wearing course is performed using calcium chloride, emulsion or a product with at least equal effect. The quantity of calcium chloride shall be not less than 0.5 kg/m^2 . The particle size distribution in accordance with ROAD 94 is designed for calcium chloride only. The particle size distribution of the gravel wearing course may therefore have to be adjusted when products other than calcium chloride are used in dust control.

ROAD 94 recommends that the gravel wearing course should be compacted. The roller shall have a static line load not less than 15 kN/m . ROAD 94 also recommends that at least two passes should be applied.

5.1.3.2 Requirements for base course

ROAD 94 specifies requirements for base course material both as delivered and deposited on the road, and for its spreading and compaction.

Requirements for base course material

The composition of the base course for gravel roads shall be such that it complies with the requirements concerning both bearing capacity and moisture retention

properties. The best results are obtained if the material is produced from moraine (till) or a mixture of moraine and crushed rock. The content (0.002/0.075) should be 10-30% by weight. Organic content shall not exceed 2% by weight. Ball-mill value ≤ 30 .

ROAD 94 specifies requirements for the particle size distribution and proportion of uncrushed material for base courses.

The particle size distribution of material deposited on the road shall comply with the requirements in table 5.6 and figure 5.4. The maximum stone size shall not exceed half the course thickness. The proportion of uncrushed material >16 mm shall be $<50\%$ by weight.

When dust control of gravel wearing courses is performed using emulsion, base courses for paved roads in accordance with Subclause 5.5.1 of ROAD 94 should be used instead of the base course specified in this Subclause. If this decision is made, dust control using calcium chloride is no longer suitable.

Table 5.6 Base course for gravel roads, requirement for particle size distribution (ROAD 94, 1996).

| Sieve mm | 0.063* | 0.075 | 0.25 | 1.0 | 4.0 | 16 | 22.4 | 31.5 | 45 |
|----------|--------|-------|------|-----|-----|----|------|------|----|
| Max % | (11) | 12 | 17 | 29 | 49 | 82 | 99 | - | - |
| Min % | (6) | 6 | 8 | 14 | 24 | 46 | 57 | 68 | 98 |

*Sieve 0.063 and its values are alternatives to sieve 0.075 mm

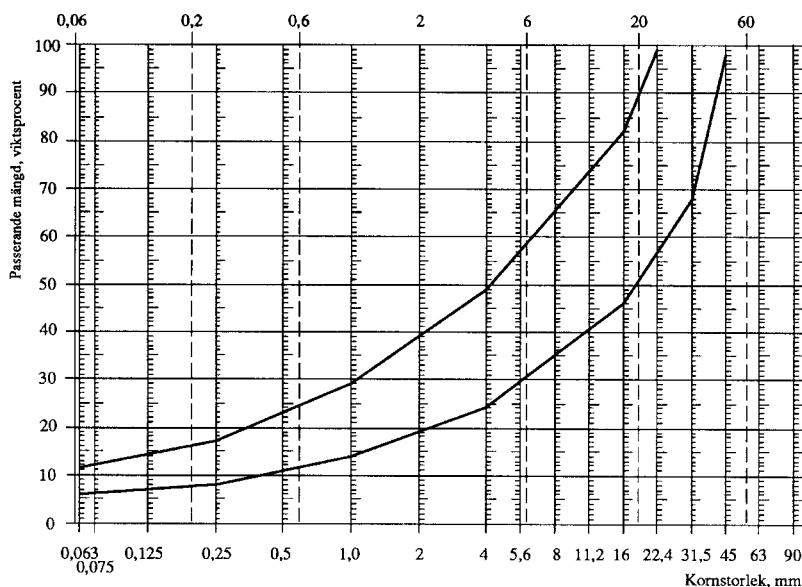


Figure 5.4 Base course for gravel roads, requirement for particle size distribution (ROAD 94, 1996).

Requirements for spreading and compaction of base course material

According to ROAD 94, the base course material shall be spread and handled in such a way that a homogeneous layer is obtained. In order to reduce the risk of segregation and unevenness, the material may be deposited with a spreader.

The material shall not be frozen when compacted. The base course shall be compacted with a vibratory or oscillating single wheel roller with at least 15-30 kN/m line load and constant speed within the range 2.5-4.0 km/m. If a compaction meter with documentation is used, at least 4 passes shall be applied. Surfaces where the bearing capacity increases are to be further compacted. If there is no compaction meter, at least 6 passes shall be applied. Compaction should be carried out at a low amplitude to reduce the risk of crushing the material. The results of compaction will be best if the water ratio is near the optimum.

5.1.3.3 Requirements for the sub-base

The composition of the sub-base for a gravel road shall be such as to satisfy the requirements for both bearing capacity and moisture retention properties. The best results are achieved if the material is produced from moraine (till) or a mixture of moraine and crushed rock. ROAD 94 specifies requirements for sub-base material as delivered and spread on the road. There are also requirements for workmanship and compaction.

Requirements for sub-base material

When delivered, the ball-mill value of the material shall not exceed 30. The (0.002/0.075) content should be 10-30% by weight. Organic content shall not exceed 2% by weight.

The particle size distribution of the spread sub-base shall comply with the requirements in table 5.7 and figure 5.5. The maximum stone size shall not exceed half the thickness of the layer.

If test results are within but very near one of the limiting curves, sampling frequency should be increased.

When dust control of the gravel wearing course is performed using emulsion, a sub-base for paved roads, in accordance with subclause 5.5.1 of ROAD 94, "Requirements for flexible constructions", should be used instead of the sub-base described in this subclause. If this is decided on, dust control with calcium chloride is thereafter inappropriate.

Table 5.7 *Sub-base for gravel roads, requirement for particle size distribution (ROAD 94, 1996).*

| Sieve mm | 0.063* | 0.075 | 0.25 | 1.0 | 4.0 | 16 | 31.52 | 90 |
|----------|--------|-------|------|-----|-----|----|-------|----|
| Max % | (11) | 12 | 17 | 29 | 49 | 82 | 99 | - |
| Min % | (6) | 6 | 8 | 14 | 24 | 46 | 60 | 98 |

*Sieve 0.063 and its values are alternatives to sieve 0.075 mm

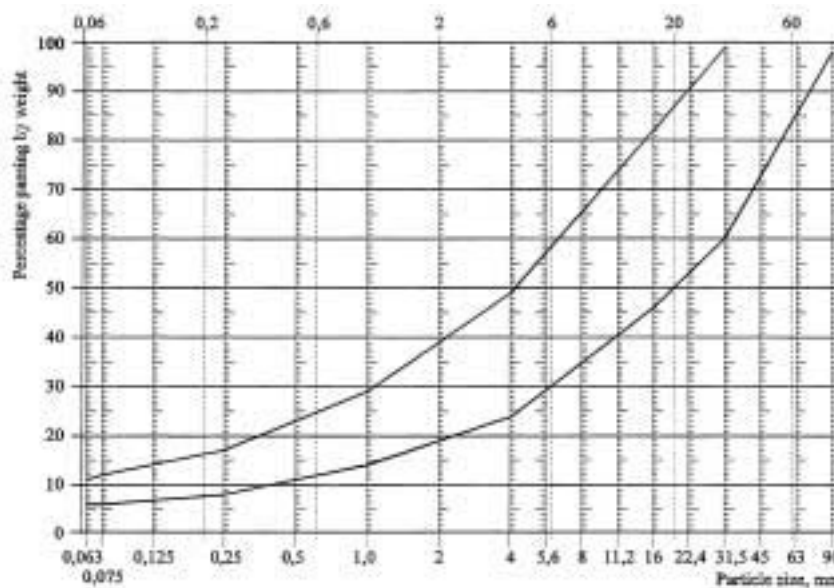


Figure 5.5 *Sub-base for gravel roads, requirement for particle size distribution (ROAD 94, 1996).*

Requirements for spreading of sub-base material

The material shall be spread and handled in such a way that a homogeneous layer is obtained. If necessary, hungry patches shall be sealed and the sub-base adjusted using base course material according to subclause 5.5.1 of ROAD 94.

ROAD 94 specifies that the material shall not be frozen when compacted. The sub-base shall be compacted with a vibratory or oscillating single wheel roller according to Table 5.8 or with a similar compaction equipment. The roller shall move at a constant speed within the range 2.5-4.0 km/m. When a compaction meter with documentation is used, at least 4 passes shall be applied. Surfaces where the bearing capacity increases are to be further compacted. If there is no compaction meter, at least 8 passes shall be applied; see table 5.8.

Table 5.8 *Maximum thickness of layer when compacted with rollers of different line loads (ROAD 94).*

| Line load kN/m | Maximum layer thickness, m |
|----------------|----------------------------|
| 15 | 0.2 |
| 25 | 0.3 |
| 30 | 0.4 |
| 45 | 0.6 |

ROAD 94 adds that table 5.8 sets out the least compaction effort which is shown by experience to achieve the necessary compaction of friction material when its water ratio is near the optimum.

5.1.3.4 Requirements for protection course

ROAD 94 specifies requirements for protection course material both as delivered and deposited on the road, and for its spreading. The composition of the protection course for gravel roads should be such that the moisture retention properties are maintained. The protection course shall consist of non-frost susceptible friction soil in which either the (0.075/16) content is below 12% by

weight or capillarity is below 1 m. Alternatively, the particle size distribution shall comply with the requirements for the sub-base as in table 5.7 and figure 5.5. Organic content shall not exceed 2% by weight on delivery.

Requirements for spreading of protection course material

The material shall be spread and handled in such a way that a homogeneous layer is obtained. ROAD 94 permits a protection course of less than 0.5m thickness to be compacted together with the sub-base.

5.2 Technical requirements for the operation and maintenance of Swedish gravel roads

The requirements of the National Swedish Road Administration for the operation and maintenance of the three standard classes A, B and C are laid down in "Regulations for Maintenance and Operation, 1990. Performance and Standard Specifications, "FSB" (1998), in Swedish, lay down requirements for the operation and maintenance of gravel roads. The material for the wearing course and execution and control of spreading shall comply with the requirements in ROAD 94. It is worth noting that the requirements for gravel roads vary to some extent between regions.

5.2.1 Requirements for the three standard classes

The requirements in Regulations for Maintenance and Operation for the three standard classes are as follows:

5.2.1.1 Standard Class A ($AADT_t \geq 125$)

Surface evenness and binding ability should be such that they satisfy the requirements for at least Condition Class 2, Swedish National Road Administration Method Specification 106, "Assessment of Gravel Roads". Conditions according to Condition Class 3 may occur, but for not more than 3 consecutive working days. Condition classes are described in Chapter 8.

5.2.1.2 Standard Class B ($50 \leq AADT_t \leq 124$)

Surface evenness and binding ability should be such that they satisfy the requirements for at least Condition Class 2, Swedish National Road Administration Method Specification 106, "Assessment of Gravel Roads". Conditions according to Condition Class 3 may occur, but for not more than 7 consecutive working days.

5.2.1.3 Standard Class C ($AADT_t < 50$)

Surface evenness and binding ability should be such that they satisfy the requirements for at least Condition Class 2, Swedish National Road Administration Method Specification 106, "Assessment of Gravel Roads". Binding ability according to Condition Class 3 may occur on road sections where there is no building development along the road. In other respects also, conditions according to Condition Class 3 may occur, but for not more than 7 consecutive working days. Building development along the road is defined as an area where there are 6 dwellings/buildings within 500 m along the road. The distance between a dwelling/building and the edge of the road shall be less than 100 m.

5.2.2 Other requirements for operation and maintenance

Other requirements which will be described are requirements for surface evenness and binding ability, Trafficability and continuity, crossfall, least acceptable condition class, drainage, slopes, friction, quality of wearing course, freedom from obstacles, diversion of traffic and requirements for special conditions. The following performance and standard specifications relate to requirements laid down in the basic operation package for different regions (FSB, 1998).

5.2.2.1 Surface evenness and binding ability

A road shall be so firm and cohesive and shall have such surface regularity that permitted vehicles can pass along the road in safety. Binding ability shall be such that the surroundings are not exposed to dust to a substantial degree. Dust clouds may occur along roads with little traffic where there is no building development (Regulations for Maintenance and Operation, 1990).

5.2.2.2 Trafficability and continuity

Unless there are special restrictions, the road shall be traffickable by vehicles that are normally permitted on the road network in question.

Roads shall be traffickable by vehicles of at least 4 tonnes gross weight over the whole year. In conjunction with frost damage restrictions, uniform limits shall be applied regarding permissible loading. These limits shall be chosen so that it is possible for unloaded heavy vehicle combinations to pass along roads with frost damage restrictions. Suitable limitation of permissible loading varies between regions and is 10-12 tonnes gross weight (FSB, 1998).

FSB states that during frost, prolonged rain or for some other reason restrictions may be imposed on traffic after consultations with the road management authority. Restrictions shall be imposed when damage has occurred after heavy traffic and to prevent further damage. The contractor assesses when a restriction shall be imposed and cancelled. The decision is made by the road management authority. The contractor is responsible for traffic sign and keeping records. In establishing a road management standard the need for continuity shall be borne in mind. Restrictions shall be imposed and cancelled without delay in accordance with the road management authority's decision.

5.2.2.3 Crossfall

Camber should not be less than 2%, with the exception of transitional sections between camber and superelevation. Superelevation should not exceed 5.5%. For transitional sections adjoining superelevation and maximum values of crossfall/superelevation, the recommendations in "TV 124 E, Standard Specifications for Geometric Design of Rural Roads" (FSB, 1998) apply.

5.2.2.4 Least acceptable condition class

The carriageway of a gravel road shall comply with Condition Class 2 in accordance with Swedish National Road Administration Method Specification No 106:1996 "Assessment of Gravel Roads", i.e. the road shall:

- To a substantial degree, have the necessary crossfall.
- Have no potholes or surface unevenness. Exceptions may occur over shorter distances.
- Have an even surface and be firm. Loose aggregate may occur over shorter distances.
- Be so cohesive that only small dust clouds are raised by traffic.

The road shall be in the above condition during periods when there is no frost (FSB, 1998).

5.2.2.5 Drainage

Ditches, spaces below handrails, culverts, surface water and drainage pipes with gulleys and manholes, and road culverts shall be kept open so that drainage is secured. Missing gully and manhole covers shall be replaced and damaged ones repaired without delay. Ponding of water on the road surface because of obstacles outside the edge of the road shall be prevented (FSB, 1998).

5.2.2.6 Slopes

Inner slopes shall have an inclination of 1:2 or flatter and outer slopes 1:2 or flatter, and the bottom of the ditch shall be at least 0.7 m below the carriageway. Slopes shall have no erosion channels deeper than 0.2 m and wider than 0.3 m. Slopes shall retain their stability. Spoil from ditching and edge trimming shall be removed (FSB, 1998).

5.2.2.7 Friction

According to Operation 96, the road shall not be slippery, except during periods with winter road conditions. Spills of clay, stones and similar shall not occur on the carriageway (FSB, 1998).

5.2.2.8 Quality of wearing course

During the contract period the quality of the gravel wearing course shall be maintained or improved. Grading shall therefore be carried out with care so that the gravel wearing course material is not crushed unnecessarily (FSB, 1998).

5.2.2.9 Freedom from obstacles

The carriageway shall be free from physical obstacles of such size or extent that traffic safety or Trafficability is reduced. Examples of physical obstacles are abandoned vehicles, stones, trees felled by storm, pieces of tyres, remains of animals, flooding etc (FSB, 1998).

5.2.2.10 Diversion of traffic

Where an obstacle is estimated to cause closure of the whole carriageway for more than 2 hours, work on providing a diversion shall commence without delay (FSB, 1998).

Subclauses 5.2.2.9 and 5.2.2.10 also apply for paved roads and are not specifically intended for gravel roads.

5.2.2.11 Special conditions

Consideration shall be given to special conditions which necessitate a higher or lower road management standard. Examples of such special conditions are large variations in public transport and other utility traffic (FSB, 1998).

6

Factors which influence the operation and maintenance of gravel roads

The scope, frequency and cost of maintenance measures are influenced by road standard, traffic dependent factors, geometric factors and physical factors. The traffic dependent factors are traffic flow, traffic composition, proportion of heavy traffic and vehicle speed. The geometric factors dealt with in this chapter are road width, crossfall and the longitudinal and transverse profile of the road. Examples of physical factors are the composition, especially petrographical composition, of the wearing course, particle shape and particle size distribution. Other physical factors are the frost susceptibility and drainage conditions of the subgrade and road structure, the type of landscape, the surroundings of the road, the appearance of the terrain and building development. The meteorological factors which are briefly discussed are precipitation of different forms, the number of sunshine hours, the length of the period when the road is free from snow and ice, and humidity.

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6.1 Road standard

Owing to the requirements for the three standard classes A, B and C with regard to surface roughness and binding ability, a high road standard naturally demands that maintenance measures are carried out at greater frequency. A high road standard also necessitates more comprehensive maintenance and thus higher expenditure.

The condition in which total costs, i.e. road management costs and traffic costs, are the least is called optimum condition.

Bäckman et al (1998) quotes Lange (1996) and supplies a diagram with a curve for optimum standard which shows how road management costs increase for a higher road standard while the costs of traffic decrease for a higher standard. See figure 6.1.

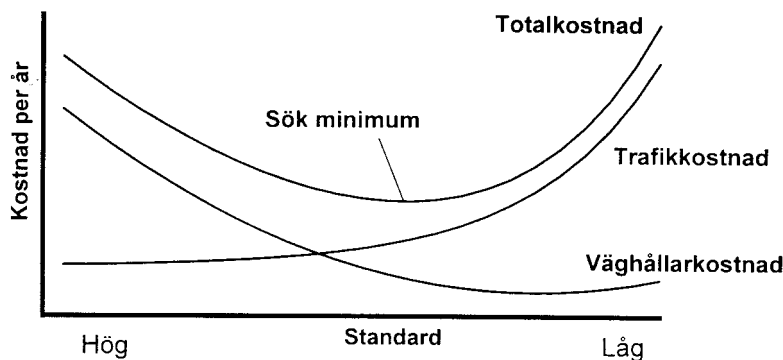


Figure 6.1 Principle of optimum condition and relationship between costs and road standard (Bäckman et al., 1998).

Vertical axis-Annual cost

Horizontal axis-Standard

Totalkostnad=Total cost

Sök minimum=Find minimum

Trafikkostnad=Traffic cost

Väghållarkostnad=Road management cost

Hög=High

Låg=Low

6.2 Traffic dependent factors

Traffic is considered to be highly significant regarding the scope of maintenance work. It is mainly the magnitude of traffic volume but also its composition that is regarded important (Isemo and Johansson, 1976).

Traffic dependent factors are traffic volume, composition of traffic, proportion of heavy traffic and vehicle speed.

6.2.1 Traffic volume AADT

Dobson and Postill (1983) quote Bauman and Betz (1980) and confirm that operation and maintenance costs for e.g. gravel roads increase as AADT and road width increase.

Isemo and Johansson (1976) state that it is obvious that traffic flow influences the scope of maintenance work. The higher the traffic flow, the greater is wear and removal of material.

Bergfalk and Åkeson (1969) quote a Swedish investigation which examined the costs on 80 gravel road sections in six counties over the period 1953-1956. Separate diagrams showing the relationship between traffic flow and resources expended were drawn for each activity, regravelling, grading, dust control, watering, patching and clay spreading. The costs of these (SEK/m) were then calculated and plotted in a total cost diagram. See figure 6.2.

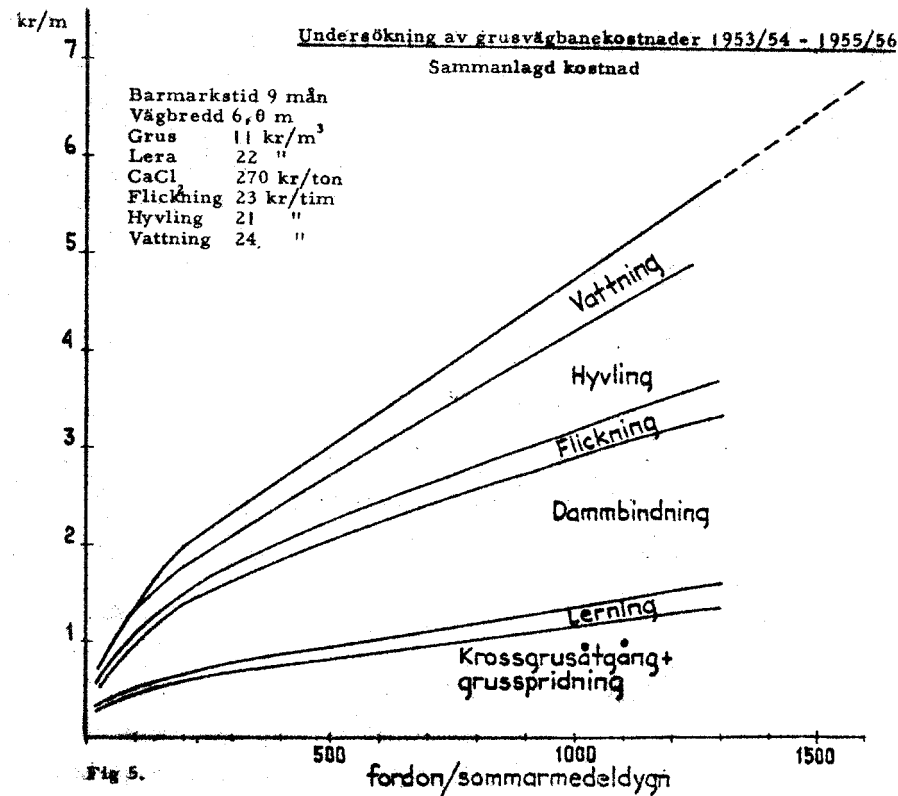


Figure 6.2 Relationship between number of vehicles and the costs (SEK/m) of different operation and maintenance measures (Bergfalk and Åkeson, 1969).

Vertical axis- SEK/m

Horizontal axes-vehicles/mean summer day

Undersökning av grusvägbanekostnader 1953/54-1955/56, Sammanlagd kostnad = Investigation of gravel road costs, 1953/54-1955/56, Aggregate costs

Barmarkstid=Snow & ice free period 9 months

Vägbredd= Road width

Grus=gravel

Lera=Clay

Flickning=Patching

Hyvling=Grading

Vattning=Watering

Dammbindning=Dust control

Lerning=Clay spreading

Grusspridning=Regravelling

Over the period 1966-1969, Bergfalk and Åkeson (1969) themselves carried out an investigation on 20 gravel roads to study the relationship between traffic mileage and costs. The other results of this work are given in the form of curves in a series of diagrams for regravelling, patching, dust control, grading, snow clearance and skid prevention measures. The general arrangement of these diagrams is shown in figure 6.3. Service work and actual maintenance, which are named in the figure, are defined in Chapter 2.

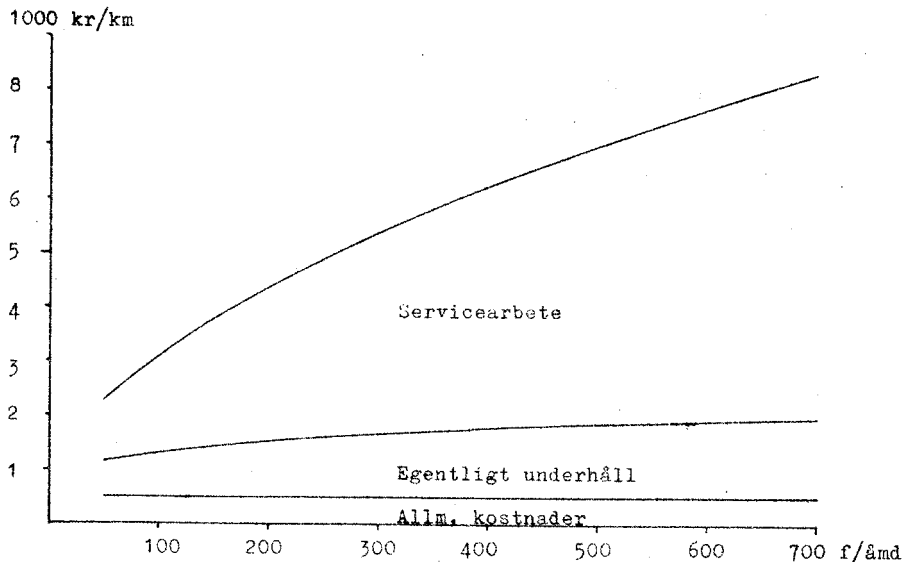


Figure 6.3 Maintenance costs for gravel roads.

Vertical axis- SEK 1000/m

Horizontal axis- Vehicles/annual mean day

Servicearbete=Service work

Egentlig underhåll=Actual maintenance

Allm. kostnader=General costs

The curves for regravelling, patching, grading and dust control are in relatively good agreement with the results of the previous investigation in six counties over the period 1953-1956 (Bergfalk and Åkeson, 1969).

In Data for Management Planning (1983), in Swedish, it is stated that changes in quality were monitored in 1980 on three gravel roads in Kalmar County. It was found that, on average, maintenance was carried out on these roads after ca 7500 vehicle passages.

6.2.2 Traffic composition

Not only the magnitude of traffic flow but also its composition is considered to influence the scope of management measures. An increasing proportion of heavy traffic produces greater wear (Isemo and Johansson, 1976).

Höbeda (1978) quotes Marten (1957) and states that cars travelling at 80 km/h do not give rise to corrugations even after many passages; aggregate is rather thrown to the sides of the road. On the other hand, lorries can cause serious corrugation after only 100 passages. Buses can also give rise to corrugation if their suspension systems are substandard.

The type of transport is also significant, and also if it is concentrated over a period. For instance, extensive timber lorry traffic during the thaw period can be devastating for a gravel road (Isemo and Johansson, 1976).

6.2.3 Vehicle speed

Lindh (1981) establishes that the quantity of emitted dust varies exponentially with vehicle speed. Guidelines for cost effective use and application of dust palliatives "GDP" (1987) gives figures of annual loss of aggregate at different speeds. Figure 6.4 is constructed on the basis of the literature studied by those involved in the report GDP (1987).

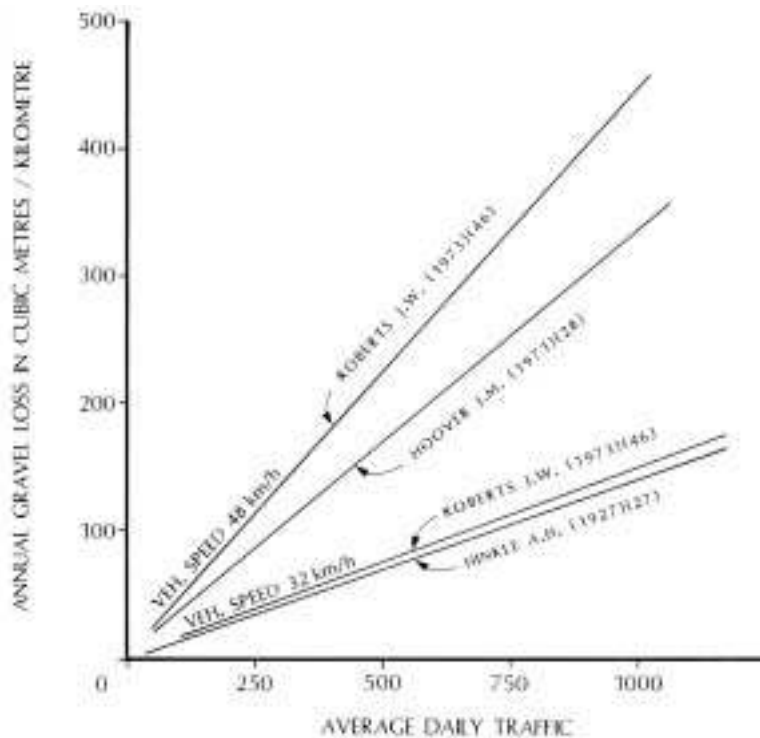


Figure 6.4 Estimated annual loss of aggregate at different speeds (GDP, 1987).

6.3 Geometric factors

The geometric factors discussed here are width of road and alignment and profile of the road.

6.3.1 Width of road

Isemo and Johansson (1976) state that a wider road normally requires greater use of resources in the form of applied material and similar. At the same time there is some equalisation of the effect of traffic, since traffic on a narrower road must keep to a smaller area, which results in a more trackbound traffic.

On narrow roads, a lot of plant cannot be used for maintenance. Bergström and Grebacken (1995) give an example of how road geometry influences maintenance work. If the road is narrow and the wearing course extremely thin, a windrow spreader cannot be used for final adjustment of camber and superelevation.

6.3.2 Alignment and profile of the road

Certain combinations of alignment and profile can increase the need for maintenance. A winding road probably demands more comprehensive maintenance than a level, straighter road. One of the reasons for this is that stresses are higher on curves and that material is therefore dislodged and thrown into the ditches. Furthermore, on a hilly road, the wearing course material can be moved by traffic to low points. On slopes, rainwater can cause erosion of finer material (Isemo and Johansson, 1976).

Bergström and Grebacken (1995) state that potholes are in most cases formed at points of inflexion in the road between superelevation and camber where the road is level and water does not drain.

6.4 Physical factors

The material properties of the wearing course are of particularly great significance for the durability of gravel roads. Material properties are determined by a number of factors such as the composition of the wearing course. Other physical factors are the frost susceptibility of the subgrade and road structure, and drainage conditions.

6.4.1 Composition of the wearing course

The material used in gravel roads can vary with regard to its petrographical (mineralogical and chemical) composition, particle shape and particle size distribution.

6.4.1.1 Petrographical composition (mineralogical and chemical)

While chemical variations in the stone material used for roads play a very important role in most countries, in Sweden they are relatively unimportant. Most of both natural aggregate and crushed rock has a very similar chemical composition.

Together with Finland and parts of Norway, Sweden forms an area in which the rock essentially consists of primary rock. This rock is mainly of granitic composition. Another important factor is that this area was in recent times covered by an ice sheet. Owing to these two interacting factors, natural aggregate and stone material of high strength is available. From the standpoint of gravel road construction, this puts Sweden in a very favourable position in relation to the rest of Europe and most parts of the world.

Nevertheless, there are significant areas in Sweden where the rock is not the normal primary rock or of similar composition, but essentially consists of softer rocks, chiefly limestone, slate and mudstone. Such areas are south west Skåne, Öland and Gotland, the central Swedish slate areas, the Silurian area in Jämtland and the mountain chain (Beskow, 1934).

The quality of the stone material used in the wearing course affects the extent to which the aggregate is crushed by traffic. Abrasion by traffic is of particularly great extent for weak rock components which are quickly broken down. Slate is

easily worn down into a clayey fine material, and where there is an excess of slate a highly water sensitive gravel wearing course results.

Höboda (1978) notes that experience in Sweden and Norway indicates that the coarse material in the wearing course must consist of fragments of strong rocks which are not crushed by the weight of traffic. In his report "Ideal aggregates for wearing courses", Höboda says that rocks such as slate, mudstone and limestone have a lower strength than primary rock material, and should therefore be avoided in gravel roads.

Höboda (1978) quotes Rosenqvist (1943) who specially recommends the use of "basic" rocks. Basic rocks are, as a rule, tough and produce rock flour of better cohesive properties than acidic, quartzitic rocks.

Compared with what is used in Scandinavia, very poor stone material is often used in wearing courses abroad. Ritter (1954) in Höboda (1978) says that local materials such as porous lava, soft and porous limestone, shells, mine waste, topsoil, weathered granite etc are used with varying degrees of success as wearing courses on low traffic roads in the USA. In many cases, however, it appears that such weak materials have been used in climates with low rainfall and no frost problems, which may have alleviated the problems that can otherwise arise.

In his literature study, Höboda (1978) considers that a strong aggregate material sometimes produces a worse gravel layer than material containing weak particles, the probable cause being that in the latter case suitable soil binder is produced by abrasion. A very strong aggregate material of inappropriate particle size distribution is not crushed as easily into a stable, tight distribution with fewer voids as a material containing a "sufficient" quantity of weak particles. Some weak materials are also compacted into tight and stable masses, and the fine material may sometimes even have cementing properties. Höboda therefore considers that a partly weathered material that exhibits cementing properties in the gravel pit may be preferable to unweathered aggregate for the production of gravel wearing courses.

The above does not apply to stone material in surfacings bound with bitumen or cement. Nor should base course gravel change too much in time through abrasion. According to American codes or regulations, a Los Angeles number no greater than 50 (impact value ≈ 70) is recommended in order to prevent excessive abrasion. The strength of material for gravel wearing courses is seldom specified, the probable reason being not to hinder the use of local material sources (Höboda, 1978).

ROAD 94 lays down technical requirements for the material, such as ball-mill value, content of organic matter, particle size distribution and proportion of uncrushed material, for four different courses, wearing course, base course, sub-base and protection course if any. See Chapter 5, "Technical requirements for Swedish gravel roads", in this report.

Dust control agents have some significance for the degradation of certain rocks. Micaceous materials, mainly slate, can be broken down by calcium chloride

which exerts a dispersing effect on micaceous material, thus increasing the fine material content. However, this effect does not appear to have been investigated in detail. Salt should not therefore be applied to gravel wearing courses containing a large amount of micaceous rock, unless there is a shortage of soil binder (Höbeda "Ideal aggregate", 1978).

A high gravel shape index for gravel in the wearing course also appears favourable for the results of dust control, for instance with lignin. Hoover (1973) also points out that the effect of dust control with lignin is improved if the wearing course consists of limestone.

Bergström and Grebacken (1995) point out that on Gotland the gravel material in the wearing course is limestone. Limestone is a weak rock and is broken down every time the road is given maintenance grading, which means that the fines content increases in time and the effect of dust control treatment with bitumen emulsion diminishes. This problem is believed to have been solved by complementing the composition of the wearing course with certain fractions at the time of maintenance grading in order to get as near the ideal aggregate curve as possible.

Höbeda (1978) says that it is rare for particularly suitable materials to be hauled a long distance for gravel roads. For reasons of cost, local supplies must be made use of as far as this is possible.

6.4.1.2 Particle shape

The main significance of particle shape for the wearing course and other layers is that angular particles have higher internal friction than rounded ones. This impedes movement between particles and limits deformation. Crushed rock material is therefore preferable to natural aggregate. In addition, the density of material consisting of irregular particles is higher than that made up of rounded particles. But the smaller the particle size, the smaller is the significance of the difference in particle shape between different materials. Even for the common aggregate sizes, the difference in properties due to the particle shapes of natural aggregate and crushed aggregate has relatively small significance. This applies in particular after aggregate has been subjected to wear in the carriageway for some time, when the edges of crushed aggregate particles have been rounded (Beskow, 1934).

Höbeda (1978) confirms that the shapes of particles in gravel wearing courses are significant for the properties of the wearing course. In the same way as the composition of the material, particle shape is also altered by the action of traffic, especially in the case of weak materials. Particles with sharp edges are rounded off, and flaky particles are broken into more "cubic" shapes. The significance of particle shape depends on the prevailing stress conditions. Under the stress conditions met with in a road construction, sharp edged particles are generally advantageous. Höbeda points out that the particle shape of the fine material may also have a great influence in base courses and wearing courses, but this does not appear to have been investigated so far.

6.4.1.3 Particle size distribution

Gravel wearing courses must have a special particle size distribution. Wearing courses consist of particles of different sizes. The maximum size of aggregate in a wearing course must not exceed 20 mm.

For a wearing course, it is desirable for the particle size distribution to be such that the layer has the least possible number of voids. It is to be noted that in normal gravel road maintenance it has been found difficult to achieve homogeneous mixes, although laboratory tests assume that this is the case (Höbeda, 1978).

Particle size distribution affects bulk density and voids ratio, which, in their turn, influence both the elastic and plastic properties (Lekarp, 1995). The general consensus is that bulk density and voids ratio have a great influence on the elastic properties of unbound granular materials.

In essence, the wearing course must satisfy two requirements, full bearing capacity when saturated and a particle size distribution at the surface which provides the greatest possible cohesion in dry weather and also permits mechanical levelling of the surface in the form of grading (Beskow, 1934).

What the particle size distribution of the wearing course gravel should be and what requirements this distribution should satisfy will be described under the following seven headings:

- Bearing capacity
- Abrasion resistance
- Combination of bearing capacity and abrasion resistance
- Fine material
- Properties of soil binder
- Changes in the original particle size distribution
- Relationship between particle size distribution and maintenance costs

- **Bearing capacity**

The bearing capacity of gravel roads is of particular importance when they are saturated. In this context, bearing capacity refers to the resistance of the wearing course to pressure, which is primarily dependent on the particle size distribution, degree of compaction and water ratio of the wearing course.

Beskow (1934) says that stress is highest on the surface of the road, immediately below the contact area of the wheel, and decreases with depth owing to dispersion of pressure. Deformations are normally localised at the surface. The fact that softening by rain or snowmelt begins and is greatest at the surface is a contributory factor to this.

According to Beskow, figure 6.5 shows what the limiting curves are for a wearing course gravel of good bearing capacity properties. He points out however that the positions of these curves may vary slightly depending on the maximum particle size of the material. The larger this is, the greater the fines content that can be allowed, and vice versa.

The limiting curve can be rotated about a certain point, and its slope in each case depends on the initial particle size. Figure 6.5 shows the extreme positions that the bearing capacity limits can normally assume. The full line is primarily applicable for the wearing course.

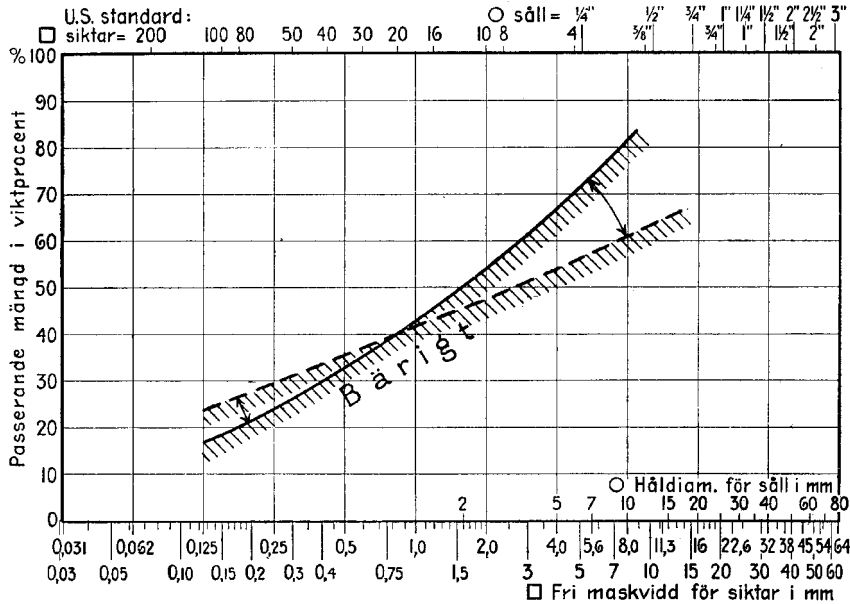


Figure 6.5 Limiting curves for carriageway composition of acceptable bearing capacity.

Vertical axis- Percentage by weight passing

Horizontal axis- Håldiam. för säll i mm=Hole dia of screen in mm

Fri maskvidd för siktar i mm=Clear aperture of sieve in mm

Bärligt=acceptable bearing capacity

The limiting curve for acceptable bearing capacity is drawn in the figure in such a way that compositions of the wearing course gravel below this limit without a doubt have full bearing capacity even in the most severe conditions, i.e. when saturated over a prolonged period and subjected to high traffic load. From this limiting curve towards a composition of greater fines content, bearing capacity in the event of saturation gradually diminishes.

Beskow (1934) summarises the practical conclusions and states that, in view of bearing capacity, the quantity of coarse material in the carriageway should be increased. Material coarser than 4 mm is most effective. In contrast, fine aggregate particles and sand have considerably less effect. It is only when the carriageway contains a lot of clay that a small addition of fine aggregate and sand, together with the coarse material, may be necessary.

• **Abrasion resistance**

Beskow (1934) is of the opinion that the requirements which a carriageway should satisfy from this standpoint are freedom from dust and surface regularity.

Freedom from dust can be achieved by ensuring that the road contains no particles of a size such that they form dust, or by keeping these particles bound so that they cannot be dislodged by traffic.

Beskow (1940) summarises the practical conclusions and says that for most roads, and especially those carrying the most traffic, it is not bearing capacity but resistance to corrugation that is critical. It is worth noting that today's traffic is entirely different from that in 1940, for instance lorries are much heavier.

- **Combination of bearing capacity and abrasion resistance**

One result of Beskow's investigations was the production of an ideal aggregate zone. Beskow (1934) states that the range of variation for a carriageway of acceptable bearing capacity in the event of saturation, and that for a firm, cohesive and corrugation resistant carriageway, have quite different positions. They can however overlap to a certain extent so that there is a common zone where the particle size distribution satisfies both the requirement for full bearing capacity in the event of saturation and the requirement for a carriageway of good binding ability and resistance to corrugation.

According to Beskow, the aggregate whose particle size distribution curve is inside this zone may be denoted the ideal road aggregate or the "universal" aggregate. According to Beskow (1934), the **ideal aggregate zone** is the common zone between the upper boundary for material of good bearing capacity and the lower boundary for cohesive material. See figure 6.7.

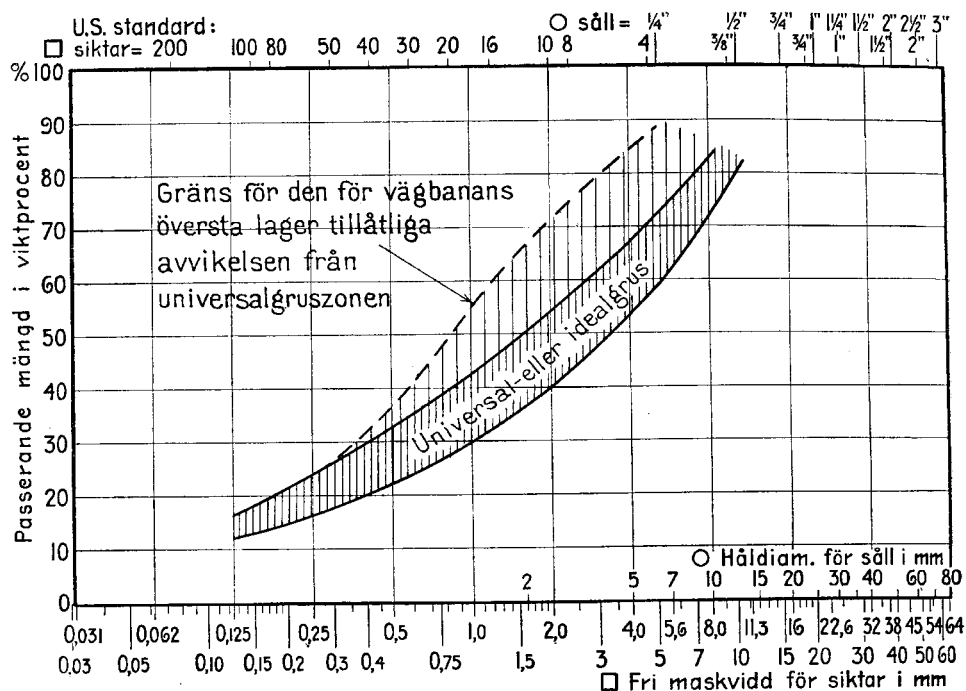


Figure 6.7 The ideal road aggregate or "universal" aggregate (Beskow, 1934).

Vertical axis- Percentage by weight passing

Horizontal axis-Diameter för säll i mm=Hole dia of screen in mm

Fri maskvidd för siktar i mm=Clear aperture of sieve in mm

Gräns för den för vägbanans översta lager tillåtliga avvikelser från universalgruszonens= Boundary for the permissible deviation of the top layer of the carriageway from the universal aggregate zone

Universal-eller idealgrus=Universal or ideal aggregate

In an "ideal" gravel carriageway there should be ca 60% coarse material, material larger than 4 mm, 25% material between 4 and 0.125 mm, and 15% fine material. Höboda (1978) says that particles somewhat larger than in Swedish "ideal" aggregate are sometimes permitted abroad.

If there is too little coarse material, the wearing course has poor bearing capacity and strength. If there is too much coarse material, the coarse particles do not form a cohesive mass, they are dislodged and thrown out. Nor has the wearing course sufficient cohesion if there is too little fine material since it is the fine material that acts as the binder in the wearing course. The fine material is sometimes referred to as the soil binder. If there is too much fine material in the road, it has not sufficient bearing capacity when wet and road becomes rutted. In summer, however, when there is not too much rain, it may be an advantage to have a slight excess of fines. In such a case, if the wearing course has been given good dust control treatment, it becomes smooth and even as a concrete floor. In the autumn and winter it will however be much worse if coarse material is not added.

If the wearing course contains too much material between 0.125 and 4 mm, i.e. sand, it easily becomes corrugated. The prerequisite for the formation of corrugations is an excess of sand. Even an insignificant excess, a few per cent, may be enough for the wearing course to be susceptible to corrugation. Sand collects in the corrugation ridges, while in open sections rich in stone potholes are formed.

If the wearing course has too high a fines content, dust control with emulsion will not be successful because the emulsion must adhere to a much larger particle surface than if the wearing course has the correct particle size distribution.

Isemo and Johansson (1976) state that gravel roads normally contain too little fine and coarse material, i.e. they often have a considerable excess of sand. In time, excess of sand increases because of crushing, dusting, winter sanding, etc.

The gravel wearing course should not contain too many large stones in order to facilitate maintenance with a grader (Höboda, 1978).

- **Fine material**

Fine material is defined as material passing a 0.075 mm sieve in accordance with Swedish Standards (Lekarp, 1995).

The term fines is also used as a generic term for the silt and clay fractions, i.e. material smaller than 0.063 or 0.075 mm (ROAD 94).

"Guidelines for cost effective use and application of dust palliatives" (1987) contains a figure that shows three different stone materials, one with no fines, one with the right amount of fines, and one with an excess. See figure 6.8.

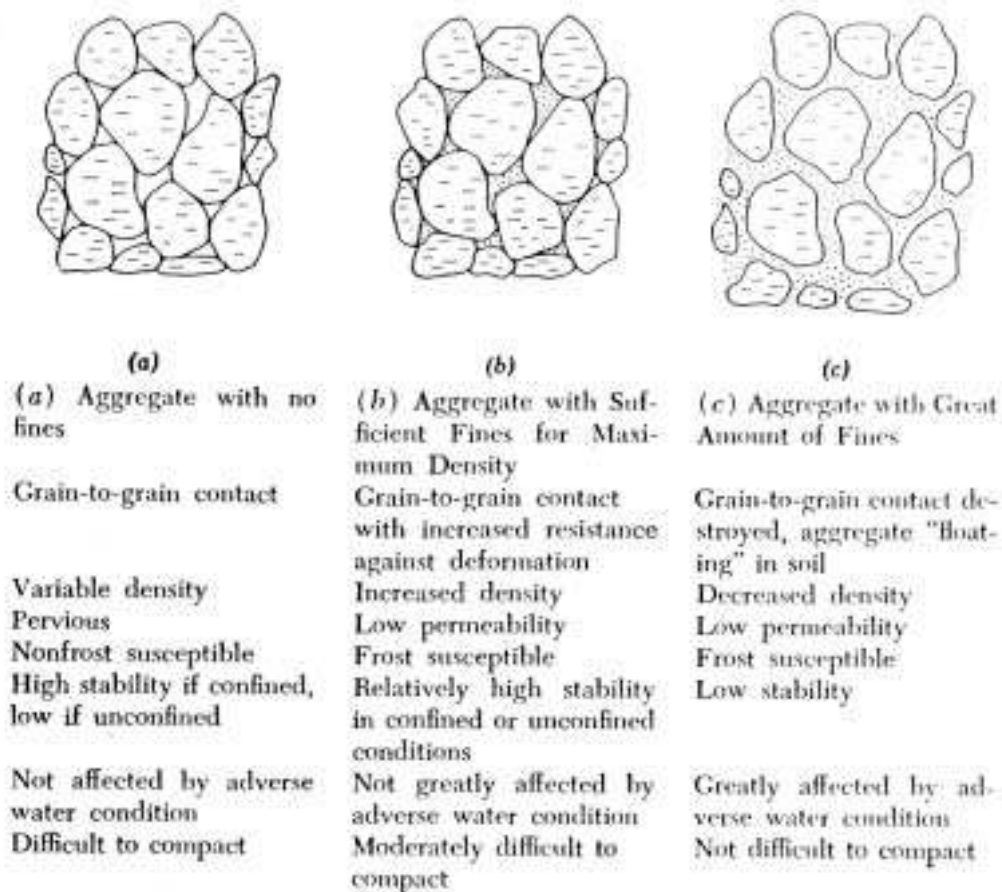


Figure 6.8 Aggregate of different fines contents.

Fines in the wearing course should also have certain plastic properties. If the water ratio after a dry period is too low, the wearing course starts to become brittle and fissured, which leads to increased permeability to water. Particles begin to loosen and to be thrown by traffic to the sides of the road. The soil binder also begins to be lost through dust. On the other hand, if the water ratio is too high, cohesion breaks down in the wearing course and clay begins to act as a lubricant, resulting in bearing capacity problems (Höbeda, 1978).

Lekarp (1995) quotes Barksdale (1972) and says that:

- Well graded fractions have a higher resistance to permanent deformations than homogeneously graded fractions.
- Increasing fines content causes an increase in permanent deformation. See figure 6.9.

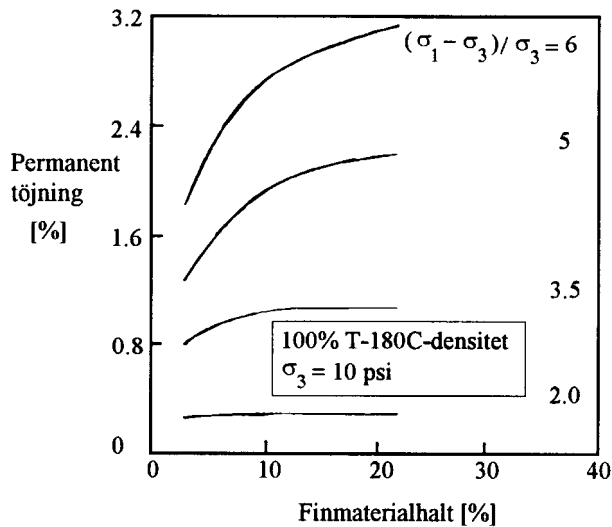


Figure 6.9 Effect of fines content on permanent deformations in base course consisting of crushed gneiss-granite after 10^5 loading cycles (Lekarp, 1995).

Vertical axis- Permanent strain

Horizontal axis-Fines content

100% T-180C-densitet=100% T-180C-density

• Properties of soil binder

There is no clear definition of the term "soil binder". According to AASHTO M 147, soil binder is defined as material passing a 0.425 mm sieve.

Bergström and Grebacken (1995) point out, however, that in gravel road maintenance the 0-0.125 mm fraction is referred to as soil binder since it is this that binds the other particles into a durable carriageway.

The task of soil binder in the wearing course is both to act as a filler and reduce voids, and to give the stone skeleton cohesion, i.e. act as a binder. The breakdown of the gravel wearing course appreciably decreases if there is some cohesion so that the particles are bound mechanically and are not rearranged by the action of traffic. Another task of the soil binder is to seal the wearing course against precipitation and to prevent softening (Höbeda, 1978).

In principle, a material that is added so as to conform to the wearing course aggregate curve is also a soil binder. This implies that the material must contain a certain quantity of clay. This quantity depends on what the original material looks like. In many cases, pure clay is used as soil binder. Höbeda (1978) says that clay is the most common soil binder in gravel carriageways, but its great weakness is its sensitivity to water. The wearing course must be moist, but not saturated, to bind the fines and to keep the clay constituents at the appropriate consistence for good cohesion.

Moraine of high clay content is also suitable as binder in the wearing course, while moraine with a high content of fine sand and silt should be avoided, especially on roads treated with salt or some other binder (Höbeda, 1978).

- **Change in the original composition**

According to Beskow (1934), the original composition of the gravel wearing course changes in time due to the following factors:

- A. Removal of material
- B. Breakdown of existing material
- C. Supply of new material

These three factors are briefly described below.

A. Removal of material

In an unbound wearing course, it is mostly the finest particles that are removed, either in the form of dust or as a suspension in water that drains from the road. The coarsest particles are also removed by the action of traffic. This process tends to result in a preponderance of medium-coarse and sandy material, which causes deterioration of the composition of the wearing course aggregate.

B. Breakdown of existing material

Mechanical breakdown of material mainly occurs through abrasion of the loose aggregate particles by both grading and traffic. Breakdown by traffic mainly occurs in gravel wearing courses which are not bound by high grade binders such as asphalt or cement. Breakdown is accelerated by stress, but also by insufficient compaction, the probable reason being that the particles are rearranged more easily. The composition of a road material can also change owing to frost degradation of certain stone materials (Höbeda, 1978).

According to Beskow (1934), experience shows that, as a rule, mechanical breakdown of the material is not sufficient to compensate for the quantity of fines removed from the road.

C. Addition of new material

The fines content of a road can be increased by the supply of material that takes place when tractors carry soil and other organic material in the form of plant residues on to the road (Beskow, 1934).

Bergström and Grebacken (1995) also point out that on Gotland, on gravel roads adjacent to agricultural land, tractors and other implements that carry clay and soil from the fields on to the road cause problems. The effect is that the fines content of the wearing course gravel becomes excessive. The countermeasure employed is that aggregate of 8-16 mm fraction, at the appropriate rate, is added when the road is graded in order to optimise the particle size curve.

- **Relationship between particle size distribution and maintenance costs**

Eriksson and Henningson (1957) in Höbeda (1978) studied the relationship between the particle size distribution of the wearing course gravel and maintenance costs. The results showed there was a tendency for grading to be reduced as the wearing course gravel studied approached the ideal aggregate curve. The results also indicated a tendency for the quantities of salts needed to be lower as the wearing course gravel approached the ideal aggregate curve.

6.4.2 Frost susceptibility of subgrade and road structure

The material in the subgrade and the road structure is important for the scope of maintenance. A road structure on subgrade containing frost susceptible material, which at the same time has inadequate drainage or is too near the groundwater level, is exposed to much higher stresses than a relatively dry road built on top of a gravel esker. Damage occurs in the form of freezing, softening of the surface during thaw, and erosion by running water (Isemo and Johansson, 1976). Frost damage is dealt with in Chapter 4.

6.4.3 Type of landscape and the surroundings of the road

The surroundings of the road have a great influence on maintenance. A road through a forest region retains its moisture much longer than a road in open country. The surrounding terrain in the immediate vicinity of the road should be studied to gain a measure of the exposure of the road to weather and wind. According to Isemo and Johansson (1976), roads can be classified as open on both sides, open on one side or enclosed.

6.4.4 Buildings

Especially in conjunction with dust control treatment, the number of buildings along the road may be significant, since people living there often demand better dust control (Isemo and Johansson, 1976).

Bergström and Grebacken (1995) state that, on Gotland where dust control using emulsion was tested, the driver of the emulsion spreader applied a little more in front of farms and houses and a little less in on sections through forest.

6.5 Meteorological factors

The climate is a further factor of essential importance. With a slight exaggeration, it can be said that most types of climatic situations have a negative effect on operation and maintenance activities. Meteorological data are usually obtained from the Swedish Meteorological and Hydrological Institute (SMHI) or VViS (Road Weather Information System).

The meteorological factors discussed in the following are precipitation of different forms, the number of sunshine hours, and the length of the period when the road is free from snow and ice, and humidity.

6.5.1 Precipitation of different forms

Too little rain necessitates measures to prevent dusting, too much rain causes erosion and makes the road generally sensitive to the action of traffic (Isemo and Johansson, 1976).

6.5.2 Number of sunshine hours

Bergström and Grebacken (1995) state that, in conjunction with dust control with emulsion on Gotland, a problem that was noted was that on roads running in the east-west direction the carriageway is dried more easily by sun and wind. However, it is not clear why the road treated with emulsion is sensitive to sun and wind. It may possibly be due to the fact that the road in winter is subjected to

freeze-thaw cycles, resulting in degradation of the material or oxidation of the bitumen. Salt that is carried in from the Baltic by the wind, in combination with sun and wind, may reinforce the degrading effect on emulsion. Emulsion treatments on roads on the south coast of Gotland have a shorter life (Bergström and Grebacken, 1995).

6.5.3 Length of period when the road is free from snow and ice

The length of this period determines the length of time over which maintenance measures appropriate to this period must be applied (Isemo and Johansson, 1976). Areas where this period is longer probably have higher maintenance costs. It is however difficult to calculate the effect of this period on the total maintenance cost with any great accuracy, since many other local factors exert an influence.

6.5.4 Humidity

Humidity has an important role for the cohesion of a dry carriageway and also for the drying out of a wet carriageway. Bergström and Grebacken (1995) note that on Gotland emulsion treatment of roads every year begins from the south. This is due to the fact that there are fewer forests in the south and the natural moisture is lost more quickly from roads exposed to wind and not sheltered by trees.

7

Operation and maintenance methods

The methods applied for the operation and maintenance of gravel roads during the time of year when the roads are free from snow and ice are largely the same in most countries. The purpose of operation and maintenance measures is to try to keep the surface of the gravel road dustfree, even, of the correct shape and firm, and thus enhance e.g. driving comfort and traffic safety.

Gravel road maintenance chiefly concentrates on the wearing course. The principal measures comprise dust control, grading, edge trimming and aggregate recycling, regravelling, watering, patching, dragging, ditching and removing stones from the carriageway. The method to be used is governed to a high degree by the damage sustained by the road surface and the road structure.

Operation and maintenance of gravel roads costs SEK 6-10 per metre of road (1997). The cost varies depending on the factors described in detail in Chapter 6, "Factors which influence the operation and maintenance of gravel roads".

Different dust control agents are studied in this chapter. These agents are water, clay, inorganic salts such as calcium chloride CaCl_2 and magnesium chloride MgCl_2 , non-bituminous organic chemicals such as lignin, bituminous binders such as bitumen emulsion, and dust control oil. The time of year, frequency, coverage, workmanship and the environmental impact of dust control with different agents are also studied in this chapter.

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7.1 Dust control

Dust control of gravel roads is expensive. It may account for as much as about 25-30% of maintenance costs during the period when the road is free from snow and ice (Bergström and Grebacken, 1995).

Dust control became necessary when traffic increased in the 1920s. Dusty gravel roads are a serious problem for both road users and those living near the road. A gravel wearing course that contains too little fine material is not cohesive enough, with the result that there is a greater risk of loose aggregate and corrugation of the wearing course. On gravel roads with a large volume of traffic, a lot of money can be saved by keeping the road under constant dust control. Dust control makes it possible for the wearing course material to retain its correct composition for a longer period. The road can remain in a good state longer without being graded and having new aggregate spread on it, and this reduces costs.

Dust control of gravel roads is a measure whose effect does not last long and it may therefore have to be repeated several times a year. The matter of which roads are to be given a permanent surfacing is largely decided by traffic volume.

Han (1992) quotes a report by the Transport Research Board and says that gravel roads with a traffic flow of 15-500 AADT should be dust controlled. According to this report, gravel roads with a traffic flow >500 AADT should be paved. Guidelines for Cost Effective Use and Application of Dust Palliatives (1987) states that it can be economically justifiable to dust control gravel roads with an AADT below 500.

The goal of the Swedish National Road Administration is to pave all roads with traffic exceeding 250 vehicles per day, and to pave for environmental reasons gravel roads where there are buildings along the road and the average traffic is greater than 125 vehicles per day. In 1996 the length of gravel roads with an average traffic greater than 250 vehicles per day was 475 km, and there were 273 km of gravel roads with buildings along the road on which traffic was in excess of 125 vehicles per day (Statistics from SNRA, 1997, in Swedish). In 1996 the total length of State gravel roads was 22,267 km; see table 3.2.

It would appear that the number of times that a road needs dust control every year varies from one to three. According to interviews conducted by Bergström and Grebacken (1995), dust control with salt and lignosulphonates must on average be repeated three times per season. Han (1992) says that a road needs dust control more often than three times when:

- Speed is higher and there is a higher proportion of heavy traffic
- Humidity is lower
- Fines content in the wearing course is below 10%
- The wearing course contains large quantities of loose aggregate

Han (1992) states that previous experience is the best basis for determining when and how often dust control should be carried out.

Dust control in Sweden is performed in the form of a basic treatment in the spring and additional applications during the season (Jämsä, 1983). This applies to dust control with salt and lignosulphonates. During supplementary applications the concentration of the solution must normally be about 50% of that used for the basic treatment. It is sometimes necessary first of all to make minor local dust control applications in open country where the road surface dries out very quickly (Jämsä, 1982).

7.1.1 Different reasons for dust control

Dust control is mainly necessary where there is a large volume of traffic, near built-up areas, near cultivated land and where there is a lot of pedestrian and cycle traffic. Lindh (1981) gives four reasons for dust control:

- Road engineering reasons
- Economic reasons
- Traffic engineering reasons
- Sanitary reasons.

The **road engineering and economic** reasons are that road dust mostly consists of the finest particles of the wearing course. If these are allowed to disappear as dust, the carriageway loses cohesion, becomes unstable and susceptible to corrugation since there is an excess of sand. Persson (1993) says that this necessitates more frequent maintenance in the form of grading or regravelling. Each time the road is graded, some of the aggregate material is crushed. More frequent maintenance results in increased expenditure. The **traffic engineering** reasons are that on a carriageway with good dust control, with a smooth and firm surface and good friction, traffic safety is higher than on an uneven, dusty carriageway with loose aggregate on the surface. Visibility is also improved since there is less dust. A road with good dust control also increases capacity to some extent since speeds are higher (Lindh, 1981). The aim of dust control for **sanitary** reasons is to prevent or alleviate dust pollution of the surroundings. It is mainly carried out in built-up areas, on sections where there are buildings and cultivated areas along the road, and on sections where pedestrian and cycle traffic is of considerable extent (Persson, 1993).

7.1.2 Different types of dust control

No simple definition of the term dust control or dust control methods has been found in the literature. Methods of dust control, surface sealing, surface strengthening and stabilisation often overlap. It is almost impossible to draw precise boundaries between e.g. bituminous stabilisation, dust control with bituminous binders, and the use of surface dressing such as Y1G.

The main reason for these difficulties in definition is that it is the purpose of the measures and the importance attached to the dust control function which determine whether or not the method in question can be regarded as a dust control method. Dust control comprises one or more elements depending on the type of dust control agent; for instance, dust control with salt comprises the elements watering, grading and spreading of salt.

Lindh (1981) says that every action which keeps the emission of dust particles below an acceptable maximum level, is carried out with the chief purpose of controlling dust and uses a method that does not alter the character of the road as a gravel road, may be said to be dust control action. Han (1992) quotes three methods of dust control:

- Chemical method
- Mechanical method
- Administrative method

In the **chemical method**, chemical agents for instance salt such as calcium chloride CaCl_2 , magnesium chloride MgCl_2 or sodium chloride NaCl , or organic bituminous binders or non-bituminous organic chemicals such as lignin, are spread or added to the road. This literature study mainly deals with this method.

The **mechanical method** is based on consideration of the dust problem already during the design and construction of a gravel road. This method entails the use of filtersheet or "dust free surface material" in the road structure (Brown and Elton, 1994). How the use of filtersheet in the road structure reduces dust emission is not described clearly in the literature. Foley (1996) describes the mechanical method as a type of stabilisation.

The **administrative method** entails the imposition of a speed limit on the road. When speed is reduced, dust emission decreases. Han (1992) says that this method is described in detail by Metzger (1967) in his report "Dust suppression and drilling with foaming agent". Han (1992) quotes Metzger (1967) who says that dust emission decreased by 40% when vehicle speed was reduced from 40 mph (64 km/h) to 35 mph (56 km/h).

Lindh (1981) says in his literature study that dust can be controlled or eliminated in three ways:

By covering the surface of the gravel road with an impervious layer, e.g. a surfacing. Surfacing is a permanent solution of the dust problem.

By keeping the dust particles bound in the surface of the wearing course. This can be achieved by keeping the road moist and in this way utilising surface tension effects at the air-liquid phase boundary. This method is applied in dust control with water and solutions of certain hygroscopic salts such as calcium chloride.

By agglomerating dust particles with larger particles, for instance by using lignin and oil products.

7.1.3 Different types of dust control agent

Since dust control on gravel roads is an old problem which has engaged researchers and road management authorities over several decades, a large number of dust control agents have been tested over the years in order to find the agents which best satisfy the task of effectively controlling road dust at an acceptable cost. Dust control agents are usually classified on the basis of what they contain. These classes may have different forms. The same types of dust control agent may be marketed under different product names.

Hoover (1981) quotes one of the RRL reports (1971) and gives the following classification:

- Water, sea water or fresh water
- Inorganic salts and bases, e.g. calcium chloride, magnesium chloride, sodium chloride, and other inorganic salts such as solutions of aluminium or calcium salts
- Other inorganic chemicals
- Organic non-bituminous binders such as calcium lignosulphonate, enzyme products, and other organic non-bituminous binders
- Bituminous materials and elastomers such as bitumen emulsion, asphalt solution, elastomers and polymers

Another classification may be as follows (Jämsä, 1983):

- Hygroscopic salts such as calcium chloride, magnesium chloride and sodium chloride
- Industrial waste products, for instance calcium lignosulphonate
- Clay
- Dust control oil

In this study, these two classes above are amalgamated as follows:

- Water
- Inorganic salts
- Non-bituminous organic chemicals
- Bituminous materials
- Clay
- Dust control oil

7.1.3.1 Water

Water is the cheapest temporary dust control agent. Few publications regard water to be a dust control agent on its own. Hubendick in Lindh (1981) describes its effect as follows:

When the material in the wearing course is moist, the different particles are surrounded by thin water membranes. Such a water membrane can resist a certain, relatively large, force by surface tension. When the water membranes between two particles come into contact, the surface tension endeavours to move the particles towards one another and to keep them together.

As a consequence, the moist particles of dust in the wearing course are bound together, both with each other and with the coarser material. Quite a large force is needed to overcome surface tension and to dislodge moist dust particles from the wearing course, and this is the reason why a moist wearing course emits no dust. The drawback of water as a dust control agent is that it rapidly evaporates. In order to keep a road free of dust, it is necessary to water it more often, which increases maintenance costs.

The dust control effect of water depends on e.g. traffic volume and the weather. It varies between a minimum of half an hour and a maximum of twelve hours (Foley, 1996).

Studies by Struss and Mikucki in Lindh (1981) are stated to show that the water potential in soil material is a statistically significant factor in determining dust formation. One conclusion of these studies is that water, if it is readily available, may be an economic alternative in dust control if it is applied at the correct time during the drying process.

Sea water is usually more effective than fresh water due to its content of small quantities of dissolved salts, mainly magnesium chloride. According to Lindh (1981), sea water has been used in Norway along the coast as an alternative to dust control with calcium chloride. Both Foley (1996) and Lindh (1981) state that if the air along the road has a sufficiently high relative humidity, these chemicals retain the absorbed water and the road remains free of dust for a longer period than if fresh water is used.

7.1.3.2 Inorganic salts

Inorganic salts account for 75-80% of all dust control agents (Han, 1992). Several inorganic salts with hygroscopic or deliquescent properties have been used as dust control agents. The most important are considered to be calcium chloride CaCl_2 , magnesium chloride MgCl_2 and sodium chloride NaCl .

The two designations hygroscopic and deliquescent are used in the literature not entirely consistently, the probable reason being that different authors ascribe a somewhat different meaning to these designations.

A **hygroscopic** salt is a salt that can absorb atmospheric humidity to such a high degree that the crystal dissolves.

Lindh (1981) quotes a dictionary of chemistry and defines the word **deliquescent** as follows: "When a salt absorbs moisture from the atmosphere and is dissolved in the absorbed water it is said to be deliquescent. This occurs only if the vapour pressure of the water over the solid is lower than the vapour pressure in the ambient air". Lindh (1981) makes a distinction between hygroscopic and deliquescent properties and quotes Miall and Sharp (1976). Miall and Sharp classify calcium chloride and magnesium chloride as deliquescent salts, while they regard sodium chloride to be a hygroscopic salt. It should however be pointed out that Lindh (1981) writes that these three chemicals are all hygroscopic and that all three may also be deliquescent.

The dust control effect of salts is due to the fact that 1. the surface tension of a salt solution is greater than that of water, and 2. the vapour pressure over a salt solution is lower than that over water of the same temperature, and that evaporation of water from the road surface is consequently of lower extent and may change into absorption of moisture from the air. Lindh (1981) quotes Reyier (1972) who describes the dust control effect of salts. Lindh says that if dust control of a gravel road is performed using water, the wet road dries out as soon as the relative humidity of air is less than 100%, i.e. when the vapour pressure of air is lower than its saturation pressure at the prevailing temperature. Since the saturation pressure over a salt solution is lower than that over water, the saturation pressure can be lowered with a salt that is capable of forming a solution with water, and water can thus be retained at the surface of the road even when relative humidity is lower than 100%.

The dust control effect of a certain quantity of salt is a function of the volume of the solution that is formed when the salt absorbs water. The volume of solution depends on the chemical character of the salt, temperature and humidity. According to Reyier (1972) in Lindh (1981), there are two factors which are critical for the dust control effect of salts, namely the ability to go into solution and the solution volume formed.

The inorganic salts described in the following are calcium chloride CaCl_2 , magnesium chloride MgCl_2 , sodium chloride NaCl , calcium nitrate and calcium chloride+sodium chloride.

Calcium chloride

Calcium chloride CaCl_2 was tested as a dust control agent as early as the 1920s (Jämsä, 1983). Many consider that calcium chloride is one of the best dust control agents that are at present available (Persson, 1993). In Sweden about 20,000-40,000 tonnes of calcium chloride are used annually for dust control of gravel roads (Walterson, 1995). Calcium chloride is produced by Kemira Kemi AB.

The dust control effect of calcium chloride is based on the fact that the salt deliquesces, forms a solution with atmospheric humidity which, due to its high surface tension, binds the particles together and prevents evaporation of water.

Calcium chloride is sold in the form of a hydrate with the chemical formula $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ (Svensson, 1997). It is delivered as white flakes either in bulk or in bags (Hallberg, 1989). As it absorbs moisture, it changes from white flakes into a white

jelly-like mass and finally into a colourless viscous liquid. On delivery calcium chloride contains about 20-25% water (Glänneskog and Skog, 1994). Calcium chloride must be stored so that the salt does not come into contact with moisture.

Reyier (1972) says that commercial calcium chloride theoretically contains about 75% water-free salt, while Nilsson (1980) in Svensson (1997) gives a higher value, 77-80%. The solubility of calcium chloride in water is stated by Thornburn and Mura (1969) in Lindh (1981) to be 59.5 g per 100 ml water at 0°C and 159 g at 100°C.

The **relative humidity** needed for calcium chloride to be able to absorb moisture from air varies with temperature. Lindh (1981) quotes Thornburn and Mura (1969) and says that more than 30% relative humidity is required to enable calcium chloride to absorb moisture from air. Bergström and Grebacken (1995), on the other hand, say that relative humidity should be higher than 35%.

As regards the **time of year** and **frequency**, there are different opinions as to when salt must be spread in the spring as basic treatment. Certain road management areas spread most of their calcium chloride as early as possible in order to make use of spring moisture. The Swedish National Road Administration recommends that the first dust control treatment should be applied in the spring when thaw has penetrated to a sufficient depth. The reference does not however say what this depth is. Dust control is carried out after the thaw when the carriageway has stabilised but still retains spring moisture. The road must be graded because of the settlements that had occurred after the thaw. A road with good cohesion must be deep graded, as a result of which some of the salt is wasted (Road maintenance-roads free from snow and ice, 1992, in Swedish).

According to ROAD 94, the **quantity of calcium chloride** must be at least 0.5 kg/m². This applies to new roads, i.e. the first coverage. The whole section of road need not be dust controlled with the same quantity, but the coverage must be adjusted in view of the needs of the road section (Road maintenance-roads free from snow and ice, 1992). For practical reasons, however, the same quantity is in actual fact applied to the whole section.

According to the literature, the quantity of calcium chloride used in dust control depends on four factors:

- A. Composition of the wearing course
- B. Open terrain or terrain sheltered by forest
- C. Road width
- D. Traffic volume, proportion of heavy vehicles, and speed.

A. Composition of wearing course

It is evident from ROAD 94 that the particle size distribution of the gravel wearing course may have to be adjusted when dust control is performed using a product other than calcium chloride.

Beskow (1934) says that if the quantity of material passing a 0.125 mm sieve is less than 10%, addition of soil binder to a road treated with a dust control agent is warranted.

The results of tests (Hallberg, 1989) suggest that wearing courses deficient in soil binder are controlled better with calcium chloride than with Dustex. He adds that these results agree quite well with previous tests. However, Hallberg does not define the term "wearing course deficient in soil binder".

Brown and Elton (1994) tested both calcium chloride and lignosulphonate. The results suggest that the effect of calcium chloride is better on sandy wearing courses. Lignosulphonate produces better results on wearing courses containing quite a lot of clay.

B. Open terrain or terrain sheltered by forest

Open and dry sections require more dust control than shady and moist sections. Curves and the tops of hills are also places where coverage must be slightly higher. In Sweden, the need for dust control is in direct proportion to the number of vehicle passages, openness and the time during which the road is free from snow and ice. The quantities of calcium chloride used in Sweden are set out in table 7.1 (Jämsä, 1983). Jämsä has not defined the term openness in the table. According to Isemo and Johansson (1976), openness can be classified as open surroundings, i.e. both sides open, open on one side or both sides shaded.

Table 7.1 Quantity of CaCl_2 (kg/metre run) used in Sweden for dust control.

| Traffic AADT | Openness (%) | | |
|--------------|--------------|-------|-----|
| | 0-9 | 10-19 | 20- |
| 0-49 | 0.7 | 0.8 | 1.0 |
| 50-124 | 0.9 | 1.1 | 1.3 |
| 125-249 | 1.3 | 1.5 | 1.8 |
| 250- | 1.7 | 2.1 | 2.6 |

C. Road width

Table 7.2 sets out the average quantities of calcium chloride (tonnes/km) used in Finland for different road widths and traffic volumes.

Table 7.2 *Quantities of calcium chloride (tonnes/km) per application used in Finland for different road widths (Jämsä, 1983).*

| AADT (vehicles/day) | Standard classes* | Road width (m) | | | |
|------------------------|-------------------|----------------|-----|-----|-----|
| | | 4 | 5 | 6 | 7 |
| -100 | 7 | 0.9 | 1.2 | 1.4 | 1.7 |
| 101-200 | 6 | 1.4 | 1.7 | 1.9 | 2.2 |
| 201-500 | 5 | 2.1 | 2.3 | 2.6 | 2.9 |
| 501-1500 | 4 | - | 3.4 | 3.7 | 3.9 |
| 1501-6000 | 3 | - | - | 5.0 | 5.2 |

* see Chapter 8 "Condition assessment of gravel roads"

D. Traffic volume, proportion of heavy vehicles, and speed

The higher the speed and the greater the volume of traffic, the more the salt needed.

Persson (1993) writes that the normal quantity during a year is 0.6-1.5 tonne/km. If it is necessary to use more than 1.0 tonne/km, about two thirds of this are spread in the spring on the first occasion. The remainder is spread in conjunction with grading in the summer, or when it is otherwise necessary to apply dust control.

"Road maintenance -roads free from snow and ice" (1992) lays down that in the spring about 1.5 kg/metre of road should be used. Bergström and Grebacken (1995) add that this quantity applies for a road of 4 m width. Hallberg (1989) has used 1 tonne/km in his test. During maintenance grading in the summer months, light dust control, about 0.2-0.5 kg/m road, is generally needed (Road maintenance-roads free from snow and ice, 1992).

Salt retains its dust control properties for 1.5-2 months (Bergström and Grebacken, 1995). However, Han (1992) gives a considerably longer period, 6-12 months.

Han (1992) says that the quantity of CaCl_2 for American conditions is 1.0-1.5 lb/yd² which is equivalent to 0.5-0.8 kg/m². No traffic volumes are quoted. Beckemeyer and McPeak (1995) give the quantity for American conditions as 0.65 kg/m², which is the same as the quantities used in Sweden.

It is seen from the report "Dust control of gravel roads" (1993) that the quantity of calcium chloride used in Norway in this test is 1.5-2.0 kg CaCl_2 /m.

Calcium chloride solution is prepared by mixing 50-200 kg CaCl_2 with 1 m³ water. Calcium chloride solution is used as a first aid measure, and on roads carrying little traffic, in both Finland and Iceland (Jämsä, 1983).

Magnesium chloride

Magnesium chloride MgCl_2 and calcium chloride CaCl_2 have several common properties. Magnesium chloride is also hygroscopic and easy to dissolve. Both these road salts are also industrial waste products. Magnesium chloride is obtained when certain naturally occurring potassium salts (e.g. carnallite) are refined. Magnesium chloride is also obtained from sea water. Both these salts are marketed in the form of a hydrate, i.e. as solid chemical compounds.

Theoretically, commercial magnesium chloride contains 47% (46.86%) water-free salt. In practice, commercial products also contain small quantities of other salts such as basic chlorides and sulphates. This means that the salt content of magnesium chloride is lower than that of calcium chloride. The moisture content of magnesium chloride on delivery is about 40-50%.

The relationship between **relative humidity** and temperature is shown in figure 7.1.

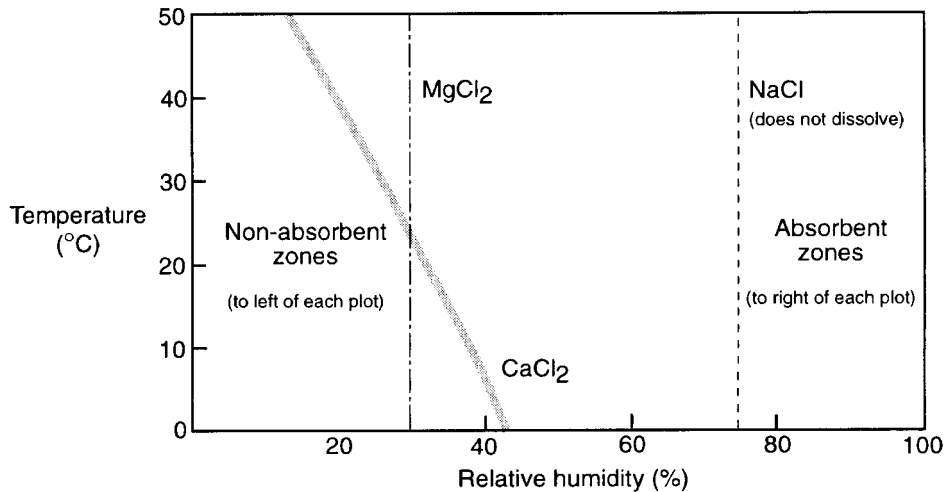


Figure 7.1 Relationship between the relative humidity at which the salt goes into solution and temperature (Foley, 1996).

Foley points out that the figure only applies when the salt is not mixed with other materials. If the salt is mixed with the road material, the relationship is different.

It can be seen from the figure that calcium chloride goes into solution at a lower relative humidity than magnesium chloride when the air temperature is higher than about 23°C, which is the temperature on a quite warm summer day in the Nordic countries (Jämsä, 1983). This means that calcium chloride has a better dust control action than magnesium chloride on warm summer days.

The figure also shows that magnesium chloride has the advantage that it can go into solution at a low temperature by absorbing less moisture, i.e. it has a more rapid dust control effect, while the opposite applies at higher temperatures. However, it is considered that the saving made by using magnesium chloride, because less water needs to be spread, is small compared with the cost of purchase, transport, storage and spreading. In order to achieve the same effect as in using calcium chloride, 18% more magnesium chloride per m² is needed (Reyier, 1972). Others consider that up to 20% more is needed.

Glänneskog and Skog (1994) state that the final sum is approximately the same. Magnesium chloride may be even a little more expensive.

Magnesium chloride **costs** about SEK 1300/tonne (1998) which is about 15% cheaper than calcium chloride that costs about SEK 1500/tonne (1998).

The differences between $MgCl_2$ and $CaCl_2$ have been investigated by Nilsson (1994). He carried out a small scale dust control test on gravel roads between Alvesta and Vislanda in Kronoberg County. Both magnesium chloride and calcium chloride were used in the test. Nilsson (1994) summarises the results as follows:

- Magnesium chloride is more pleasant to handle than calcium chloride. What is most important, it raises less dust when loaded and spread than calcium chloride.
- Dust control effect is the same as that of calcium chloride.
- The consumption of magnesium chloride at two of the test areas is slightly higher than that of calcium chloride.
- Magnesium chloride combines with about 30% less chlorine than calcium chloride. This may be seen as environmentally favourable if the consumption of the two salts used in dust control is equal.
- Magnesium chloride runs out of the spreader more freely than calcium chloride.
- The road has a lighter colour after treatment with magnesium chloride.
- Magnesium chloride should not be loaded the evening before spreading since it appears to be more hygroscopic than calcium chloride.

Sodium chloride

The cheapest dust control agent is sodium chloride or cooking salt $NaCl$ whose principal field of application in road management is however as a skid control agent (Han, 1992). Sodium chloride occurs naturally as rock salt in a number of places over the whole world, and makes up 3% of sea water. The lowest relative humidity at which sodium chloride can absorb atmospheric moisture is 80% (Lindh, 1981 quoting Thornburn and Mura, 1969). RRL in Lindh points out, however, that the corresponding percentage is 75%. Han (1992) states that the lowest relative humidity is 76%. Sodium chloride has been tested to a limited extent in dust control of gravel roads, but the results have not been satisfactory. The reason is the high relative humidity needed (75-80%) before sodium chloride can absorb atmospheric moisture and go into solution (Jämsä, 1983).

Calcium chloride + Sodium chloride

According to Han (1992) a mixture of calcium chloride and sodium chloride can reduce maintenance costs. He says that dust control with this mixture is 20% cheaper than when only calcium chloride is used, but the dust control effect is 5% lower. In the Norwegian report Dust control of gravel roads (1993), this mixture is called **Norsalt**. The chemical composition of Norsalt is as follows:

- Calcium chloride 30-40%
- Sodium chloride 40-50%
- Magnesium chloride 10-20%
- Potassium chloride 2-10%
- Magnesium fluoride and calcium fluoride 1%.

The above report refers to an investigation in which calcium chloride, Dustex and Norsalt were tested. The report states that the quantity of Norsalt used in the test in Norway was 1.8-2.0 tonnes/km.

Calcium nitrate

Calcium nitrate as a dust control agent has not been dealt with to any major extent in the literature. In Norway, however, an investigation has been made to find if calcium nitrate is suitable as a dust control agent for gravel roads.

Calcium nitrate is cheaper than calcium chloride. Jämsä (1982) states that the use of calcium nitrate saves about NK 400-500/km (1980) when the quantity of calcium nitrate used is the same as that of calcium chloride.

Jämsä (1982) refers to investigations made in 1980 in Oslo by the National Norwegian Road Laboratory in which the properties of calcium nitrate were investigated by field and laboratory experiments. Calcium chloride was used as the reference material. It was found that calcium nitrate raises less dust than calcium chloride when it is spread.

It may be stated on the basis of experience that, in spite of its weaker dust control effect in comparison with calcium chloride, under certain conditions satisfactory results can be achieved by using calcium nitrate.

Use of calcium nitrate may in the first place be considered:

- On roads with low traffic which do not emit a lot of dust
- In areas with a wet climate

Jämsä (1982) considers that the risk of environmental damage poses no obstacle to the use of calcium nitrate. Although calcium nitrate is a fertilizer, Jämsä's report makes no mention of the risk of eutrophication and anoxia.

7.1.3.2.1 Application of dust control agent

Application of the dust control agent may be said to comprise three stages:

- A. Analysis of road
- B. Spreading or mixing of dust control agent
- C. Choice of plant and equipment

Analysis of the road is broadly the same whether salt, lignosulphonate or bitumen emulsion is used as a dust control agent.

A. Analysis of road

In order that dust control should be as effective as possible, an investigation should be made to find whether the road is suited to dust control treatment with salt, lignosulphonate or bitumen emulsion. The analysis is in two stages, check on the composition of the wearing course and check on the camber and superelevation.

A1. Check on composition of wearing course

If **salt** is used for dust control, the particle size distribution curve of the wearing course should agree with the ideal aggregate curve in ROAD 94 and contain a sufficient quantity of fines, about 6-8%. If the fines content of the wearing course is too low and it contains too much sand, the road surface will become corrugated (Bergström and Grebacken, 1995). The road shall have the appropriate moisture content before the salt is spread. The appropriate or optimum moisture content is that at which the best degree of compaction can be achieved. This moisture content is 4-6%. Bergström and Grebacken quote a simple test that can be made on the site. A sample of the wearing course is taken and rolled up into a ball the size of a tennis ball; it must not fall apart and it should not be possible to squeeze fines out of it. Glänneskog and Skog (1994) describe the same test by saying that the ball must not be sticky. However, the road must be allowed to become stabilised after the thaw before dust control can commence.

In dust control using **lignosulphonate**, the composition of the wearing course must be such that the specific properties of the sulphite lye are utilised. Examples of such specific properties are good cementing action and resistance to water. The tightest possible composition maximises the adhesive capacity of sulphite lye. A wearing course with a high gravel shape index is also favourable for the results. Bergström and Grebacken (1995) write that the particle size distribution curve given for the wearing course in ROAD 94 is largely suitable when lignosulphonate is used as the dust control agent, but consider that the fine material should preferably have a clay content of about 40%. The results of Hallberg's (1989) tests suggest that Dustex produces a better dust control effect than calcium chloride when the wearing course is rich in soil binder. He adds that these results are in quite good agreement with previous experiments. However, Hallberg does not define the term "wearing course rich in soil binder". Brown and Elton (1994) tested both calcium chloride and lignosulphonate. The results indicate that lignosulphonate produces better results on a wearing course containing quite a lot of clay.

When dust control is carried out using **bitumen emulsion** the ideal particle size distribution given in ROAD 94 should be aimed for, but according to Bergström and Grebacken (1995), tests on Gotland show that a wearing course with approximately half as much fine material (<0.25 mm) produces better results when emulsion is used for dust control. The reason is that the limestone found on Gotland is easily broken down and in this way the fines content increases.

Before dust control treatment begins the wearing course should be inspected, the need for new aggregate assessed and regravelling if necessary. Regravelling is described in Clause 7.3.

A2. Check on camber and superelevation

Most of the references say that crossfall on a gravel road should be at least about 3-5% so that water drains from the carriageway so quickly the wearing course is not softened. ROAD 94, on the other hand, states that the crossfall on a carriageway with a wearing course of gravel should not be less than 3%.

The edges of the road shall be trimmed prior to watering and grading so that water can drain unobstructed and so that vegetation is not drawn on to the road by the grader. If water ponds on the carriageway, salt and lignosulphonate are dissolved and the dust control function disappears. When emulsion is used for dust control, the advance patrol for edge trimming, which consists of two graders and a water tanker, should be deployed not more than 4-5 hours before emulsion treatment to ensure that the road has the correct moisture content (Bergström and Grebacken, 1995). Edge trimming is described in more detail in Clause 7.4.

In order that dust control should have long duration, the road must then be graded to ensure that camber and superelevation are correct. The road shall have the appropriate moisture content prior to grading. The natural moisture content of the road can with advantage be utilised by grading the road directly after a heavy fall of rain or before there has been time for it to dry out after the thaw. If for some reason the natural moisture content is not enough, the road must be watered until the correct moisture content is obtained. Watering is described in Clause 7.5.

A road with salt as the dust control agent is easy to grade. A grader blade of ordinary plain steel works well. Bergström and Grebacken (1995) say that, depending on how badly damaged the road is, the grader blade should penetrate about 1.5-3 cm. The reason for shallow grading is to minimise the quantity of loose material in front of the grader blade and to avoid the risk of cutting into poor material below the wearing course. Since, as a rule, the road is not constructed in accordance with any specification, one does not know what there is below the wearing course.

A road previously treated with bitumen emulsion should be watered and graded to a depth of 5-10 cm irrespective of how damaged it is. Deep grading is necessary to break down the lumps of emulsion and to adjust camber and superelevation. Grading is described in detail in Clause 7.2.

B. Spreading or mixing the salt

There are two methods for dust control with salt, the **surface salting method** and the **mix-in-place method**.

B1. Surface salting method

Salt is spread as an aqueous solution or as a solid. Today, salt is mostly spread in the solid state. A lorry with a tipping body and a towed salt spreader are used. Salt is not mixed into the wearing course. The wearing course is compacted by traffic (Bergström and Grebacken, 1995).

Han (1992) considers that 15-30 cm of adjacent passes must be overlapped when salt solution is applied. He adds that the road should not be used immediately after the salt has been spread to ensure that the material mixed with salt does not get caught up in the tyres. This holds for salt both in solid form and as a solution. The wait is about 4 hours and depends on the type of wearing course and the climate. A wearing course with a high fines content requires a longer time. He suggests that if the road must be used immediately after salt has been spread the surface should be compacted before the road is opened to traffic.

B2. The mix-in-place method

Another working method mentioned by Jämsä (1982), Hoover (1981), Sultan (1974) and others is the mix-in-place method. There are different methods of mixing the agent into the wearing course.

Jämsä (1982) describes the mix-in-place method as follows: The wearing course is worked over with a grader. The road must be watered prior to grading to facilitate both mixing and compaction. In normal conditions, two passes are needed to loosen up and mix the material. After this treatment the loose wearing course material forms a windrow in the middle of the road. The material is then spread and evened out, during which process the coarse material is spread evenly over the two halves of the carriageway. Salt is then spread on the road. After this, the salt is mixed into the wearing course and the road is accurately shaped. Mixing is carried out using an aggregate windrow spreader attached to a grader or a road drag. After mixing and fine adjustment, the road is compacted with suitable equipment, e.g. a pneumatic tyred or smooth wheeled roller.

Sultan (1974) recommends that the road should be watered both before and after grading.

Beckemeyer and McPeak (1995) write that the salt must be mixed into wearing course material of 25-50 mm thickness. The road must then be rolled. Water must be added if necessary.

C. Choice of plant and equipment

The plant and equipment described below are needed for the surface salting method. A windrow spreader to mix the salt into the wearing course, and a roller for compaction, are also required in the mixing method.

The plant and equipment used in dust control with salt are a water tanker, road grader and spreading equipment.

Spreading equipments which are used are sand spreader, salt spreader or fertiliser spreader. A brief description of each of these is given below.

A **sand spreader** is often used for the spring salt treatment at which time a large amount is spread (about 1.5 tonnes/km). A sand spreader must be used if more than 0.7-0.8 tonne/km is to be spread (Persson, 1993); a lorry with a tipper body and a spreader towed behind are employed. See figure 7.2.



Figure 7.2 Dust control treatment with a sand spreader (Maintenance of gravel and earth roads, 1994).

The spreaders which are towed by the lorry have a small container into which the salt can be tipped from the lorry. This equipment is capable of spreading a constant quantity of material per unit of surface irrespective of the speed of the lorry (Jämsä, 1983).

According to "Road maintenance-roads free from snow and ice" (1992), salt should be spread in two passes so that the whole width of the road is treated. On dry sections further passes may be needed.

A **salt spreader** is a simpler version of a sand spreader. A salt spreader is either only a tipper lorry or some form of spreader appliance that is fixed at the back of the tipper. Some spreaders are fitted with a number of flaps that can be shut to reduce the width of spread (Jämsä, 1983). Salt spreaders are often used during summer grading when small quantities are spread (Road maintenance-roads free from snow and ice, 1992).

A **fertiliser spreader** mounted on a tractor can be used when small quantities are to be spread. When a fertiliser spreader is used, covers must be used on each side of the spreader and the speed kept low to ensure that the width of spread is correct; see figure 7.3.



Figure 7.3 Fertiliser spreader (Persson, 1993).

7.1.3.2.2 Environmental impact of calcium chloride and magnesium chloride

Most people in Sweden know that treatment of winter roads with salt makes for a safer traffic environment. It is also known that salt affects and destroys vegetation and shoes and increases the corrosion of e.g. car bodies. What people may not think about is that salt is also spread on roads in the summer and that this gives rise to even more corrosion.

The term environmental impact or environmental effects may refer to many things. According to "Road maintenance-roads free from snow and ice" (1992), the term environmental effects relates to impact in three areas:

- Natural environment (sources of water supply, soil, buildings and vegetation)
- Working environment (people)
- Road environment (corrosion, soiling)

On the other hand, Bergström and Grebacken (1995) classify environmental impact as follows:

- Impact on vegetation
- Water pollution
- Corrosion
- Health hazards

Glänneskog and Skog (1994) deal with the following areas in conjunction with the environmental effects of salt:

- Sources of water supply
- Vegetation
- Corrosion
- People

Walterson (1995) describes environmental effects in greater detail and groups them in three areas:

- Aquatic environment
 - Acute toxicity
 - Chronic toxicity
- Land environment
 - Toxicity to plants and animals
 - Other effects on the land environment
- Health effects

In the handbook Environmental Impact Assessments for Roads (1995), the following areas are quoted in conjunction with the environmental effects of road construction:

- Landscape
- Recreation
- Cultural environment

- Natural environment (geology, water, vegetation, animals)
- Natural resources (forestry, agriculture, materials and minerals, groundwater, commercial fishing)
- Dangerous goods
- Spoil
- Noise
- Air pollution
- Damage during the construction period

For **operation and maintenance measures**, the following are of interest:

- A. Effects on vegetation and the soil
- B. Effects on sources of water supply
- C. Corrosion
- D. Health hazards

A. Effects on vegetation and the soil

Calcium chloride is mainly spread into the natural environment by leaching of the salt into the surrounding land and water environment.

Walterson (1995) quotes Segerros (1972) and claims that as early as during the 1930s and 1940s it was seen that calcium chloride damaged trees and bushes along Swedish roads.

Bergström and Grebacken (1995) write that the effect of salt on vegetation is limited to a strip of about 20 m from the road. Walterson (1995) does not disagree with an investigation made by Bäckman (1980) which suggests that damage to vegetation, especially to conifers, occurs more or less generally along winter roads treated with salt over a distance up to 10 m from the edge of the road.

Calcium chloride CaCl_2 consists of three ions, a calcium ion Ca^{2+} which is a natural and necessary constituent of soil, and two chloride ions Cl^- which are not equally beneficial to the soil. Glänneskog and Skog (1994) claim that chloride ions are easily taken up by plants and attack their cell membranes so that they cannot absorb water and nutrients as easily as before.

Walterson (1995) quotes Dragsted (1988) and says that in an experimental study it was found that treatment of young maple trees with sodium chloride or calcium chloride caused damage which was correlated with the chloride content of the leaves. The greatest damage was caused by calcium chloride.

Chloride damage to deciduous trees is characterised by the leaves wilting from the outside towards the centre. The same symptoms are also found in conifers; the tips of the needles are affected first, and gradually the whole needle turns a reddish-brown colour. Entire annual growths of needles can disappear, and branches and needles are thinned out. Nature can deal with salts in low concentrations (Glänneskog and Skog, 1994). Halophytic plants such as lyme grass are favoured

by increased salt content and may therefore grow in certain road environments (Bergström and Grebacken, 1995).

Solutions of calcium chloride are classified as substances that cannot accumulate in the soil (Walterson, 1995). Walterson claims that the large scale dispersion of chlorides, both via the atmosphere and application to the roads, together with the progressive acidification of the ground, can, at least theoretically, be assumed to promote or accelerate natural formation of organic chlorine compounds. Bergström and Grebacken (1995) consider that the salt affects the structure of the soil. Voids are reduced, and this makes it more difficult for oxygen and water to penetrate into the ground.

B. The effect on sources of water supply

It is difficult and expensive to restore a source of water supply that is polluted by salt. Storage dumps for road salt must be planned in consultation with municipal authorities so that no damage is caused to sources of water supply and similar (Glänneskog and Skog, 1994).

Finnish investigations show that problems due to increased chloride content in groundwater can occur along roads treated with salt. This may result, for instance, in wells along the road becoming unfit for use (Bergström and Grebacken, 1995).

The conclusions drawn by Walterson (1995) suggest that there is little risk of groundwater being affected by the use of calcium chloride on roads. On the other hand, groundwater has on several occasions been contaminated in Sweden by sodium chloride used in winter for skid prevention.

C. Corrosion

Glänneskog and Skog (1994) claim that calcium chloride accelerates the corrosion process by retaining moisture and increasing the conductivity of the layer of liquid on the vehicle body. Salt facilitates combination of oxygen with iron.

Lindh (1981) quotes Hubendick (1975) and says that a corrosion investigation performed by the Swedish National Road Administration shows that dust control with hygroscopic salt makes a considerably higher contribution to the corrosion of vehicles on gravel roads than that due to chemical skid control with sodium chloride. However, if the small volume of traffic on gravel roads is compared with that on paved roads, a different picture of the effect of corrosion on vehicles emerges.

Reyier (1972) quotes Bergström (1956) who claims that one essential difference between magnesium chloride and calcium chloride is considered to be the greater aggressivity of the latter towards concrete. Other investigations have however pointed in the opposite direction.

In order that a complete comparison may be made between $MgCl_2$ and $CaCl_2$, their environmental impact should be studied not only locally but over a whole life cycle. In a life cycle analysis (LCA), an analysis is made of e.g. what these contain, how they are made, what transportation they require, etc. $MgCl_2$ is brought in from Israel, which in itself is a negative environmental impact.

D. Health hazards

In the literature studied, there are conflicting data concerning the toxicity of salts.

Svensson (1997) claims that calcium chloride is not poisonous but that it irritates the skin and the eyes. Calcium chloride may also burn the skin on contact. When being handled, road salt may emit dust which may irritate the airways. Protective clothing and gloves should therefore be used when handling road salt so as to avoid skin contact. When dust is likely to develop during handling, protective spectacles and respirators should also be worn.

Walterson (1995) quotes Flatla (1976) and says practical observations indicate that calcium chloride may poison cattle and sheep grazing in the vicinity of roads treated with salt. Preliminary results from a study made by the Institute of Internal Medicine in Norway show that high doses, 2-8 g/kg of body weight, taken by cattle orally caused toxic symptoms and death.

7.1.3.2.3 Secondary effects of salt

The secondary effects described by Reyier (1972) are direct and indirect effects on bearing capacity.

A. Direct effect on bearing capacity

According to Reyier, tests have shown that in spite of quite high concentrations of calcium chloride there was insignificant direct effect on the bearing capacity of soil. Brown and Elton (1994) state, however, that calcium chloride increases the strength of soil.

B. Indirect effect on bearing capacity

Reyier (1972) states that increased water content in the road structure and a depression of the freezing point are among the indirect effects on bearing capacity.

B.1 Increased water content in the road structure

Treatment with a hygroscopic salt causes a change in the water balance of the road structure. Obviously, when a road is treated with a hygroscopic salt, it will dry out less after a dry summer. Reyier (1972) points out that it is shown by investigations that normal autumn rains are not sufficient to saturate the road structure if no salt treatment has been carried out. If the road has been treated with salt, there will be so much excess water after the autumn rains that saturation occurs and bearing capacity is reduced. This reduction occurs irrespective of whether calcium chloride or magnesium chloride has been used.

B.2 Depression of the freezing point

It is considered that depression of the freezing point of the soil may result in an unfrozen carriageway being supported by a frozen pavement.

7.1.3.2.4 Practical experiences from dust treatment with salts

Some experiences may be quoted from the studied literature:

- Good results are obtained if the road is graded and is immediately treated with salt. The road surface is then porous and salt can more easily penetrate into the surface layer. However, grading should never be carried out if the

road is not moist enough. In conjunction with grading the road must be accurately shaped.

- It is satisfactory to spread salt directly on a naturally moist carriageway, for instance after rain, snowmelt or a thaw, but it is necessary for the road surface to have stabilised if it has softened due to thaw.
- Another possibility is to spread salt in the evening when humidity is high.
- Salt must not be spread during sustained rainfall since it can be washed off the road and contaminate sources of water supply. The greatest disbenefit is that salt is wasted without doing any good.
- Höbeda (1978) considers that the effect on the resistance to abrasion is slightly greater if the hygroscopic salts are mixed into the gravel wearing course than if they are spread on the surface.
- According to Lindh (1981), indications are that mechanical admixture of the salt improves the durability of dust control treatment.
- According to Jämsä (1982), relative humidity may be so low on hot summer days that calcium chloride changes into the solid state and has no dust control effect. However, relative humidity in any case increases in the evening, so that CaCl_2 absorbs water from the air and this produces a dust control effect the next day.
- In cold weather the air contains only small quantities of water and dissolution may therefore take a long time although relative humidity is high. In consequence, the CaCl_2 grains may be thrown to the edge of the road before a solution is formed. For this reason, the effect of calcium chloride is weak early in the spring when the roads are free from snow and ice but frost still occurs overnight (Jämsä, 1983). Han (1982) recommends that dust control with either chemicals or organic substances should not be carried out at temperatures below 4°C.
- According to "Road maintenance-roads free from snow and ice" (1992), dust control treatment should cover the whole width of the road.
- Beskow (1932) confirms that salts have a dispersing effect on aggregate containing a lot of slate. Salt treatment under such conditions reduces the bearing capacity of the road in spring and autumn. In Sweden, such aggregate is found only in certain relatively small areas such as parts of the northern mountain chain and smaller slaty areas in southern and central Sweden. It is only in these areas that care should be taken in treating roads with salts. Such aggregate has a low ball-mill value and is probably not permitted by ROAD 94.

7.1.3.3 Non-bituminous organic chemicals

For dust control treatment of gravel roads, organic substances other than bituminous binders can be used. Examples of such organic substances are lignosulphonates. In some of the literature, the organic substances obtained from industry, e.g. vegetable oils, are classified as byproducts or waste products (Jämsä, 1983).

The effect of industrial byproducts is due to either the hygroscopicity of the material or the ability of these products to bind the fine material in the wearing course, so that a dust-free, firm and abrasion resistant surface is formed. They also have the same effect as clay and make the wearing course material more plastic and mouldable, which results in greater density after compaction (Foley, 1996).

The results of Foley's report suggest that non-bituminous organic chemicals perform best in dry climates and that their effect is reduced in conjunction with rain. They also produce a lower effect on volcanic rocks, on intermediate and coarse grained materials and on crushed rock.

Lignosulphonates

In Sweden, about 15000 tonnes of lignosulphonate are used annually for dust control and stabilisation of gravel roads (Walterson, 1995).

There are several types of lignosulphonates. They are calcium lignosulphonate, sodium lignosulphonate and ammonium lignosulphonate (Guidelines for cost effective use and application of dust palliatives "GED", 1987). Lignosulphonate is also called sulphite lye or lignin. The types used in Sweden are calcium lignosulphonate and sodium lignosulphonate.

Arnfeld (1941) in Lindh (1981) describes the production and composition of lignosulphonate. Wood consists, apart from water, of three groups of substances, cellulose, hemicelluloses and lignin. Arnfeld (1941) in Svensson (1997) states that, for instance, dry substance in coniferous wood consists of 28% lignin. Lignosulphonate is obtained as a byproduct when wood is digested in producing paper pulp by the sulphite method. Digestion dissolves lignin, the cementing material in wood so that the cellulose fibres are liberated. Lignin is converted into a water soluble form and is separated from cellulose as sulphite lye. Sulphite lye is treated and condensed from about 12% to 50-60% dry substance.

Lignin is the natural cementing agent and is the substance that binds together the fibres in wood. As a dust control agent, it acts as an adhesive and glues together the aggregate particles even in dry material.

Listab WIBAX AB (1997) states that lignosulphonates have been used for more than 80 years as dust control agents. Between 1920 and 1960 lignosulphonates were generally used as dust control agents (Lignin stabilised gravel roads, 1988, in Swedish). From the 1960s to the 1980s, their use diminished. This reduction is due to the displeasure of road users and also to reduced availability (Road maintenance-roads free from snow and ice, 1992). The reason for reduced availability of lignosulphonate is that the chemical industry has changed from sulphite to sulphate processes (Jämsä, 1983).

However, owing to the steep increase in the price of calcium chloride in recent years, there is greater interest in alternative dust control agents. Dust control using lignosulphonate has therefore again been tested by the Swedish National Road Administration since 1980 (Lindh, 1981).

Jämsä (1982) claims that the dust control effect of lignosulphonate is considerably weaker than that of calcium chloride. According to Jämsä, it is estimated that 1 kg CaCl₂ corresponds to about 1.5 kg dry lye and about 15 kg raw lye. Hallberg (1989) supports this after dust control tests with both Dustex and calcium chloride, and writes that the dust control effect is comparable at a dosage of 1.5 parts dry substance Dustex and 1 part dry substance calcium chloride.

Lignosulphonates have been subjected to development, and the lignin products used today are not the same as those used in the beginning of the 20th century. The lignin product used in the beginning of the century was mainly raw lye, i.e. 12% sulphite lye. The problems encountered then were that rainwater washed away the lye, so that no benefit was obtained.

Lignosulphonate products are used not only for dust control of gravel roads but also have other areas of application, for instance as binders in animal feed, as an adhesive and dispersing agent (Lundqvist, 1998).

Calcium lignosulphonate is marketed under the name Dustex. Sodium lignosulphonate is marketed under the name Listab. These two products are studied below.

Dustex

Dustex is produced by LignoTech. Dustex consists of liquid calcium lignosulphonate of 50% dry content (Lignin stabilised gravel roads, 1988).

The sulphite lye is neutralised and condensed from about 12% to about 50-60% dry substance. By this treatment, the previous pungent sulphite smell is largely eliminated (Hallberg, 1989). Most of the smell has been removed without reduction of the dust control capacity (Bergström and Grebacken, 1995). Hallberg states that Dustex is also used in warm and dry countries as a moisture retention agent in vegetable cultivation. Dustex is supplied as an aqueous solution with a pH of 6-7. It is stored in a tank and the product has storage stability when it consists of about 50% dry substance. When the temperature drops below -5°C, the lignin and water phases separate, but after thawing and agitation the components again form a mixture and are stable (Bergström and Grebacken, 1995).

Listab

Listab is produced by Wibax AB in Piteå. This product is considered to be competitive in the northern part of Sweden since transport costs are low. According to Lundqvist (1998), in 1997 almost 5000 km of road were dust controlled with Listab. Dustex and Listab are very closely related in that they are both based on lignin and are both byproducts in the production of sulphite pulp.

Differences between Listab and Dustex:

- Dustex is delivered in greater concentration, 50% dry substance, and it must therefore be diluted before use, while Listab is delivered in a solution ready for use (30-35%).

- Dustex is obtained from a calcium chloride process (calcium lignosulphonate) while Listab is based on sodium (sodium lignosulphonate).

7.1.3.3.1 Time of year and frequency

Depending on the time of year, treatment with lignosulphonates may be classified as basic treatment, annual treatment or supplementary treatment.

Basic treatment is described by Glänneskog and Skog (1994) as a form of stabilisation carried out once every ten years. This treatment stabilises and cements almost the whole wearing course and has a durable effect. A number of methods for mixing lignosulphonate into the wearing course are described in the literature.

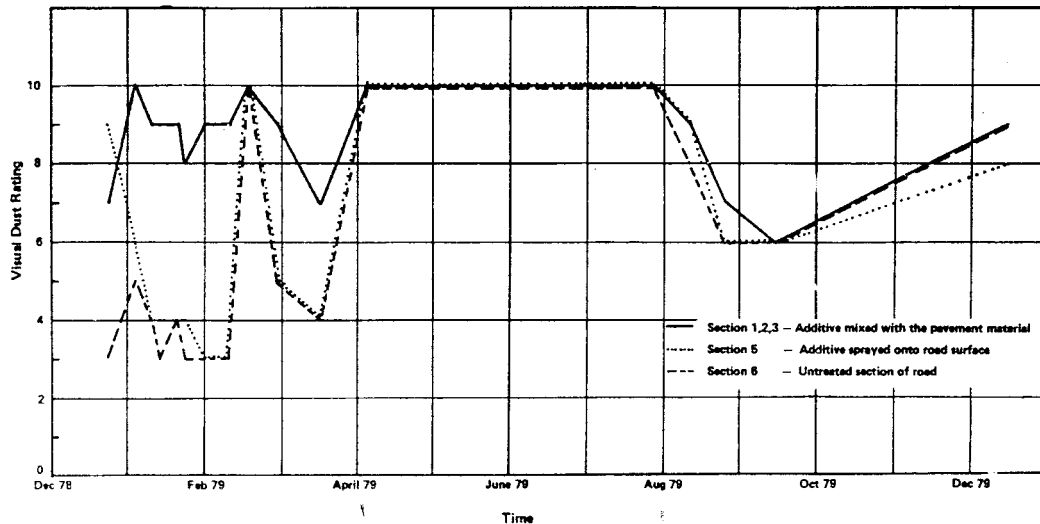
Annual treatment is carried out in the spring and is best if it is performed immediately after thaw when the road has the correct moisture content. If the road is too dry, a water tanker can be used.

Supplementary "superficial" treatment can be carried out if the road begins to deteriorate at the end of the summer after a long dry period. According to Lundqvist (1998), the proportion of road that requires supplementary treatment seldom exceeds 10%.

How often a road needs treatment with lignosulphonate varies from case to case. A test was performed in the road management area Mellerud in 1988 where only Dustex was spread. Dustex treatment was carried out on Road No 1131 on 13 May, and no more treatment was needed before 5 October (Hallberg, 1989).

According to Olsson in Bergström and Grebacken (1995), a road treated with Dustex must be maintained as much as a road treated with salt, i.e. about 3 times per season.

Armstrong (1981) carried out a test in Australia. A road was treated for dust control by mixing lignin into the wearing course at the beginning of summer. Another road was treated with lignin by merely spreading lignin on the wearing course. Results indicate that dust on the first road was reduced to an acceptable level for up to three months. On the other road dust was reduced for only two weeks before the first rain arrived and washed away the lignin. Armstrong adds that on the first road, even after three months when dust began to be emitted, some lignin was still left in the wearing course. Owing to the remaining lignin, a smaller quantity is needed on the next dust control occasion. The test also shows that the effect of spreading and admixture is the same during the period April-August. This may be due to humidity in the winter. The results of this test are set out in figure 7.4. What weather conditions were like compared with Swedish conditions is however not clear.



Visual Dust Rating of 0 - Zero Visibility Condition
 Visual Dust Rating of 10 - Dust Free Condition

Figure 7.4 Visual assessment of dust emission on three different sections (Armstrong, 1981).

7.1.3.3.2 Application of lignosulphonates

In the same way as in dust control using salts, application of lignosulphonates may be described in three stages, analysis of road, spreading or admixture of lignosulphonate, and plant and equipment.

A. Analysis of road

Analysis is largely the same in dust control using salt, lignosulphonate or bitumen emulsion. This stage was described in Subclause 7.1.3.2.1. Analysis may be performed prior to annual treatment, basic treatment and/or supplementary treatment.

B. Spreading or admixture of lignosulphonate

Lignosulphonate can either be spread on the road or mixed into the wearing course to achieve a deeper effect. The method used depends on the purpose of the treatment.

B.1 Spreading

In Sweden, lignin is often spread on the wearing course at the time of annual treatment and supplementary treatment.

At the time of annual treatment in the spring, the road is first graded so that the surface is loosened up and the lignin is then applied in two passes. To ensure that the road is also compacted, a spreader lorry can be used, but it is best to deploy a pneumatic tyred roller (Glänneskog and Skog, 1994). However, it is not clear how a spreader lorry can be used to compact the road.

According to Bergström and Grebacken (1995), tests were made with different rollers to compact the road, but the results suggest that this is not economically justifiable. Lundqvist (1998) considers however that it is best if the road can be

properly compacted after spreading so as to ensure that the dust control treatment has the maximum life.

Both Bergström and Grebacken (1995) and Glänneskog and Skog (1994) say that Dustex should be mixed with water in the proportions 1 part of Dustex to 2 parts of water so that it should mix with the aggregate more easily. Water can with advantage be pumped up by the spreader lorry from the nearest watercourse. Glänneskog and Skog consider that brackish or salt water has no deleterious effect on the results.

In his field tests, Cleghorn (1992) carried out dust control treatment with lignin as follows. The road was graded to remove surface unevenness and then compacted until about 100% degree of compaction was achieved. The road was watered if necessary before the lignin was spread.

Sultan (1974) used both spreading and admixture in his field tests. Spreading was carried out in three stages; grading with a smooth blade, spreading and compaction with a pneumatic tyred roller.

B.2 Admixture

Lignin is often mixed into the wearing course during basic treatment. Glänneskog and Skog (1994) describe admixture as follows: the road is graded, lignin is spread on the surface and is mixed into the wearing course to a depth of about 3-4 cm by turning the windrow with a grader. In the method employed in the tests carried out by the firm Vägmaskiner AB, the total quantity of binder used was 1.0-1.5 kg/m² and it was spread as a 40-43% aqueous solution. The lignin was spread and mixed in three stages (Lignin stabilised gravel roads, 1988).

Stage 1: A small quantity, about 5-15% of the total quantity of lignin, is mixed in the water used to water the road.

Stage 2: About 60-80% of the lignin solution is applied to the road in a number of passes. Between the passes the grader turns the windrow so that lignin is gradually worked into the aggregate. The grader distributes the aggregate over the road so that the camber is 4-5% with a pronounced peak "A".

Stage 3: The remaining lignin, about 20-25% of the total quantity, is then spread over the carriageway as a sealant. This quantity can to advantage be diluted in a larger quantity of water. However, the quantity of water applied should not be so large that the road is saturated. The gravel wearing course is compacted with a 5 tonne towed vibratory roller. Experiences from the test suggest that use of a smooth wheeled roller is not suitable since the moist lignin-treated aggregate easily sticks to the roller.

As mentioned above, Sultan (1974) used both spreading and mixing in his field tests. He describes the working method for mixing in the following eleven stages:

- Watering
- Ripping the surface by using the ripper attached to the grader to a depth of 8 cm

- Watering
- Spreading some of the lignin. Sultan does not however explain what proportion of the lignin should be spread
- Grading so that the loose wearing course forms a windrow along each edge
- Distribution of the two windrows evenly over the two halves of the road
- Spreading the remaining lignin
- Grading so that the loose wearing course forms a windrow in the middle of the road
- Distribution of the windrow evenly over the two halves of the carriageway
- Shaping the road surface
- Compaction with a pneumatic tyred roller

Jones (1984) calls the mixing method "mix in place". He describes this method as the one most common in Kenya for dust control with lignosulphonates. According to Jones, the thickness of the wearing course into which lignosulphonate is to be mixed should be 7.5-0.0 cm. The road is first graded and the lignin is spread, after which the wearing course and the lignin are mixed together and compacted.

C. Plant and equipment

The plant and equipment used for dust control with lignosulphonates are a water tanker, road grader and spreader vehicle.

C.1 Water tanker

A conventional water tanker is used on a road to be dust controlled with lignin. Often two tankers are needed (Lundqvist, 1998).

C.2 Road grader

Lundqvist (1998) says that two graders are needed. Bergström and Grebacken (1995) add that the grader should be equipped with "System 2000" on the blade so as to achieve best mixing and scarification of the wearing course. System 2000 is described in detail in Clause 7.2. A windrow spreader with a smooth blade should be used for final adjustment of camber and superelevation. If the road is narrow and the wearing course extremely thin, a grader equipped with a smooth blade is used instead of a windrow spreader.

C.3 Spreader vehicle

Lundqvist (1998) notes that Listab is spread with an ordinary water tanker equipped with a special spray bar with jets. This bar is pressurised with either the existing hydraulic pump or another pump. Listab is forced through the jets which produce a fine spray, resulting in good deep action on the road. With this set of vehicles, 2 graders, 2 water tankers and a spreader vehicle, the capacity is 20-35 km/day.

If lignin is spread the day after grading when the road has already been compacted by traffic, dust control acts only as a surface seal (Bergström and Grebacken, 1995).

When Listab is to be used on roads that are not in the immediate vicinity of a Listab depot, a tank is also needed for intermediate storage. In most cases the suppliers makes this tank available, which also has the advantage of being mobile (Lundqvist, 1998). Since the flow rate from the jets is known, coverage is adjusted by varying the speed.

7.1.3.3.3 Quantities of lignosulphonate

Information varies regarding the quantity of dust control agent to be spread at the time of basic treatment, supplementary and annual treatment. The quantity also varies depending on whether or not the road has already had lignosulphonates spread on it. It is at times not clear which type of treatment is referred to in the literature or what quantity of water is to be mixed with the lignin.

Quantities for basic treatment

Walterson (1995) writes that the quantity of lignosulphonate for stabilisation treatment of gravel roads shall be 2 kg/m². Bergström and Grebacken (1995) write that 1 kg Dustex solution per m² of road should be used in basic treatment. "Lignin stabilised gravel roads", (1988) says that when it is mixed in to a depth of about 5 cm, lignin at the rate of 1.0-1.5 kg/m² produces good cohesion. It is best to spread lignin as a 40-43% aqueous solution.

Quantities for annual treatment

Glänneskog and Skog (1994), Walterson (1995) and Bergström and Grebacken (1995) say that the quantity for annual treatment shall be 1.2 kg 50% Dustex/m of road. "Lignin stabilised gravel roads", (1988) gives the same quantity, but that it should be spread as a about 20% solution. Hallberg (1989) gives a larger quantity than others, 1.5-2 kg solution per metre run of road.

It is seen from the Norwegian report "Dust control of gravel roads" (1993) that the quantity of Dustex used in tests in Norway is 2.0-3.0 kg/m. Svensson (1997) quotes Holmen LignoTech (1989) and says that the quantity of Dustex should be 1.5-2 kg solution per metre of road. Lundqvist (1998) says that 0.5 kg Listab/m² should be regarded as normal coverage. This is equivalent to 3 kg/m on a road 6 m wide. In practice, coverage is 2-4 kg/m depending on several factors such as traffic flow, topography, road material, etc.

Quantities for supplementary treatment

Hallberg (1989) says that for supplementary treatment Dustex must be mixed with four parts of water and spread at a rate of 1.5-2 kg solution per metre run of road.

7.1.3.3.4 Environmental impact of lignosulphonate products

Lignosulphonates are mainly spread into the environment by leaching from the wearing course into the surrounding land and water environment. Operation and maintenance measures affect the following areas:

- A. Vegetation and soil
- B. Sources of water supply
- C. Corrosion
- D. Health hazards

A. Effects on vegetation and the soil

Walterson (1995) quotes a study performed by Stapanian and Shea (1986). This study showed that, for single application of 5-15 kg calcium lignosulphonate dry substance per m², mobility through the soil profile was low and thus the residence period was sufficiently long for degradation and/or deposition and take-up of single substances in the soil strata to take place.

It is evident from the material studied by Walterson that when lignosulphonates were applied in the field at a rate of at least 10 kg dry substance/m², no growth retardation effect was observed in green plants; this is a quantity about 30 times as high as that in dust control and 5-6 times as high as that for stabilisation of carriageways. The conclusions drawn by Walterson are that, at the quantities applied on carriageways, the risk that plants along the road will be affected is probably low. The toxicity to plants and corrosion are considerably reduced when the pH value is adjusted to between 6 and 7 (Listab WIBAX AB, 1997, in Swedish).

As regards effects on vegetation and the soil, the following facts are known from product information for lignosulphonates (Bergström and Grebacken, 1995):

- Lignosulphonates contain heavy metals, for instance cadmium, chromium, lead and mercury, but in quantities below the permissible threshold limit values. However, the heavy metal content depends on where the tree used had grown. If the raw material comes from an area with a high heavy metal content, the contents in the dust control products will also be high.
- Lignosulphonates do not give rise to any environmentally harmful degradation products.
- Lignosulphonates have little effect on vegetation.

B. Effects on sources of water supply

Dispersion of dust control agent to groundwater depends on the quantity per unit area that is supplied each year.

If lignosulphonate products get into a well the water is discoloured and has a musty smell, similar to that of humus formed by natural breakdown of plants and trees. However, the water is not dangerous to health. Walterson (1995) says there are no data in Sweden relating to the quantities in lakes and watercourses of the substances contained in lignosulphonate products which can be associated with the treatment of gravel roads.

C. Corrosion

Investigations by the Swedish Testing and Research Institute have shown that Dustex 50 causes appreciably less corrosion on steel sheeting than either clean water or hygroscopic salts (Walterson, 1995).

D. Health hazards

Lignosulphonates pose no danger to people and are not allergenic. Only ordinary working clothes need be worn during spreading. Any liquid splashes can be removed by washing in water (Bergström and Grebacken, 1995).

During evaporation that is part of the production process volatile components such as acetic acid and sulphur dioxide are given off, which makes the final product less toxic. Animal experiments show that acute toxicity is very low when the investigated lignosulphonates are administered orally. The long term effects of lignosulphonates on animal health have been the subject of many investigations. The results of studies for the permit procedure of e.g. the US Department of Health and Human Service, ADAMs (1988) are reproduced in Walterson (1995). Walterson adds that Dustex and Listab are approved by the Swedish Board of Agriculture as additives to animal feed.

According to Bergström and Grebacken (1995), the following facts are known from product information relating to lignosulphonate based products:

- Lignosulphonates contain no other organic substances in concentrations hazardous to health.
- No damage to people exposed to lignosulphonates has been reported.
- In normal cases, lignosulphonates have low toxicity to fish, but in LIGNOSOL AP-35, a product that contains 15-16% lignin, there are some resin acids that are very toxic to fish.
- Lignosulphonates contain no dioxins.
- Lignosulphonates are not toxic to mammals and do not appear to be skin or eye irritants.
- Contents of toxic trace elements are below the limits laid down by the US Environment Protection Agency.

7.1.3.3.5 Experiences from the use of lignosulphonates

The following experiences are quoted in the studied literature:

- Wearing courses rich in soil binder are dust controlled better with Dustex than with calcium chloride. The effect of Listab is very often entirely dependent on the composition of the wearing course. It is necessary for the fines content to be at least 10% and preferably higher in order that lignin should bind the material effectively.

A high fines content in the aggregate material produces a negative effect in conjunction with rain. A return to the use of lye is therefore open to doubt.

- The use of Dustex is recommended in view of corrosion. This may also be nationaleconomically justified since this product is a domestic one (Bergström and Grebacken, 1995).
- Clayey roads benefit from the stabilising effect of lignin since the surface becomes hard and resistant to precipitation.
- Handling of Dustex is often found cumbersome. Problems have been encountered in pumping from the storage tanker to the spreader. The lye

froths and blocks the pump. Hallberg (1989) gives some solutions, e.g. placing the storage tank so that gravity flow is achieved.

- Dustex requires a porous surface to penetrate into the carriageway.

"Lignin stabilised gravel roads" (1988) gives the following recommendations for best results with lye:

- The composition of the gravel wearing course should conform to the ideal aggregate curve. The actual filler proportion may be higher, but should preferably be no lower. There shall be no lumps of sand.
- If possible, the moisture content of the surface layer should, after the product has been sprayed, be equal to the optimum moisture ratio which is 4% or higher, but it should not be saturated. The surface layer shall be moist but not sticky in order that compaction should be optimal and service life long.
- The camber of the road shall be about 4-5% and there shall be a pronounced peak in the centre. There shall be no flat portions.
- Immediately after treatment, the road should be compacted with a pneumatic tyred roller or a lorry.
- Favourable results have been achieved using a combination of Dustex and clay. If the wearing course aggregate has a uniform composition with a low proportion of fines, a larger quantity of Dustex is required for satisfactory dust control.

7.1.3.4 Bituminous materials

Tests on controlling road dust with bituminous products have been made in Sweden for a long time. Lindh (1981) quotes Hubendick (1975) who says that as early as at the end of the 1930s extensive tests were made in Sweden to control road dust with Estonian shale oil. Bitumen emulsion is the most common agent.

Bitumen emulsion (BE)

In order to satisfy the wishes of road users that gravel roads should be paved, some counties in Sweden have used bitumen emulsion for dust control of gravel roads. Dust control with bitumen emulsion has already been tested in e.g. USA, Canada and New Zealand. The method is a good alternative for the maintenance of roads that are less susceptible to frost damage (Road maintenance-roads free from snow and ice, 1992). It is thought that use of bitumen emulsion on gravel roads reduces the number of times the road has to be graded (Gustafsson, 1982).

Bitumen emulsion binds the dust through its adhesive effect, and, in the same way as lignosulphonate, it can be used even when the carriageway is dry (Bergström and Grebacken, 1995).

There are three factors that impede the use of bitumen emulsion and have the effect that it is not at all times possible to determine its usefulness as a dust control agent. These factors are:

- Relatively high cost in the first few years

- Small experimental base. Only 1% of the gravel road network was dust controlled with bitumen emulsion in 1997
- Short follow-up period

However, dust control with bitumen emulsion is considered by the Swedish National Road Administration to be of such interest that further tests should be made (Road maintenance-roads free from snow and ice, 1992).

Emulsion is a chemical system comprising two liquids that are insoluble or only slightly soluble in each other, one of which is suspended in the other in the form of colloidal particles. Bitumen, the first liquid that is often in the form of spherical particles, forms the disperse phase. The other liquid is water and is the dispersing agent.

Different descriptions of the **composition of emulsion** are given in the literature.

Krigsman (1993) says that the composition of emulsion is based on a 60% bitumen emulsion, i.e. the bitumen content is at least 60% of the emulsion. The basic bitumen is normal fluxed bitumen MB 2000 which has a further about 5% flux added to give it good penetration properties when mixed into the gravel wearing course. The remaining components are emulsifiers and water. Before the bitumen emulsion is spread on the road, it is mixed by pumping it in the spreader tank with equal volumes of water.

Bergström and Grebacken (1995) describe the bitumen emulsion used in Örebro and on Gotland as a blend of the following substances:

1. About 30% fluxed bitumen. Fluxed bitumen "MB" consists of a B180 fluxed to MB 2000. The mean value of the kinematic viscosity of MB 2000 is 2000 mm²/s at 60°C. The flux used is an oil refinery product that has a lower viscosity than the basic bitumen it is mixed into. Diesel is a very common flux.
2. About 65-70% fresh water at a temperature of about 80°C. The two liquids, fluxed bitumen and fresh water, are mixed in a heated mill (Bergström and Grebacken, 1995).
3. Emulsions may also contain solvent, e.g. diesel. It is added to make bitumen less viscous for a longer period after the emulsion has broken.
4. About 0.4% emulsifying agent that prevents separation of the mixture.

There are three types of emulsifying agent, anionic, cationic and neutral. Anionic agents were introduced as early as 1930 while cationic agents first appeared in 1958 (Lindh, 1981). In Sweden cationic emulsifying agents are used almost exclusively, and specifications have therefore been developed for these.

When the emulsion has been spread on the road, the disperse phase must separate or coagulate. The emulsion must coagulate irreversibly, i.e. no new emulsion must form when water is added. During coagulation the coating on the suspended droplets is disrupted so that the bitumen begins to work as a dust control agent through its adhesive effect. As a rule, the emulsion persists for a couple days in a

tank before separation commences. The emulsion is stored in tanks at a temperature around 30-40°C the whole time, to prevent both separation and evaporation of water (Bergström and Grebacken, 1995).

7.1.3.4.1 Quantities of bitumen emulsion

The quantity of emulsion that must be applied the first year is about 2 kg/m². The rate of application during maintenance treatment is 1 kg/m², but if a larger quantity of new wearing course gravel is needed, maintenance treatment must also be applied at 2kg/m². A total of 4 kg/m² is laid in the first three years, and the road is left to rest in the fourth year. At present this method appears to be the best (Bergström and Grebacken, 1995). It is seen from the report "Effect of dust palliatives on unsealed roads in New Zealand" (1995) that 0.33 l/m² was used in tests in New Zealand. The quantity 0.33 l/m² was used for both surface dressing and stabilisation. According to the report, the term "surface dressing" means that the road surface is first watered and then graded to shape the road, and emulsion is then applied. Sometimes the road is also watered after emulsion is applied.

7.1.3.4.2 Method specification for dust control using BE

Simonsson (1978) quotes two alternative methods for dust control using bituminous materials:

- The bituminous material and the existing aggregate are mixed together by the mix-in-place method. This method is usually referred to as the **soft method**.
- Surface application to achieve penetration of the bituminous material into the road surface without the application of chippings. The method is usually referred to as the **hard method**.

In the first method, a large quantity of binder of high viscosity is used, while in the second method a smaller quantity of binder of low viscosity is applied. According to Simonsson (1978), the prevailing opinion is that dust control through surface application of different oils has a short life, which means that repeated applications are necessary and this, in turn, limits this application. Simonsson states that treatment by mixing in larger quantities of binder provides a better effect, but in reality these methods must be regarded as bitumen stabilisation or simple forms of surfacing. It is worth noting that the boundaries between the soft and hard method are indistinct. The two methods are described in the following.

A. The soft method

In the soft method, the character of the gravel road is retained, but dust is controlled. The road is still so gradable that a road grader can be used to work and shape the surface. The method comprises the following operations:

- a. Watering
- b. Grading
- c. Application of emulsion, type BE 60/65, about 2 l/m²
- d. Mixing of aggregate and emulsion with the grader
- e. Compaction by traffic

Bergström and Grebacken (1995) say that the soft method has been tested on e.g. Gotland and in Örebro. According to Junes (1988) and Karlsson (1989), the method has also been tested in Norrbotten (Råneå). "Road maintenance-roads free from snow and ice" (1992) describes another method developed during the "Västerås test". This method is difficult to classify as either the soft or hard method. The following tests or methods may be classified as soft methods and will be described below.

A.1 Test in Råneå

A.2 Gotland method

A.3 Örebro method

A.4 Västerås method

A.1 Test in Råneå

In the summer of 1988 emulsion was tried in Råneå on a road of 6 m width with a traffic volume of 130 AADT. The length of the road was 10 km (Junes, 1988) and (Karlsson, 1989). The method was applied in three stages:

Stage 1: The road is watered and 2-3 cm of the wearing course is graded into a windrow along each edge of the road.

Stage 2: About 2 litres emulsion per m² are spread on each half of the road at a time with an ordinary water butt.

Stage 3: The aggregate windrows are spread over the emulsion and the two are mixed into a homogeneous mass before the road is shaped.

A.2 Gotland method (Bergström and Grebacken 1995)

The reason that gravel roads on Gotland began to be dust controlled with bitumen emulsion is that in 1991 the Swedish National Road Administration and Gotland Municipality jointly resolved that Gotland would be completely salt free all round the year. Over the period 1992-1996 dust control using emulsion was therefore performed for Gotland Municipality on 60-70 km gravel roads annually. Road widths varied between 3.0 and 4.5 m. The Gotland method comprises three stages: analysis of road, spreading and mixing of bitumen emulsion, and plant and equipment.

A.2.1 Analysis of road

The analysis is broadly the same as for dust control with salt and lignosulphonate. This stage has been described in Subclause 7.1.3.2.1.

A.2.2 Spreading and mixing bitumen emulsion

The road is graded down to 50 mm, after which it is watered and the emulsion is spread. The emulsion is mixed into the wearing course which is then compacted. The emulsion used contains at least 55% bitumen. Emulsion spreading needs a water tanker, an emulsion spreader and a specially equipped road roller.

Application begins by watering the previously graded road immediately before the emulsion spreader to ensure that the wearing course is thoroughly wet. The quantity of water is not described; it is merely pointed out that the wearing course should be "sufficiently wet".

The quantity of emulsion applied is controlled by the speed of the spreader vehicle. The spreader vehicle is followed by the grader that mixes emulsion into the wearing course and adjusts camber and superelevation very accurately. It is essential that the grader should mix the wearing course properly and spread it evenly right out to the edges. Bergström and Grebacken (1995) draw the conclusion that accuracy on the part of the grader operator is very important for achieving satisfactory results. When the whole road has been treated and has dried to some extent, the water vehicle returns to compact the wearing course.

Final compaction is carried out by traffic. Investigations are in progress to ascertain whether or not compaction with a roller is necessary. In order that application should not be disrupted by breakdowns, tanks of emulsion and water are set out in suitable places along the road. The vehicles are designed so that the entire tank can be changed. Bergström and Grebacken (1995) are of the opinion that coordination within the application train is a highly critical factor for a good final result. All in the group must be in contact in order to regulate speeds and quantities and to make sure that work is satisfactory. See figure 7.5.

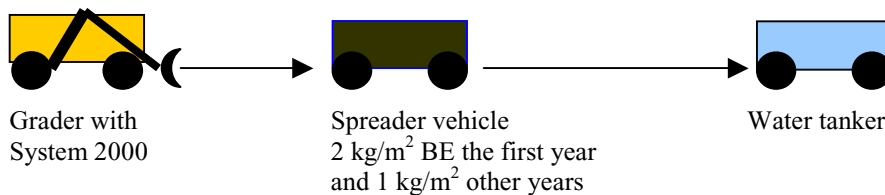


Figure 7.5 *The soft method, Gotland method.*

Drivers must maintain contact via radio. The driver of the emulsion spreader vehicle dictates the speed of the water tanker through visual assessment of the moisture content of the carriageway. In turn, the grader driver dictates the speed of the spreader vehicle in regard to the quantity of emulsion. After a day or two, the bitumen emulsion will have dried and the wearing course compacted by traffic. The results of the treatment will be satisfactory if edge trimming and grading have been performed accurately. Before the road has dried, the emulsion may soil vehicles using the road.

A.2.3 Plant and equipment

The plant and equipment that are used in dust control by this method are a water tanker, a road grader to scarify the wearing course, a road grader to spread the emulsion into the aggregate, and a spreader vehicle to distribute the bitumen emulsion.

The **water tanker** is articulated and fitted with extra wide single tyres. Conventional double tyres would produce a troublesome uncompacted bank of material between the wheels. In this way, the whole width of the double wheel is compacted in one pass. Attempts have also been made to use different kinds of

pneumatic tyred rollers, but this has not been successful or economically justifiable. The aggregate-emulsion mixture got caught up on the tyres. When the water tanker is employed, this problem does not arise.

The **road grader for scarifying** the wearing course is a 14 tonne grader equipped with System 2000 on the blade and a toothed blade on the windrow spreader. These blades break down the wearing course gravel to a lesser extent than a smooth blade.

The **road grader for mixing** the emulsion is a 14 tonne road grader equipped with System 2000 on the blade and a smooth blade on the windrow spreader. The reason that a smooth blade is fitted on the windrow spreader is that more even and better mixing of emulsion into the wearing course is to be achieved. When a toothed blade was used, windrows of emulsion-aggregate mixture were left behind the grader, with the aggregate and emulsion separated. System 2000 is described in detail in Clause 7.2.

The **spreader vehicle** is an ordinary lorry with a tank. The tank is fitted with a spray bar at the back of the lorry. The spray bar is controlled from a panel near the driver so that emulsion can be spread evenly and as needed along the entire width of the road. The tank is equipped with a pressure gauge since the rate of spread is regulated by pressure. The tank volume is 11,000 litres which is enough for about 3.5 km of road.

Experiences gained with the Gotland method

The problems encountered in the Gotland method were e.g. a high fines content, potholes with very sharp edges, formation of banks and difficulties in using the grader and windrow spreader.

- **High fines content**

There are two reasons for a high fines content on Gotland. The first is that the aggregate for the wearing course is limestone. Limestone is a weak rock that is broken down both by traffic and when the road is graded. Owing to the breakdown of limestone, the fines content increases in time and the effect of dust control diminishes. The second reason is that gravel roads on Gotland are often along agricultural land. Tractors and implements carry clay and soil from the fields to the road. This has the effect that the fines content in the wearing course gravel increases and becomes excessive.

If the wearing course has a too high fines content, dust control will be unsuccessful because the emulsion must bind a much larger surface than if the particle size distribution is correct.

This problem appears to have been solved by correcting the composition of the wearing course during maintenance by the addition of certain fractions, e.g. aggregate of 8-16 mm fraction so that the distribution comes as close as possible to the ideal curve, but with a smaller quantity of fines. Bergström and Grebacken (1995) note that when a change was made on Gotland to dust control with emulsion, the aggregate required for supplementary spreading decreased from

about 30 m³/km to about 6 m³/km annually. Supplementary regravelling is described in detail in Clause 7.4.

- **Potholes with sharp edges**

Potholes have very sharp edges and shake vehicles very badly. Single potholes can be filled with oil gravel if the road is in a good condition in other respects, otherwise the road must be graded.

- **Difficulties in using the grader and windrow spreader**

When roads began to be treated with bitumen emulsion, difficulties were encountered because the windrow spreader tended to penetrate too deeply and to break up the material below the wearing course, and because the transition sections between camber and superelevation were unsatisfactory. These problems were overcome when the supporting wheels of the windrow spreader that mixes in the emulsion were equipped with hydraulic height control. Difficulties still arise because emulsion blocks up the blade fitted with System 2000. This difficulty is minimised by properly cleaning the blade at the end of each working day.

A.3 The Örebro method

In Örebro, dust control using emulsion is still experimental activity on a small scale (Bergström and Grebacken, 1995). The Örebro method is described in three stages, road analysis, spreading and mixing the emulsion, and plant and equipment. It is worth noting that the Örebro method is no longer used.

A.3.1 Analysis of road

The analysis is performed in the same way as for other dust control agents. What must be pointed out is that in the Örebro method the road must be prepared one day prior to spreading the emulsion.

A.3.2 Spreading and mixing the bitumen emulsion

The rate of spread of emulsion is 2 kg/m² in the first year and 1 kg/m² in other years. The method requires two water tankers, one emulsion spreader, a road grader and a pneumatic tyred roller.

Treatment begins by applying large amounts of water to the road. When this pretreatment has been carried out, water is again sprayed immediately before the emulsion spreader. The wearing course should be so wet that when a shoe is pressed into the road, a pool is formed. The emulsion spreader is followed by the grader that mixes the emulsion into the wearing course and at the same time adjusts camber and superelevation.

In order to prevent the formation of ruts by ordinary vehicles, the road is compacted with a pneumatic tyred roller immediately after the grader has mixed the wearing course. However, fine material mixed with bitumen tends to stick to the wheels of the roller. It is not clear what significance this has for the final result; the wearing course might become devoid of fines. On roads wider than 6 m, one half is treated at a time.

A.3.3 Plant and equipment

Two ordinary water tankers are used to water the road. The same grader is used for pretreatment and mixing the emulsion into the wearing course. The grader is an ordinary 14 tonne road grader equipped with System 2000 on the blade, and a smooth blade on the windrow spreader. The windrow spreader is fitted with wheels that stop it from penetrating too deep; see figure 7.6.

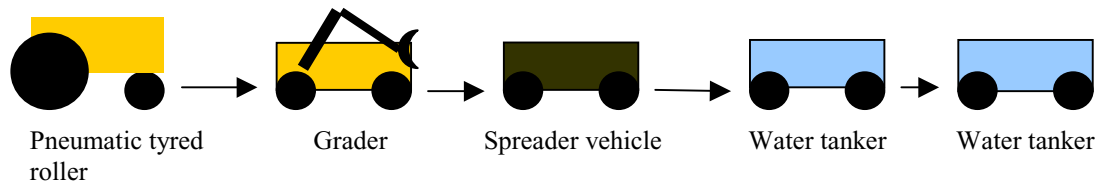


Figure 7.6 The soft method, Örebro method.

Comparison between Gotland method and Örebro method

Table 7.3 shows a comparison between Gotland method and Örebro method.

Table 7.3 Differences between Gotland method and Örebro method.

| | Gotland method | Örebro method |
|---|--|--|
| 1 | Wearing course of limestone | Wearing course of moraine aggregate and crushed rock which is less porous than limestone |
| 2 | During pretreatment comprising watering and grading, grading depends on how damaged the road is. The grader scarifies to a depth of 1.5-3 cm | During pretreatment the road is graded to a depth of 5-10 cm irrespective of how damaged the road is |
| 3 | Pretreatment should be carried out not more than 4-5 hours before emulsion treatment | Pretreatment is carried out the day before emulsion is spread |
| 4 | 1 water tanker, 1 spreader vehicle and 1 grader are used for emulsion treatment | 2 water tankers, 1 spreader vehicle, 1 grader and 1 pneumatic tyred roller are used for emulsion treatment |
| 5 | Watering in conjunction with emulsion treatment is carried out once before emulsion is spread | Watering in conjunction with emulsion treatment is carried out twice before emulsion is spread |
| 6 | Rate of spread of emulsion is 2 kg/m ² in first year and 1 kg/m ² otherwise | Same rate of spread as in Gotland method |
| 7 | Road is compacted by traffic | Road is compacted with a pneumatic tyred roller |
| 8 | Windrow spreader is equipped with toothed blade for pretreatment and with smooth blade for mixing in emulsion | Windrow spreader is equipped with smooth blade for both pretreatment and mixing in emulsion |

A.4 Västerås method

Only one experiment has been carried out by the National Swedish Road Administration. This was done in the vicinity of Västerås in the spring of 1991. The method was carried out in four stages:

Stage 1: Crushed aggregate is mixed with BE 60/65 emulsion. Mixing can be carried out in a conventional oil gravel works, but it has also been done in a

mobile slurry machine. The quantity of emulsion added is 3.5% by weight. The mixed material can be stored for later use.

Stage 2: The aggregate-emulsion mixture is deposited on the road with a lorry.

Stage 3: The material is adjusted with a road grader. The layer thickness shall be 4-5 cm.

Stage 4: The adjusted surface is rolled with a pneumatic tyred roller.

Figure 7.7, 7.8 and 7.9 show deposition, spreading, adjustment and rolling (Road maintenance-roads free from snow and ice, 1992).



Figure 7.7 *Deposition of crushed aggregate-bitumen mixture on the road.*



Figure 7.8 *Spreading and adjustment.*



Figure 7.9 Rolling.

Advantages of the soft method

Palmgren (1997) summarises the results of dust control with emulsion on Gotland. See table 7.4.

Table 7.4 Summary of results of dust control with emulsion on Gotland.

| Expected result | Previous method | Dust control with BE |
|-----------------------|--------------------------------|-------------------------------|
| Dust control | Variable result | 90% of dust bound |
| Aggregate consumption | 30 m ³ /km annually | 6 m ³ /km annually |
| Grading | 5-6 times annually | 2.5 times annually |
| Price | 100% | 75% |

The following comments may be made on the above summary.

- a. The table does not consider environmental effects.
- b. It is not clear for how many years dust control with emulsion must be carried out before the method is profitable.
- c. The table does not say what methods are being compared.
- d. What operations are included in the price?
- e. It is not clear what is meant by 90% of dust being bound.
- f. It is doubtful that all gravel roads need 30 m³ aggregate/km annually.
- g. In view of the fact that rock on the island is limestone, is the experiment on Gotland applicable in other conditions? Because of limestone, the breakdown process is different. This means that the number of grading and dust control operations will be different.

Krigsman (1993) quotes some positive properties of dust control with emulsion:

- The gravel road can be graded again and compacted in spite of previous admixture of emulsion.

- The cost of the annual regravelling can be steeply reduced or completely discontinued on sections dust controlled with emulsion. This saves wearing course aggregate.
- After three years, the road will have acquired a quantity of bitumen equivalent to the single course surface dressing.
- Maintenance is reduced since grading is carried out less often. On some of the test sections grading has been reduced by 50%.
- Environmental benefits since no salt is spread and corrosion attack on vehicles is therefore reduced.
- Expenditure on gravel road maintenance is reduced.

B. The hard method, Blekinge method

In the hard method, the road is given a bound surface, and the results are perceived by road users as though the road had been paved. This is called the hard method because the gravel wearing course becomes so hard that it must often be crushed in a crushing plant in conjunction with maintenance. The method is sometimes called the Blekinge method since it was first tested in Blekinge County. In 1987, all remaining gravel roads in the Johannishus road management area in Blekinge County were dust controlled with bitumen emulsion as an alternative to conventional dust control with calcium chloride. Thomasson has summarised this test in three reports, VFK Delrapport 1 (1988), VFK Delrapport 2 (1989) and VFK Delrapport 3 (1991). All these reports are in Swedish.

Execution of the hard method

Road maintenance-roads free from snow and ice, (1992) divides execution of the hard method into two, measures in the year before dust control and measures in the year of dust control.

B.1 The year before dust control

The following should be carried out as pretreatment the year before dust control:

- Ditch clearance.
- Removal of stones from the road.
- Regravelling of such fraction that the fines content (0.074 mm) in the top 2 cm of the wearing course is less than 10%.

B.2 The year of dust control

Dust control is carried out as follows:

- The road is watered and graded so that the correct crossfall is obtained
- The road is rolled after grading. Rolling is sometimes omitted.
- The road is kept slightly moist before emulsion is spread. Watering is sometimes omitted (Road maintenance-roads free from snow and ice, 1992).
- Emulsion BE 50 M is spread at the rate of 1.5 l/m² (Road maintenance-roads free from snow and ice, 1992). In the Blekinge method, about 1.4 kg/m² BE 45/MY is used (Thomasson, 1988).
- Sand dressing with 0-8 fraction, about 10 l/m²

- Traffic allowed to compact wearing course after dust control
- After some days the road is swept. Sweeping is sometimes omitted. See figure 7.10.

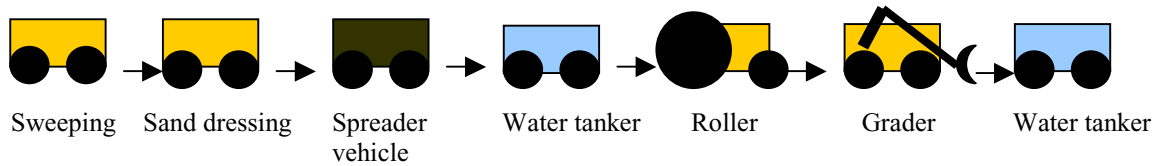


Figure 7.10 *The Hard method.*

Advantages and disadvantages of the hard method

Thomasson (1988) compares the above with gravel roads dust controlled with salt or lignosulphonate and gives the following advantages and disadvantages.

Advantages

- Large nationaleconomic gains can be achieved due to shorter trip times, reduced corrosion, etc. However, Thomasson does not say how large these gains are. No nationaleconomic calculations for gravel roads have been found in the litterature.
- The road is perceived to be a paved road.
- Use of salt can be reduced.
- Material that does not comply with specifications can be used.
- Soiling is reduced.

Disadvantages

- More expensive method. The test indicates that under some conditions it is 10-15% more expensive over a 10 year period than conventional gravel road maintenance, but this disregards the nationaleconomic gains.
- It is probably difficult to return to conventional gravel road maintenance.
- The condition of the road is slightly worse in winter since this dust control is sensitive to the action of the plough during snow clearance.

7.1.3.4.3 Differences between the soft and hard method

A comparison of the two methods is given in table 7.5.

Table 7.5 Comparison of the soft and hard method.

| | Soft method | Hard method |
|---|--|---|
| 1 | A road grader can be used to scarify and shape the road | The gravel layer must often be crushed in a crushing plant after many dust control treatments |
| 2 | Execution: a. Watering b. Grading c. Spreading emulsion d. Mixing of aggregate and emulsion e. Compaction by traffic or with roller | Execution: a. Grading b. Compaction with roller c. Spreading emulsion d. Blinding e. Sweeping after a few days |
| 3 | BE 60/65 is often used as binder. The emulsion contains 70% bitumen | Binder used is as follows: Blekinge County, BE 50 M Johannishus area, BE 45 M The emulsion contains 45-50% bitumen |
| 4 | Rate of spread is 2 kg/m ² in first year and 1 kg/m ² in maintenance treatment in other years | Rate of spread is about 1.4 kg/m ² BE 45/MY (Karlsson, 1989) 1.5 l/m ² BE 50 MY (Road maintenance-roads free from snow and ice, 1992) |
| 5 | Gravel road character is retained | Road is perceived by road users as paved road |

7.1.3.4.4 Environmental impact due to dust control with bitumen emulsion

"Environmental effects of operation and maintenance of roads and streets" (1992), in Swedish, quotes some positive environmental effects, for instance less use of salt, reduced corrosion and a dust free environment near the road. One negative secondary environmental effect may be that, when emulsion is to be removed from vehicles and plant, environmentally hazardous degreasing agents are used. Environmental impact relates to the following areas:

- A. Vegetation and water pollution
- B. Transport
- C. Corrosion
- D. Health hazards

A. Vegetation and water pollution

"Environmental effects of operation and maintenance of roads and streets" (1992) states that in Norwegian laboratory experiments studies were made to find whether noxious components can be washed out of oil gravel and affect drinking water. It was found that water soluble and highly volatile fractions may reach sources of water supply. Bergström and Grebacken (1995) have however asserted that when emulsion has reacted and dust controlled the road, it is no longer soluble in water and cannot be leached.

When aggregate from the wearing course is dislodged, the bitumen emulsion remains on the particles and is not spread out into nature further than the aggregate itself. Most of the aggregate particles removed from the road collect in the ditches; when the ditches are later cleared they are collected up and deposited in a controlled tip. According to Bergström and Grebacken (1995), the problem may be considered to be of small significance and controllable.

It is worth noting that occasionally the bitumen does not break but runs into the ditch and from there into pools of water.

"Environmental effects of operation and maintenance of roads and streets" (1992) says that one negative secondary environmental effect may be that when emulsion is to be washed off vehicles and plant, environmentally hazardous degreasing agents are used.

B. Transport

Bitumen is regarded in transport as dangerous goods since it contains fluxing oil that is flammable (Bergström and Grebacken, 1995). In the Nynäs AB product description sheet (1998) it is stated that BE 60 M/2000 is not classified as dangerous goods by any national or international standardised transport regulations.

C. Corrosion

Emulsion does not contribute to corrosion, but acts rather as a good undersealing compound (Bergström and Grebacken, 1995). "Environmental effects of operation and maintenance of roads and streets" (1992) quotes some positive environmental effects such as reduced use of salt and corrosion, and a dust free road environment.

D. Health hazards

Kandeman (1983) made an investigation of chemical health hazards, noise, dust and exhaust gases in his work on the laying of emulsion concrete, surface dressing and the production of bitumen emulsion.

Kandeman says that complaints have involved headaches, itching, white/red skin rashes, dryness in the mouth and eyes. In all cases the personnel had been engaged on laying emulsion concrete. This is puzzling, since the greatest exposure appears to occur in conjunction with surface dressing, the spreading of bitumen emulsion or production at the emulsion plant.

Bergström and Grebacken (1995) discuss some health hazards in production. When the product is made, some hazardous substances such as diesel oil, hydrochloric acid, emulsifier and the bitumen itself are used. But the process is automated so that the personnel do not need to handle these substances. Hydrochloric acid and emulsifier arrive at the plant in tanks which are simply changed over. The emulsifier, EM 44, is a very strong basic soap and may on contact cause skin and eye irritation. Health hazards for personnel working with emulsion have been minimised. How this has been done is not described in Bergström and Grebacken's report.

In Nynäs AB's product description sheet (1989) for BE 60 M/2000 it is stated under the heading "Hazardous Properties" that the hazardous effects on human health are as follows:

- The product contains emulsifiers of the amine type. Prolonged or repeated contact with bitumen emulsion may cause skin and eye irritation in specially sensitive persons.

- Storage and handling of the product at high temperature, 50-80°C, may cause skin burns.

According to the product information sheet, BM 60M/2000 is not classified as hazardous according to the EU criteria.

7.1.3.4.5 Experiences from dust control with bitumen emulsion

The following experiences appear in the studied literature:

- Emulsion treatment shall be carried out as soon as the road has stabilised after thaw so that natural moisture in the road structure can be utilised without the road being deformed by the heavy vehicles needed for application.
- Weather must be dry when the road is treated with emulsion and for about another day after compaction. The reason is that emulsion must have time to bind the dust particles; rain during this binding stage will wash out the emulsion and the treatment must be repeated.
- The temperature of the road structure must be above freezing and preferably above +5°C for good results. Han (1992) recommends that dust control with bituminous materials should not be carried out if the temperature is below 10-15°C.
- When temperatures are very high, the newly treated road may have to be watered.
- For satisfactory results, it is necessary for personnel to have greater know-how and accuracy in dust control with bitumen emulsion than with salt.
- Damage mostly consisted of puncture marks. In the first year, damage appeared in the form of small holes about 2 cm in diameter. The cause of this damage may be that there had been a small protuberance, e.g. a stone, in the road surface during treatment and that the quantity of binder at this point was too small.
- It is stated in ROAD 94 that during dust control of gravel wearing courses with emulsion, a base course for paved roads in accordance with Subclause 5.5.1 in ROAD 94 should be used instead of that specified for gravel roads in Chapter 5, "Technical requirements for gravel roads". If this is done, dust control with calcium chloride is thereafter inappropriate.
- Foley (1996) is of the opinion that if a gravel road is to be dust controlled with bituminous materials, the use of sea water must cease at least 12 months prior to dust control. The reason is that salt may give rise to efflorescence and prevent penetration of the bituminous material into the wearing course. NaCl has the same effect on bituminous materials. Foley (1996) recommends a report written by Netterberg (1979) which gives details of damage to bituminous materials caused by salt.
- The report "Unsealed Roads Manual-Guidelines to Good Practice" (1993) contains a table that summarises previous experiences gained in Australia during dust control of different soils with bitumen emulsion. See table 7.6.

Table 7.6 Summary of experiences gained during dust control of different soils with bitumen emulsion.

| Stabilisation Method | General Range of Additive (% of Total Mass) | Soil Type | | | | |
|--|--|--------------------------------------|----------------------|------------------------------|----------------------|--------------------------------|
| | | Sands | Sandy Gravels | Sand-Clays | Silty Soils | Heavy Clays |
| Mechanical Cement | 10-50 1-6 | Variable Variable | Good Variable | Good Good | Fair Fair | Difficult Difficult |
| Lime Bitumen Emulsions | 2-4 1-10 4-10 | Poor Fair to Good Fair to Good | Poor Good Good | Good Good Fair to Good | Good Fair Fair | Fair Difficult Difficult |
| Chemical Geotextile | See text for comment on these methods of stabilisation | | | | | |
| Notes: 1. The range of additive to be used is a guide only. 2. Lime contents are expressed as equivalent 100% pure hydrated lime. 3. Advice on the correct amount of additive to use should be sought following a thorough analysis of materials and conditions for use. | | | | | | |

7.1.3.5 Clay

This subclause will deal with clay as a dust control agent. In case the fine material has been lost as dust from the wearing course, soil binder must be added to bind the loose aggregate. Greasy clay is generally used as soil binder. The need is determined by analysing the particle size distribution curve for the material and comparing this to the ideal aggregate curve.

An endeavour should be made to add the soil binder after thaw and at the time that the wearing course is dressed. Natural moisture content is usually sufficient, and this reduces the need for water and makes work easier.

In his tests in Älvsborg County over three seasons, Hallberg (1989) used a residual product from the paper industry, non-fibrous filler. In its dry form, this contains about 40% kaolinite clay. The remainder is cellulose fibre. The dewatered fibrous material has a dry content of about 35%.

The effects of kaolin are considered superior to those of clay application in older days, mainly due to the more homogeneous admixture into the wearing course gravel which is accomplished due to the consistence of the material and on the way it is spread. Care must be taken not to add too much material as this may make the carriageway slippery.

Beskow (1934) states that in the usual case when the gravel wearing course is badly bound and is easily corrugated, it should be treated either with a binder or by increasing the soil binder content, or possibly by both. Soil binder is mixed into the existing aggregate material with a grader. This addition of soil binder should be carried out when the road is wet after rain or watering. Once the material has been mixed in, the road should preferably be rolled, or traffic may be used to perform the necessary compaction.

When the proportion of soil binder is determined and it is mixed into the wearing course, care must be taken not to spread excessive quantities. This may cause

problems for traffic in wet weather. For the best effect, soil binder should be applied before the first dust control treatment of the year (Bergström and Grebacken, 1995).

7.1.3.5.1 Working methods for clay spreading

Jämsä (1982) says that clay can, in principle, be spread in three ways:

Spreading soil binder from heaps at the side of the road

The material is spread with spade from the back of a lorry. After this, aggregate is drawn into the road from the edges. The wearing course is then watered and the material is mixed with a road grader or drag. Mixing should continue until the soil binder and aggregate have been properly mixed into one another and formed a firm wearing course. Drying of the mixed mass should be prevented.

Soil binder deposited along the sides of the road

When soil binder has dried out it breaks up, and after the next fall of rain the material is mixed as in the previous case. This method is cheap and suitable for roads with little traffic. The drawback of the method is that some of the soil binder is often lost due to the effect of traffic and wind.

Soil binder and aggregate loaded from different piles

The materials are mixed together during loading and spreading on the road. The material is spread on the road from the back of a tipper lorry to a layer of suitable thickness, and is mixed into the wearing course with a grader.

Storage of soil binder over the winter makes work easier since the slabs of clay are broken up by frost and this promotes the ease of mixing of the soil binder. Storage is a measure that must often be resorted to since soil binder cannot at all times be extracted in the period best for spreading, owing to slippery conditions or poor bearing capacity in clayey areas.

In Hallberg's (1989) tests with kaolin, this was spread as follows: the material was spread with a fertiliser spreader drawn by a tractor or a clay spreader that is often a converted sand spreader. The edge masses, aggregate and kaolin were mixed with a road grader. Water was added if needed.

According to Halberg (1989), the rate of spread of kaolin varies but is normally 7-10 m³/km. According to Jämsä (1982), the quantity of clay spread at one time is usually 6-12 m³/km.

7.1.3.6 Oil as dust control agent

Examples of oil used as dust control agent are crude oil and waste oil. The high price and environmental aspects of oil limit its use as a dust control agent. It is used at the rate of about 1.0-1.5 kg/m².

Lindh (1981) points out that a road treated with oil is considered to have somewhat better resistance to drying and the action of water than one treated with calcium chloride. He summarises some field tests carried out on different test sections by saying that the best results of dust control with oil have been achieved

during periods of little precipitation which necessitate large quantities of calcium chloride as dust control agent.

In 1995 a full scale test was carried out on a gravel road in South Halland using "rape seed oil gravel". The purpose of this test was to find an alternative to traditional dust control. Rape oil was mixed in at the rate of 2%. The road, provided with a 3 cm thick layer of rape seed oil gravel, was compacted by traffic to a hard and dust free gravel road. The road was harder than planned and could not therefore be maintained with a grader. Two years later only traces of rape seed oil gravel remained (Gunnarsson, 1997).

7.1.4 Costs of dust control using salt, lignosulphonates and bitumen emulsion

The rate of spread and maintenance frequency are the factors that mainly affect the cost of dust control.

Maintenance costs vary with the number of maintenance operations that must be carried out each year and the resources which these require. The number of operations varies from one (minimum) to three or four (maximum). Dust control using calcium chloride needs the least resources and plant. Costs can be broken down into two, material costs and plant costs (Bergström and Grebacken, 1995).

Han (1992) quotes four operations that must be included when dust control is costed. These are road upgrading, surface preparation, dust control agent and spreading.

Road upgrading includes improvement of drainage, geometrical improvements, repair of damage to and deformations in the road, and regravelling if necessary.

Surface preparation includes labour, plant, watering, scarifying of the road surface, compaction, traffic control and diversion if necessary for the actual spreading to begin.

Dust control agent comprises material and transport costs.

Spreading comprises labour and plant used in spreading the dust control agent.

Hallberg (1989) gives a comparison between Dustex and calcium chloride. The test was performed in Älvsborg County between 1986 and 1988. In view of a possible investment in a storage tank, the total cost of dust control with Dustex was judged to be higher.

Bergström and Grebacken (1995) compared bitumen emulsion by the soft method, calcium chloride and Dustex. According to this, calcium chloride is more expensive than Dustex. The comparison also shows that in the first four years Dustex treatment is the most economical method. After this the Örebro method is more cost effective. The Örebro method is described in detail in Subclause 7.1.3.4.

In their degree project, Bergström and Grebacken (1995) made certain assumptions so that they could make an objective comparison of the different dust control methods. These assumptions are:

- Plant and resource costs are calculated for a 10 km long and 4 m wide section.
- The roads are assumed to be in the same initial state, i.e. the same preparatory work is required.

The costs calculated by Bergström and Grebacken (1995) comprise preparatory work with watering, grading of the road, edge trimming if necessary, and spreading of emulsion. The methods require slightly different resources and plant. The results of the comparison are plotted in figure 7.11.

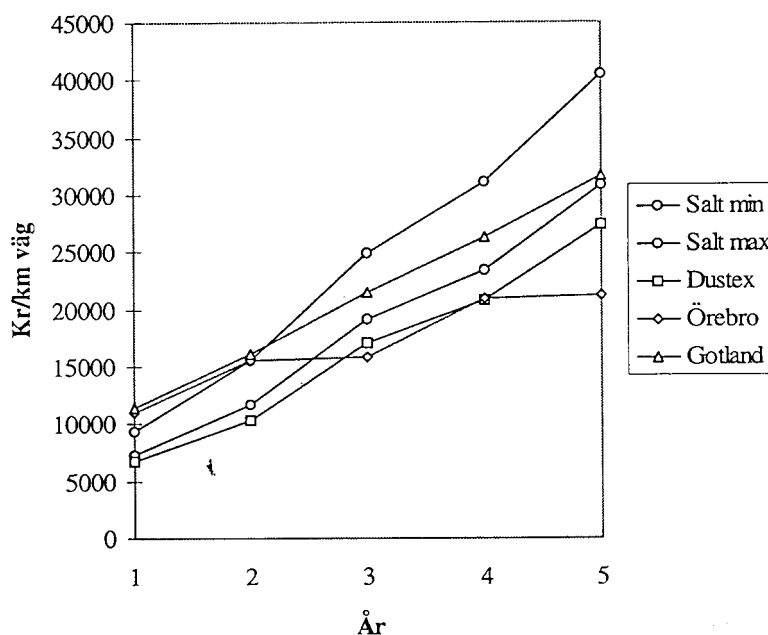


Figure 7.11 Comparison of bitumen emulsion, calcium chloride and Dustex. Min = once a year, max = three or four times a year. Vertical axis-SEK/km road Horizontal axis-Year

"Dust control of gravel roads" (1993), in Norwegian, arrives at the following costs for calcium chloride, Dustex and Norsalt.

Table 7.7 Costs of calcium chloride, Dustex and Norsalt.

| Dust control agent | Average cost NK/km |
|--------------------|--------------------|
| Norsalt | 1.586 |
| Dustex | 4.686 |
| Calcium chloride | 6.605 |

Costs of dust control with bitumen emulsion

In 1998, BE 60M/2000 cost SEK 1860/tonne, and BE 60M/65 SEK 2025/tonne. The costs of the soft and hard method are discussed below.

According to Bergström and Grebacken (1995), **the soft method** on Gotland costs SEK 8.4/m. The corresponding cost in Örebro is SEK 8.0/m. Bitumen emulsion on Gotland costs SEK 900/tonne exclusive of transport. The corresponding cost in Örebro is SEK 850/tonne.

Karlsson (1989) has calculated the cost of dust control with bitumen emulsion according to the soft method in the first year (1988). For a 5 m wide road, it was about SEK 19/m. The way costs change in subsequent years is not given in the report.

Krigsman (1993) says that the cost of dust control with bitumen emulsion according to the soft method is twice as much in the first year as that of dust control using calcium chloride. But in the second year the costs are equal. If no measures need be taken in years 3 and 4, dust control with bitumen emulsion is cost effective.

Thomasson (1991) has investigated the costs of **the hard method**. He compared the costs of dust control with bitumen emulsion according to the hard method with that using calcium chloride. The costs include the cost of surface preparation and repair of frost damage. See table 7.8.

Table 7.8 Annual costs of dust control with bitumen emulsion and calcium chloride (Thomasson, 1991).

| Year | Cost of dust control, SEK/m | |
|------|-----------------------------|-----------------------|
| | With bitumen emulsion | With calcium chloride |
| 1987 | 18.5 | 6.5 |
| 1988 | 8.0 | 7.0 |
| 1989 | 7.0 | 7.5 |
| 1990 | 3.0 | 7.0 |

According to the table, the initial cost for a 5 m road is about SEK 3.7/m². According to Karlsson (1989), the initial cost for the hard method is SEK 3.5/m². This cost does not include the cost of any other maintenance carried out in conjunction with dust control.

Cost of spreading clay

The cost of spreading clay using kaolin is mainly dictated by operating capacity. The total cost of dust control with kaolin in 1989 was about SEK 40/tonne exclusive of transport (Hallberg, 1989).

7.1.5 The benefits of dust control

Han (1992) and Foley (1996) set out the **negative effects** of dust in their reports.

- Reduced traffic safety and traffickability owing to lower visibility caused by dust.
- Loss of binder material from the road. Dust chiefly consists of fine particles from the gravel wearing course. A dusty road gives rise to a shortage of fines.
- Inconvenience and hygienic nuisance for those living along the road.

- Environmental damage and emission to the ambient atmosphere of highly volatile polluting dust.
- Deterioration in quality of agricultural products.
- Increased vehicle costs due to e.g. higher cleaning costs.
- Increased maintenance costs for installations and buildings along the road.

The above negative effects are described in greater detail in two reports, "Economic Disbenefits of Dust from Unsealed Roads" (1993) and "Effect of Dust Palliatives on Unsealed Roads in New Zealand" (1995).

The benefits of dust control can be mainly divided into short term and long term benefits. These are sometimes referred to as direct and indirect benefits.

In the short term, dust control produces concrete benefits because the dust is controlled and the road is made smoother, which means that the frequency and extent of grading and the cost of regravelling and ditching are reduced. "Guidelines for Cost Effective Use and Application of Dust Palliatives" (1987) states on the basis of experience that, by effective dust control, the costs of grading and regravelling have been reduced by 25-75% depending, for instance, on the choice of dust control agent and on how often and at which state of the road dust control was carried out.

In the long term, there are benefits for society and road users. "Guidelines for cost effective use and application of dust palliatives" (1987) describes the environmental and social effects of dust in greater detail. The areas discussed are traffic safety, aesthetics, health, vegetation, land, water resources and vehicle costs. By means of dust control, the following long term benefits are achieved:

- Vehicle costs (damage, fuel) are reduced because the road is more even
- Accident risk is reduced due to improved visibility
- Less disturbance to those living nearby and fewer complaints because of dust.
- The value of properties and other facilities increases
- Living standards are enhanced
- Reduced need for maintenance of buildings to remove dirt caused by dust
- Less damage to health and health hazards caused by dust
- Less sediment in water
- Reduced environmental impact on sensitive vegetation
- Extraction of finite resources such as fossil fuels, aggregate, rock and bitumen is reduced or limited. As pointed out by Sander (1997) in her licentiate thesis, the negative effect of the aggregate industry is reduced.
- Traffickability is improved

7.1.6 Choice of dust control agent

Karlsson (1989) says that local conditions must be taken into account when the dust control agent is chosen. The structure of the road, the composition of the wearing course, the amount of heavy traffic etc are decisive for this choice. General conclusions cannot be drawn from single test roads.

Han (1992) describes other factors that must be considered in choosing the dust control agent, such as environmental laws and other regulations, access to materials and equipment, and the views of road users. He considers environmental impacts to be the most important factor in choosing the dust control agent.

The report "Guidelines for cost effective use and application of dust palliatives" (1987) contains a table which may provide help in choosing the appropriate dust control agent. This table takes into consideration five factors, traffic volume, type of base course, climate, wearing course material and environmental impacts. The ratings used are (2) good, (1) quite good and (0) bad; see table 7.9.

Table 7.9 Choice of dust control agent.

| Agent | Traffic volume | | | Base course | | | Climate | | | Wearing course fine content % passing 0.075 mm sieve | | | | | EI |
|-------------------|----------------|---------|------|-------------|------|------|---------|--------|-----|--|------|-------|-------|-----|----|
| | <100 | 100-250 | >250 | Clay | Silt | Sand | Rain y | Normal | Dry | <5 | 5-10 | 10-20 | 20-30 | >30 | |
| CaCl ₂ | 2 | 2 | 1 | 2 | 1 | 0 | 0 | 2 | 0 | 0 | 1 | 2 | 1 | 0 | 1 |
| MgCl ₂ | 2 | 2 | 1 | 2 | 1 | 0 | 0 | 2 | 1 | 0 | 1 | 2 | 1 | 0 | 1 |
| Dustex | 2 | 1 | 0 | 2 | 1 | 0 | 1 | 2 | 2 | 0 | 1 | 2 | 2 | 1 | 1 |
| Bitumen Emulsion | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 |
| Veg. Oil | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 |

What does not look right in the above table is that environmental impacts (EI) are the same for all dust control agents.

Comparisons between dust control agents are usually made with respect to four aspects:

- Construction, i.e. can ordinary maintenance plant be used to spread the agent
- Cost
- Dust control effect
- Corrosivity and other environmental effects

In FSB Version (1998), in Swedish, it is stated that the material for dust control must be approved by the management authority. A report on the quantities of dust control agent used must also be submitted to the authority once a year after the season, but no later than 15 October.

7.1.7 Laboratory tests to evaluate dust control agents

The effect of different dust control agents was tested by laboratory experiments with respect to the following properties:

- Strength
- Durability
- Trafficability
- Resistance to freezing and thawing
- Moisture retention
- Density

As regards **strength**, Han (1992) and Hoover (1973) both say that a triaxial compression test can be used to evaluate dust control agents. A cylindrical test specimen (5.08 cm x 5.08 cm) of the wearing course material treated with the dust control agent is loaded to failure in a triaxial compression test. By comparing the compressive stresses at which failure occurs, different dust control agents can be compared and evaluated.

In order to determine **durability or susceptibility to erosion**, Sultan (1974) performed a very comprehensive investigation comprising a study of the literature, laboratory experiments and field tests. In his laboratory experiments, he used traffic abrasion apparatus to assess the effectiveness of some selected dust control agents. Among these agents there was a product called Redicote E 52 Emulsion which is stated to be a cationic asphalt emulsion. In his summary of the project, Sultan says that use of a 7.5 cm thick wearing course mixed with Redicote E 52 cationic emulsion produced an excellent wearing course surface. Langdon and Williamson (1983) refer to another laboratory method for the determination of the durability of bituminous materials. The method is called Modified Pellet Abrasion (MPA) test. This method is used to measure the abrasion of bitumen bound test specimens. Bolander (1997) says that durability can also be determined by an indirect tensile test. A cylindrical specimen (101.6 mm x 116.4 mm) is used. Bolander (1997) recommends Hudson and Kennedy's report (1968) that describes this test.

In order to investigate and test the **trafficability** of bituminous products, Hoover (1973) used an equipment called Traffic Simulator Apparatus in his comprehensive investigation in Iowa. The following bituminous products were tested by Hoover:

- Redicote E-36, cationic bitumen emulsion
- MC-800, cutback bitumen
- Petroset SB, cationic latex emulsion
- Petroset RB, cationic latex emulsion
- Penprime, a special asphalt emulsion
- Semi-Pave, a special asphalt emulsion

The traffic simulator apparatus is a about 3.5 m long linear road simulator. The width of the test lane is 0.9 m and its height above the ground is 0.6 m. The apparatus is shown in figure 7.12.

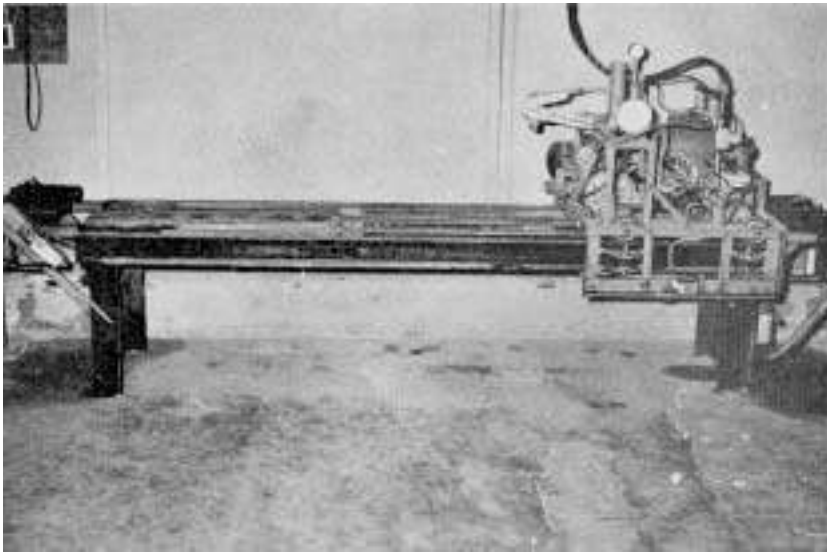


Figure 7.12 Traffic simulator apparatus.

In the laboratory experiments, the most promising results were yielded by Redicote E-36, MC-800 cutback bitumen and Petroset SB. The results of Hoover's (1973) tests are summarised in figure 7.13. The experiments are described in detail in Hoover's report.

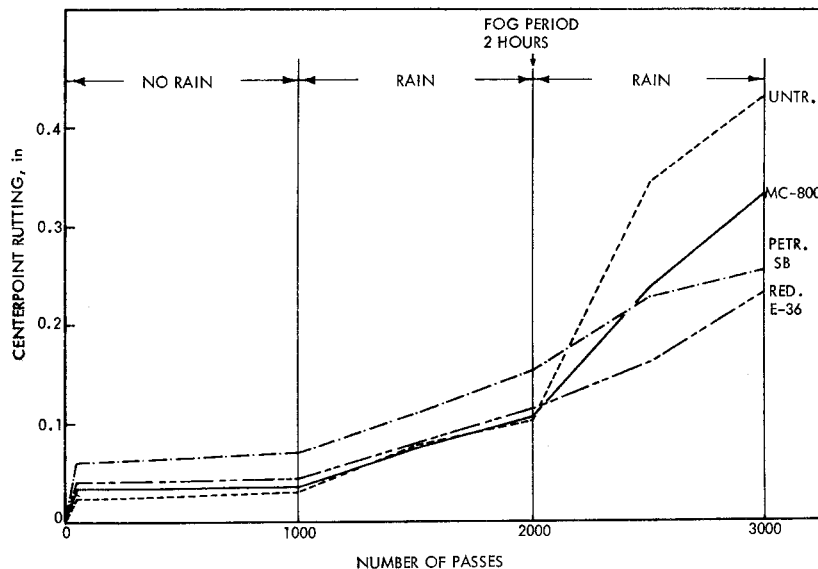
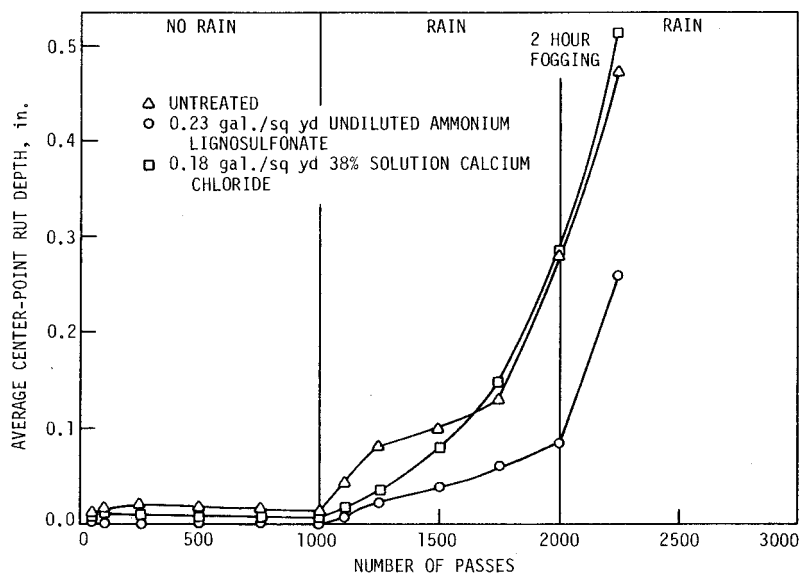


Figure 7.13 Results of Hoover's (1973) tests with the Traffic Simulator Apparatus.

In 1981, Hoover performed another test with the Traffic Simulator Apparatus. He tested calcium chloride CaCl_2 , lignosulphonate and bitumen emulsion. The test was carried out on eight sections on which the wearing course had different compositions and material types. The material properties and wearing course composition on these eight sections are set out in table 7.10. The results of the tests are plotted in figure 7.14 (Hoover, 1981).

Table 7.10 *Material properties and wearing course composition for the eight sections.*

| Location | Buchanan County | Franklin County | Marion County | Plymouth County | Pottawattamie County | | | Story County |
|---|-----------------|-----------------|---------------|-----------------|----------------------|------------|--------------|--------------|
| | | | | | Honey Creek | Mud Hollow | Neola | |
| Textural Composition, % by weight: | | | | | | | | |
| Gravel, > 4.76 mm | 20 | 26 | 35 | 17 | 23 | 13 | 10 | 7 |
| Sand, 4.76 - 0.074 mm | 60 | 51 | 47 | 42 | 30 | 26 | 19 | 47 |
| Silt, 0.074 - 0.005 mm | 8 | 14 | 10 | 25 | 31 | 46 | 33 | 25 |
| Clay, < 0.005 mm | 12 | 9 | 8 | 16 | 16 | 15 | 38 | 21 |
| Index Properties: | | | | | | | | |
| Liquid limit, % | 16.1 | 18.8 | 16.6 | 18.5 | 27.2 | 30.8 | 46.4 | 33.5 |
| Plastic limit, % | N.P. | 14.9 | 16.4 | 16.1 | 11.2 | 28.0 | 25.0 | 17.7 |
| Plasticity index, % | N.P. | 3.9 | 0.2 | 2.4 | 16.0 | 2.8 | 21.4 | 15.8 |
| Moisture-Density, Standard AASHTO T-99: | | | | | | | | |
| Maximum density, pcf | 131.5 | 130.0 | 137.0 | 125.4 | 124.8 | 117.9 | 113.5 | 108.2 |
| Optimum moisture content, % | 7.8 | 8.5 | 7.5 | 9.8 | 10.0 | 13.0 | 15.0 | 17.5 |
| Engineering Soil Class: | | | | | | | | |
| AASHTO Unified | A-2-4(0) SM | A-2-4(0) SM | A-2-4(0) SM | A-4(0) SM | A-6(4) SC | A-4(0) SM | A-7-5(12) CL | A-6(4) SC |
| Dominant Soil Series: | | | | | | | | |
| SCS | Sparta | Dinsdale | Ladoga | Wadena | Sarpy | Wabash | Marshall | Clarion |

**Figure 7.14** *Results of Hoover's (1981) tests with the Traffic Simulator Apparatus.*

7.2 Grading of gravel roads

According to "Road maintenance-roads free from snow and ice" (1992), grading is an operation in which the road is graded by one pass in each direction with the aim of restoring the surface evenness of the road.

There is no other measure in gravel road maintenance that is so critical for condition and costs as the adjustment of the shape of the road in terms of camber

and superelevation. Camber and superelevation are adjusted by deep grading. All other measures such as aggregate recycling, regravelling, ditch clearance etc will be of little use if the road after grading remains flat without sufficient camber and superelevation. A badly shaped gravel road is easily potholed by rain. A well shaped road from which water quickly drains often stands up to several falls of rain before further grading is needed (Road maintenance-roads free from snow and ice, 1992).

7.2.1 Surface grading and deep grading

Two types of grading are referred to in the literature, surface grading and deep grading.

According to Hubendick (1969), in **surface grading** the blade is set vertically or at an angle in the direction of travel, so that its action is not to cut but to scrape. The blade is set an angle across the road so that material that is scraped off is mixed and rolls along the blade towards its rear end.

The grader thus leaves a windrow which must be spread across the road. This is done with a windrow spreader that is mounted on the blade. The windrow spreader is also set at an angle, but in the opposite direction, so that the material is returned to the road and runs out between the teeth of the windrow spreader.

Hubendick (1969) considers that surface grading is really nothing but more or less shallow dragging and should really be called dragging. See Clause 7.7, Dragging. Hubendick adds that, in all other cases, grading is deep grading, i.e. "proper" grading.

In **deep grading**, a small cutting angle is used, with the result that the blade easily cuts into the road to a sufficient depth. A small cutting angle also gives a blade angle that is advantageous for good mixing of dislodged material. Material that has been cut out is then used for adjustment of the shape.

"Plant operator's handbook" (1995), in Swedish, describes deep grading as more comprehensive dressing of the road. What must be done is to restore the shape of the road. The endeavour in deep grading is to cut down to the bottom of potholes and ruts. Deep grading is described in detail in the following.

The aim of deep grading can be described as follows:

- To shape the road so that it has the correct crossfall.
- To make the wearing course even. This can be done by either surface or deep grading.
- To mix the aggregate material. This gives the wearing course aggregate a more homogeneous composition which improves the cohesion of the road (Persson, 1993). In order that grading may be meaningful, the gravel wearing course must have the correct composition.
- To cut away clumps of grass and similar from the edge of the road, so that water can drain from the carriageway.

7.2.2 Factors which influence grading

According to "Road maintenance-roads free from snow and ice" (1992), the factors which have the greatest effect on the scope and frequency of grading are as follows:

- Traffic
- Weather
- Length of snow and ice free period
- Composition of wearing course
- Thickness of wearing course
- Ditches
- Presence of stones in carriageway and at the edges of the road
- Crossfall of the road

7.2.3 Frequency and times of year

The number of grading events depends on what dust control agent had been used before. A road on which salt is used for dust control requires relatively extensive maintenance, grading or dragging 3-4 times a year. (Bergström and Grebacken, 1995). The following five times are mentioned in the literature:

- **Early spring:** As the road thaws and its surface becomes soft, the road is graded lightly to repair damage and to aerate and dry out the road (Road maintenance-roads free from snow and ice, 1992).
- **In summer:** The road is graded to even out corrugations, ruts and potholes. This must be done to as small an extent as possible, since dust control treatment must often be complemented by repeated grading.
- **In autumn:** The road is graded as aggregate is spread so as to mix the new aggregate with the old aggregate material and to shape the road.
- **Other occasions:** Grading may be necessary on other occasions if the material on the road has been washed off by heavy rain or if the road has become rutted, potholed or corrugated by the action of traffic. Manual of Standard Photographs in Method Specifications 106 (1996), in Swedish, must be used as an aid in assessing when a gravel road must be graded (Persson, 1993). Glänneskog and Skog (1994) add that in some cases grading is carried out both before and after aggregate is spread as a maintenance measure.

7.2.4 Method specification for grading

Grading may be carried out in conjunction with rain or watering. Grading of a gravel road adjacent to a paved road and the grading of roads with curves will also be described.

- **Grading in conjunction with rain** is as a rule good economy but requires attention and experience. Grading must never be carried out if there is too little rain, and it should also be discontinued in heavy rain. It should also be stopped in good time after rain has ceased. "Road maintenance-roads free from snow and ice" (1992) states that a water tanker must be deployed when there is a risk that the road will dry out.

- The road must be **watered** to ensure that material dislodged by grading and the base are moist enough for compaction by traffic. Watering is described in Clause 7.5. Grading in conjunction with watering may be carried out in several ways. "Road maintenance-roads free from snow and ice" (1992) describes one alternative.
 - The road is be watered in good time before grading begins.
 - The road is broken up by two passes of the grader, one in each direction. Dislodged material is deposited at the sides of the road; it should not run on to the slopes.
 - The road and the rows of aggregate are watered again.
 - The rows of aggregate are graded in and are distributed evenly over the road with a windrow spreader. The road is watered again if necessary.
 - The road is compacted by the water tanker.

Grading of gravel road adjacent to a paved road is carried out in two passes. figure 7.15 illustrates the reason for this (Plant operator training, 1995).

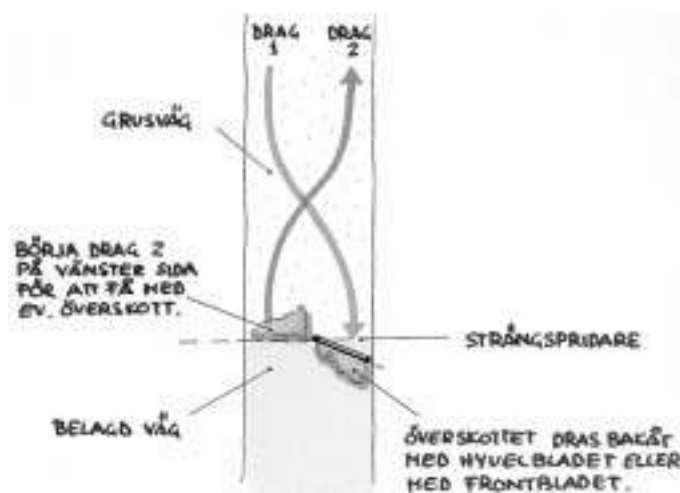


Figure 7.15 Grading of gravel road adjacent to a paved road.

DRAG 1=PASS 1

DRAG 2=PASS 2

GRUSVÄG=GRAVEL ROAD

BÖRJA DRAG 2 PÅ VÄNSTER SIDA FÖR ATT FÅ MED EV. ÖVERSKOTT=START PASS 2 ON LEFT HAND SIDE TO GATHER UP ANY EXCESS

STRÅNGSPRIDARE=WINDROW SPREADER

BELAGD VÄG=PAVED ROAD

ÖVERSKOTT DRAS BAKÅT MED HYVELBLADET ELLER MED FRONTBLADET = EXCESS IS DRAWN BACKWARDS WITH GRADER BLADE OR WITH FRONT BLADE

When **roads with curves** are graded, it is difficult to decide which sections should be cambered or superelevated. If all curves are superelevated, there will be too many transitional sections. Some of these will always be flat and drainage will be unsatisfactory. "Road maintenance-roads free from snow and ice" (1992) therefore recommends that only curves of small radius should be superelevated after consultation with the grader operator and the road engineer. The rest of the road should be cambered. It is difficult to quote a definite radius for superelevation. The decision can only be made on the basis of experience and judgment.

7.2.5 Plant and equipment for grading

Grading is carried out with a grader and a windrow spreader.

The road grader is superior to all alternative equipment for the shaping and smoothing of gravel roads. It is one of the most important items of plant in highway engineering. The need for graders has decreased as the extent of the gravel road network has been reduced, since an increasing number of roads are treated with Y1G (Gustafsson, 1982). The most common graders used by the Swedish National Road Administration are in the 14-17 tonne weight class.

Hubendick (1969) describes the construction and use of the road grader in greater detail. A grader is a versatile construction plant which may have either a rigid or articulated frame. It can be equipped with:

- Dozer blade for excavation work
- Grader blade for levelling, adjustment and winter work
- Grader blade and windrow spreader for grading gravel roads
- The road grader can also be used as a platform for implements.

Attempts have been made to find a replacement for or additions to the road grader in both gravel road and winter road maintenance because both the first and running costs of graders are high. Gustafsson (1982) compares a road grader with a wheeled loader with a mounted blade, two lorries with blades and four road drags. His results showed, inter alia, that it is only the road grader that can carry out deep grading.

In all grading, it is essential that the blade is correctly set as regards cutting angle, horizontal and vertical angle. See figure 7.16 (Plant operator training, 1995).

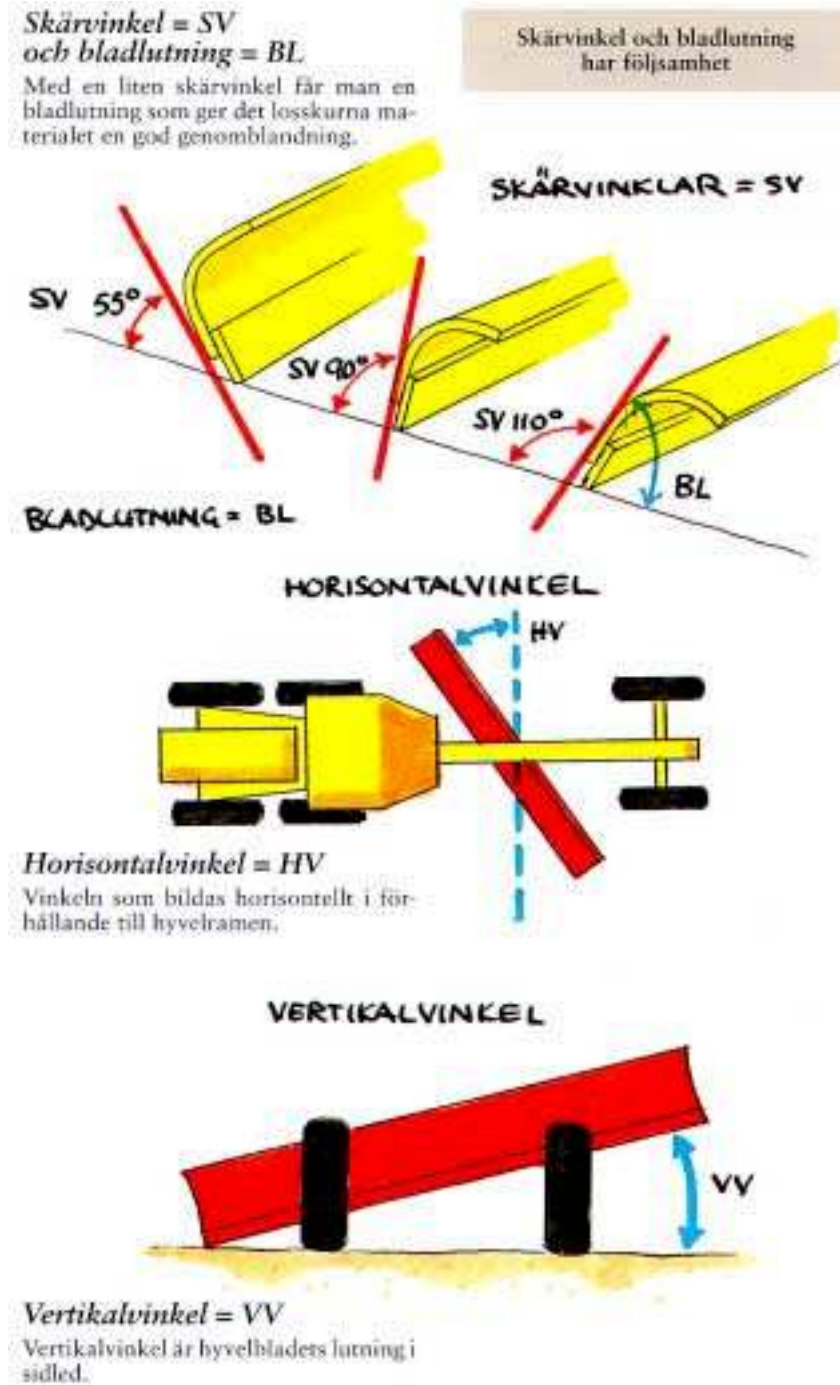


Figure 7.16 Grader blade settings.

Skärvinkel = SV = Cutting angle

Bladlutning = BL = Blade angle

Med en liten skärvinkel får man en bladlutning som ger det losskurna materialet en god genombländning = A small cutting angle gives a blade angle that will mix the loose material

Skärvinkel och bladlutning har följsamhet = Cutting angle and blade angle are complementary

Horisontalvinkel = HV = Horizontal angle

Vinkeln som bildas horisontellt i förhållande till hyvelramen = Angle that is formed horizontally in relation to the grader frame

Vertikalvinkel = VV = Vertical angle

Vertikalvinkel är hyvelbladets lutning i sidled = The vertical angle is the lateral inclination of the blade

The duty of the **windrow spreader** is to distribute over the graded surface the material dislodged by the grader. It is important that the spreader should be correctly set, so that the material is evenly distributed and the intended crossfall is retained.

Källqvist (1991) says that the old windrow spreader used by the National Swedish Road Administration had many faults. The most serious of these was that it was difficult to shape the wearing course to the correct crossfall on narrow gravel roads, which make up the greatest proportion of gravel roads, in conjunction with maintenance grading with two passes, one in each direction. According to "Road maintenance-roads free from snow and ice" (1992), a narrow road is one less than 5 m wide. Källqvist describes other shortcomings of the old windrow spreader as follows:

- The horizontal angle of the blade could not be altered
- Lateral extension was limited
- The blade could not be bent longitudinally
- It was difficult to set the right vertical angle

In his BD report, Källqvist mentions a number of characteristics that give spreaders greater flexibility:

- Better manoeuvrability that makes it possible to shape the road correctly
- Snap connector to grader to make implement change easier
- Manual or automatic setting of vertical angle
- Manual or automatic spread regulation

By developing a more effective windrow spreader, it is possible to achieve:

- Grading of higher quality which reduces the number of grading events and gives road users better riding quality
- Automatic setting makes it easier to achieve the correct shape which reduces the number of passes and makes it easier for new operators to achieve the right quality

As a result of Källqvist's investigation, the National Swedish Road Administration changed over to the type of windrow spreader shown in figure 7.17.



Figure 7.17 *Windrow spreaders. At left, made by Mähler, and at right, made by Kommunalmaskin (Road maintenance-roads free from snow and ice, 1992).*

The windrow spreader shall at all times put the camber in the correct position irrespective of road width. For narrow roads, the windrow of aggregate must be inside the grader wheels, and on wide roads it must be outside the wheels. See figure 7.18.

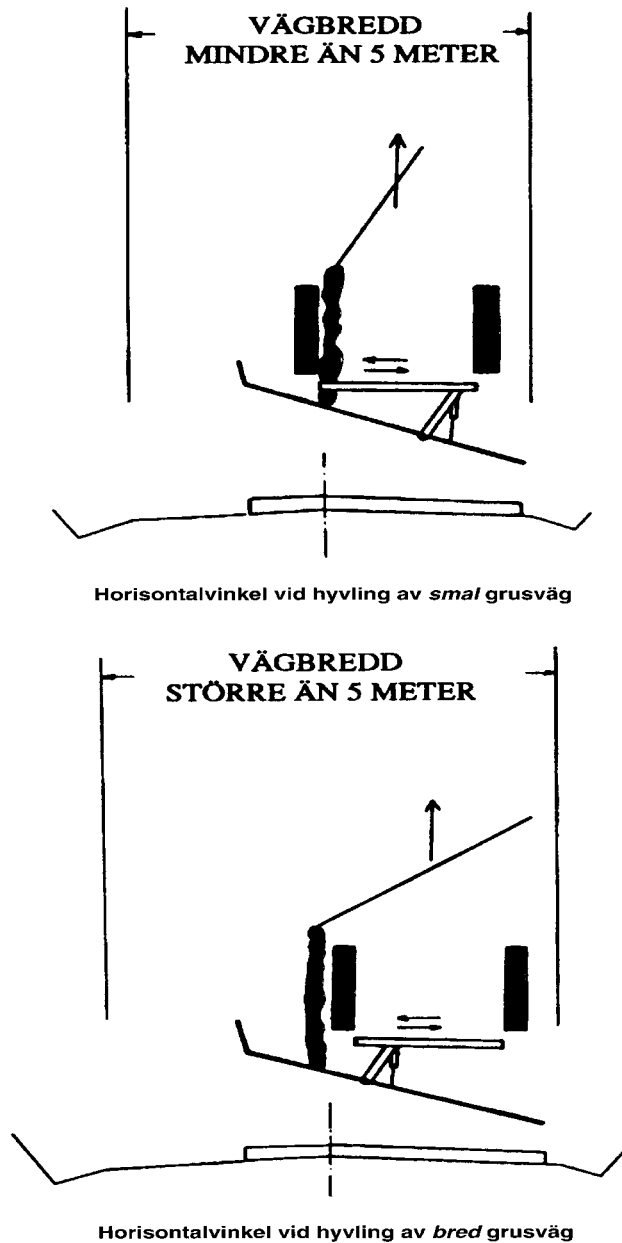


Figure 7.18 Grading of narrow and wide road (Road maintenance-roads free from snow and ice, 1992).

VÄGBREDD MINDRE ÄN 5 METER=ROAD WIDTH LESS THAN 5 M

Horisontalvinkel vid hyvling av *smal* grusväg=Horizontal angle when grading a narrow gravel road

VÄGBREDD STÖRRE ÄN 5 METER=ROAD WIDTH GREATER THAN 5 M

Horisontalvinkel vid hyvling av *bred* grusväg=Horizontal angle when grading a wide gravel road

Different types of grader blade

Different blades can be mounted on the grader. All types of blade are divided into lengths of 1.220 or 1.525 m. Blades are also available in different thicknesses. An unserviceable section can be easily replaced, and in the event of uneven wear, sections can be changed round. Blades are fixed in position with bolts or cotter joints. There are two types of grader blade, a smooth blade and System 2000, a toothed blade (Road maintenance-roads free from snow and ice, 1992).

A. Smooth blade

"Road maintenance-roads free from snow and ice" (1992) quotes two drawbacks of the conventional smooth grader blade:

- Material is removed by cutting, which requires a lot of energy.
- Wear on the blade and the aggregate material is high.

B. System 2000

The system was initially introduced for demanding winter grading and later began to be applied for summer grading (Junes, 1989). Junes states that one prerequisite for System 2000 is that roads should not be too stony. He says that the recommended user and maintenance instructions should be complied with, otherwise experiences will be gained at a high price. The blade consists of 4 mounting plates and 104 replaceable cutter teeth which are rotating tines (Svensson, 1997). Grading is normally performed with toothed blades. Through the years, these produced low steel costs and satisfactory results. Both types of blade are shown in figure 7.19.



Figure 7.19 At front, smooth blade and behind, System 2000 that is mounted on the blade (Road maintenance-roads free from snow and ice, 1992).

Junes lists the following **advantages of System 2000** from the standpoints of quality and user convenience:

- Owing to the larger depth of grading, better grading quality and longer grading intervals. The road should be more even immediately after grading, and it should take longer for the road to need grading again.
- Less crushing of aggregate and better final results because a rougher surface is obtained, which means that less water is needed and loose material stays on the road and can be gathered up again.

"Road maintenance-roads free from snow and ice" (1992) adds two more advantages:

- Less energy than in using a conventional blade because cutting is achieved by rotary action

- Lower stress on plant and equipment.

"Road maintenance-roads free from snow and ice" (1992) points out some **drawbacks of S2000**:

- System 2000 always has a straight blade surface
- System 2000 demands care such as cleaning and lubrication for the system to work.

Junes (1989) carried a **comparative investigation** of conventional flat untoothed grader blades and System 2000 over a summer season. The comparison is presented in the form of index numbers in table 7.11.

Table 7.11 Comparison of conventional flat untoothed grader blades and System 2000.

| Type of cutter | Life | Capacity | | | Fuel | Costs | |
|----------------|------|-------------|-----------------------|---------------------------------------|------|-----------------|---------------------------------|
| | | Blade depth | km pass/ unit time | m ³ (actual)/ unit time | | Cost/km pass | Cost/m ³ (actual) |
| Conventional | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| S 2000 | 4 | 1.5 | 0.85 | 1.3 | 1.03 | 1.2 | 0.8 |

The results show that System 2000 can cut deeper. The reasons for the differences in capacity and costs depend on whether costs are counted for km of passes carried out or the volume of material loosened up. Junes adds that in order for capacity to be higher and cost to be lower, it is necessary for either deep grading to be needed or for the surface to be very hard.

7.2.6 Costs of grading

Grading costs vary between Swedish counties. The highest cost is SEK 2900/km, and the lowest SEK 1222/km. These differences may be due to different operations being included in calculating costs. The mean cost for the country as a whole is SEK 1550/km (Road maintenance-roads free from snow and ice, 1992).

The right measure should be selected in order to restore a gravel road to good standard at least possible maintenance cost. "Road maintenance-roads free from snow and ice" (1992) lists different measures in table 7.12.

Table 7.12 Capacities and index numbers for the costs of different kinds of measures.

| Measures | Capacity | Index number |
|--|-----------|--------------|
| Watering, grading, dust control | 8 km/day | 12 |
| Grading during rain without dust control | 16 km/day | 1 |
| Grading during rain with dust control | 16 km/day | 4 |

The following criticism can be directed at table 7.12:

- It is not clear how the index numbers have been calculated.
- Is capacity really the same for grading during rain both with and without dust control.

According to "Road maintenance-roads free from snow and ice" (1992), the above figures prove that week-end and shift working in suitable grading weather are both justifiable and necessary from the standpoint of economy. It is very often cost effective during rain to grade even roads that have an acceptable standard. The alternative might be that expensive grading combined with watering must be resorted to after the rain.

7.2.7 Experience from grading

The following practical experience is evident:

- The road must be sufficiently moist when it is graded; if the road is dry, aggregate material is crushed to a higher degree. Aggregate also segregates during grading, so that the fines are at the bottom and larger material above. This results in a wearing course of bad composition and a road of unsatisfactory cohesion, with a lot of loose aggregate. It is best to grade the road the day after heavy rain.
- It is also important that the grader should achieve a sufficient crossfall on the carriageway so that water can drain off. A crossfall of 3-5% is suitable on gravel roads. If the gravel wearing course has sufficient thickness, properly performed grading produces excellent results without additional measures. According to "Road maintenance-roads free from snow and ice" (1992), a wearing course 4-5 cm thick is considered the most suitable. If, on the other hand, the wearing course is too thin, the grader can easily tear up stones from the base course. Such stones are dangerous for road users and must be removed immediately (Persson, 1993).
- The grader must not drive too fast. Speed must be adapted to road conditions. On no account must it exceed 4-6 km/h. If speed is higher, the road may become wavy, and the results will be completely different from those expected (Persson, 1993).
- When grading is carried out with the intention of smoothing out corrugations, ruts and potholes in the wearing course, it is essential to grade down to the bottom of the deepest holes, otherwise the holes will reappear after a short time. Figure 7.20 illustrates this.

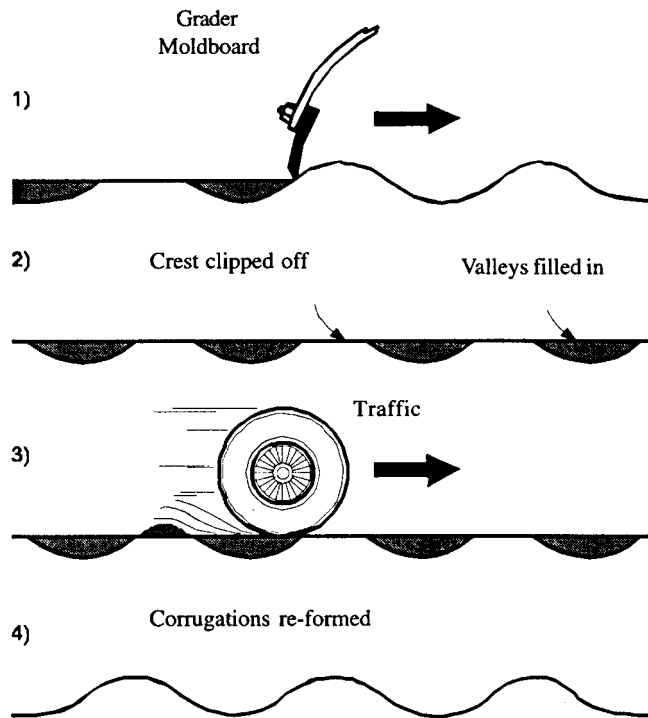


Figure 7.20 Reforming of corrugations (Problems associated with gravel roads, 1998).

- After dust control treatment, an endeavour should be made not to grade the road too often, since the effect of the treatment is ruined by repeated grading (Glänneskog and Skog, 1994).
- After a gravel wearing course has been graded, the road surface is loosened up. It may be thought that compaction is desirable. However, investigations made by Johansson (1980) showed that the road did not become more durable after rolling subsequent to grading. Johansson found that, from the standpoint of road users, compaction produced a smooth surface more quickly, but production costs were higher. Johansson is therefore of the opinion that the effect of using compaction plant is marginal.
- When roads that had previously been treated with emulsion are graded, it is important to make sure that the grader does not penetrate right through the previous emulsion-aggregate mix, since there is substandard material directly below the wearing course. Grading can be carried out without added water, preferably in the spring when the material is somewhat easier to grade (Bergström and Grebacken, 1995).

7.3 Regravelling

The object of regravelling is to give the wearing course sufficient thickness and the correct particle size distribution (Persson, 1993). The particle size distribution curve of the wearing course should conform to the ideal aggregate curve and contain sufficient fine material (Bergström and Grebacken, 1995). Before development of the aggregate recycling method, only regravelling was employed, and this is still the case in most countries. The term **regravelling** means that aggregate or rock material of 0-18 mm particle size is spread. Particles of 0-20

mm size are also used. According to Bergström and Grebacken (1995), roads with too high a fines content should be improved by adding 8-16 mm aggregate. The need for aggregate should be determined by a person of great experience of these roads and their condition.

A **special regravelling** means that the actual composition of the wearing course is determined and the fractions necessary to achieve a material conforming to the ideal aggregate curve are added (Isemo and Johansson, 1976). Regravelling was initially carried out without consideration of the composition of the existing wearing course.

Beskow (1934) confirms that improvement of the material composition of existing roads can largely be accomplished by adapting both the quality and quantity of the added material to the former composition of the road. What must be done first of all is to earmark the sections where the composition of the existing road material has been found unsatisfactory by practical observation, e.g. softening of the surface, corrugations or other surface irregularities. According to Beskow, the sections which exhibit insufficient bearing capacity after thaw or prolonged rain should be strengthened by adding coarse aggregate, mainly the fractions 4-20 mm, in quantities that can be determined on the basis of road analyses. This coarse aggregate should be added while the road is soft.

Lack of stone material causes first rutting and then inadequate crossfall. Aggregate should be spread before the road has lost its crossfall (Maintenance of unpaved roads, 1985). The composition of the added material can vary depending on what is locally available (Isemo and Johansson, 1976).

There are several reasons that aggregate must be spread on a road:

1. A wearing course of insufficient thickness because rain has washed away the aggregate (Maintenance of unpaved roads, 1985).
2. The composition of the wearing course has become unsatisfactory because the fines have been washed away or vehicle wheels have dislodged particles of aggregate from the wearing course (Persson, 1993).
3. The aggregate layer is continuously broken down by vehicle wheels which crush the coarser particles. This gives rise to a lack of stone material and an excess of sand. Such a road is easily corrugated. Even when the road is graded, the material in the wearing course is crushed (Persson, 1993).
4. According to the report "Maintenance of unpaved roads" (1985), aggregate can also be spread when damage such as potholes, rutting or erosion tracks has occurred on the road and has become extensive.
5. During thaw, the surface often becomes inconveniently soft. Aggregate must then be spread on the road to make the carriageway sufficiently stable for traffic (Persson, 1993).

As regards **plant and equipment**, regravelling requires no special implements apart from a lorry with a spreader flap. The driver can adjust the vehicle speed and control the spreader gap (Persson, 1993).

As regards the **frequency** of regravelling, it is often most rational to spread aggregate about once every three years. According to Persson (1993), Isemo and Johansson (1976) and Hoover (1981), three times the annual amount is spread on this occasion. Intervals may be shorter or longer depending on traffic and the weather.

It is essential to repair or restore the drainage system before regravelling. If aggregate is spread in spite of poor drainage, the new aggregate will soon disappear. The carriageway must be moist when aggregate is spread, since new material can then be mixed into the wearing course more easily. According to Persson (1993), the appropriate time is therefore the spring or after the thaw, and the autumn. In the autumn edge trimming, regravelling and dust control should be carried out at the same time. The report "Maintenance of unpaved roads" (1985) states that compaction is necessary to prevent rutting.

From the standpoint of **costs**, regravelling is one of the heaviest items in gravel road maintenance (Isemo and Johansson, 1976). Bergström and Grebacken (1995) say that the aggregate requirement is 30 m³/km every other year, which gives an aggregate cost of about SEK 1500/km of road. Persson (1993) points out that 14-25 m³ aggregate per km is annually needed. The quantity depends on road width and traffic intensity, and whether the road is given dust control treatment.

7.4 Edge trimming and aggregate recycling

Edge trimming is carried out to improve the shape of the road and thus drainage. Edge trimming also has the aim to prevent vegetation being carried into the road by the grader. Aggregate recycling means that usable material found during edge trimming is collected up instead of being removed. "Road maintenance-roads free from snow and ice" (1992) states that about 30% of the length of public gravel roads are maintained with recycled aggregate. Edge trimming and aggregate recycling are referred to in foreign literature as a method developed in Sweden.

The object of aggregate recycling is to draw in edge material and in this way to recover some of the material thrown to the sides, and to improve the abraded gravel wearing course. The edge material may however contain some clumps of grass and stones. These can be removed. The material that can be used is mixed into the wearing course. By the addition of 4-18 mm fraction, a particle size distribution conforming to the ideal aggregate curve can be achieved.

The reason why the 4-18 mm fraction is often added is given in "Road maintenance-roads free from snow and ice" (1992). A sufficient quantity of fine material has already been added to the road by drawing in material thrown to the edges, and therefore only the lack of stone material has to be made up. Since crushed aggregate from which sand has been removed contains about 40% of the 0-4 mm fraction, of which there is an excess on the road, in most cases material of 4-18 mm fraction is most profitable to use. The choice between using crushed aggregate from which sand has been removed and the 4-18 mm fraction is determined by cost.

According to "Road maintenance-roads free from snow and ice" (1992), table 7.13 can be used for guidance. The figures in the table include material from the existing wearing course, edge material plus added aggregate fraction.

Table 7.13 *Variation of aggregate requirement with road width.*

| Road width (m) | 3.5 | 4 | 4.5 | 5 | 5.5 | 6 |
|--|-----|-----|-----|-----|-----|-----|
| Quantity of material m ³ /km | 120 | 160 | 200 | 240 | 270 | 300 |

The term for the determination of how much supplementary material is needed is called **proportioning**. This is done in different ways. Computer programs for the calculation of distribution curves have been designed to facilitate proportioning. In order to obtain an ideal gravel wearing course of the right thickness, several calculations are often needed with different quantities of edge material and supplementary aggregate.

In order to carry out aggregate recycling for spreading supplementary aggregate, samples must be taken. "Road maintenance-roads free from snow and ice" (1992) gives some recommendations on how this is to be carried out. "Lignin stabilised gravel roads" (1988) recommends that samples of both the existing gravel wearing course and edge material should be taken for sieve analysis. The volumes of the sieved material to be used must also be calculated to ensure that supplementary material is correctly proportioned.

In 1992, about 500,000 m³ of aggregate were used for the maintenance of gravel roads. Spreading of appropriate aggregate fractions in combination with aggregate recycling could reduce this requirement by about 50%. "Road maintenance-roads free from snow and ice" (1992) states that if all road management areas in Sweden applied the recycling method, the aggregate requirement would be reduced by about 200,000 m³, lorry transport by about 1,000,000 km, and air pollution would also decrease.

7.4.1 Working methods in aggregate recycling

"Road maintenance-roads free from snow and ice" (1992) gives three methods for aggregate recycling:

Alternative 1 – Classification using a vibratory screen

Edge trimming is carried out with a grader, and aggregate material that has been thrown to the side is drawn up on the road. The drawn-up material is deposited in a windrow about 1 m from the edge of the road. The grader can dress the windrow with the tines and windrow spreader to break up the clumps of grass. The windrow is loaded up into the vibratory screen for classification. The classified material is spread evenly over half the road which makes it easier for traffic to use the road. Material rejected after classification is disposed of in the surrounding country or is carried away by lorry. The classified material is mixed with the existing wearing course. More aggregate is spread a little later in the autumn when the weather is suitable. The aggregate spread is mixed into the existing wearing course. See figure 7.21.



Figure 7.21 Classification with vibratory screen (*Road maintenance-roads free from snow and ice, 1992*).

Alternative 2 – Classification using Saga oversize aggregate remover (towed by tractor or wheeled loader)

Aggregate of 4-18 mm fraction is spread 1-2 days before the edge material is drawn in. Edge trimming is carried out with a road grader and the windrow is drawn up onto the road with a modified windrow spreader. The windrow is classified and mixed with the towed Saga. Material rejected is loaded into the wheeled loader to be taken away. The classified material is mixed into the wearing course at the time of subsequent watering, grading and dust control treatment. See figure 7.22.



Figure 7.22 Classification with tractor-drawn oversize aggregate remover (*Road maintenance-roads free from snow and ice, 1992*).

Alternative 3 –Classification using Saga oversized aggregate remover (drawn by grader)

Aggregate of 4-18 mm fraction is spread 1-2 days before the edge material is drawn in. The edge is trimmed and the windrow drawn in with an articulated road grader in one operation. The material is deposited with the grader blade in the correct position for classification by the Saga towed by the grader. Saga is followed by a wheeled loader with a large bucket which carries reject material to a tip in a suitable place along the road. A road grader and water tanker following behind carry out mixing and shaping. The Swedish National Road Administration recommends that the road should then be given dust control treatment. See figure 7.23. "Road maintenance-roads free from snow and ice" (1992) states that Alternative 3 is shown by studies and follow-up investigations to be the most effective plant combination.



Figure 7.23 Classification with grader-drawn oversized aggregate remover; inset: edge trimmer.

7.5 Watering

Watering reduces crushing of the aggregate material, but its primary object is to maintain the efficacy of previous dust control treatment or to facilitate subsequent dust control treatment and compaction. Unless the road is sufficiently moist when salt is spread, only the topmost layer of the wearing course will be bound by the salt, and there is a much higher risk of corrugation and potholing in the carriageway (Bergström and Grebacken, 1995).

It is essential that the correct quantity of water is added. A large excess of water during grading may give the wearing course aggregate a porridge-like consistence. This makes conditions difficult for road users. The wearing course material may segregate and some of it may run into the ditch. Subsequent compaction is made difficult and the carriageway may become rutted. If too little water is added, dust control treatment and subsequent compaction are jeopardised. (Road maintenance-roads free from snow and ice, 1992).

The number of water tankers which carry out watering must be adapted to the capacity of the grader, the need for water and the transport distance. It is best to begin watering about 1 hour prior to grading. Permanent water stations should be arranged to reduce transport.

In Sweden, about 400,000 m³ water or 14 m³/km of gravel road are spread every year. The total cost of watering, in terms of 1990 prices, is SEK 17m. Watering is expensive but it can be minimised by increased utilisation of rain. There are large differences in cost between Swedish counties. The range is SEK 1076-116/km.

Han (1992) considers that water should be added at the rate of 0.03-0.3 gal/yd² which is equivalent to 0.136-1.358 l/m² or 0.544-5.432 m³/km for a 4 m wide road.

Bergström and Grebacken (1995) claim that the road has optimum moisture content when the best compaction is achieved, which occurs for about 4-6% water in the wearing course. If work is planned properly, natural moisture after thaw can be utilised.

7.6 Patching

Repair of potholes on a gravel road by hand is also referred to as patching. Using a shovel, potholes are filled with suitable aggregate material.

Patching is recommended if there are only few holes and it is a long time until the next grading event (Persson, 1993). Hubendick (1969) points out that the choice between patching and grading should be determined not only by the number of potholes but also by the cohesion of the carriageway, whether it is dry or moist, etc. In other words, consideration must be given to how easy it will be to treat the road. On the insides of curves, near paved areas or bridges, it may at times be difficult to remove a few potholes by grader, especially if they are deep.

In the summer, plenty of dust control agent should be mixed into the aggregate used for patching to prevent the material being lost in the form of dust. In the same way, when frozen potholes are to be patched, calcium chloride solution should be added to the aggregate so that it can melt the sides of the hole.

Hubendick (1969) says that the aggregate must not be thrown into the pothole but laid in place in order to prevent segregation. Traffic will compact the material in the hole. It is therefore necessary to add excess material so that the carriageway will be flat after compaction.

7.7 Dragging

The aim of dragging is to remove incipient corrugation, rutting, shallow potholes, etc. Superficial levelling is achieved by drawing over the road a steel implement that scrapes the surface.

In many cases it is unnecessary to grade the road when all is needed is superficial levelling; dragging may be sufficient instead. Dragging produces the best effect when the carriageway is moist.

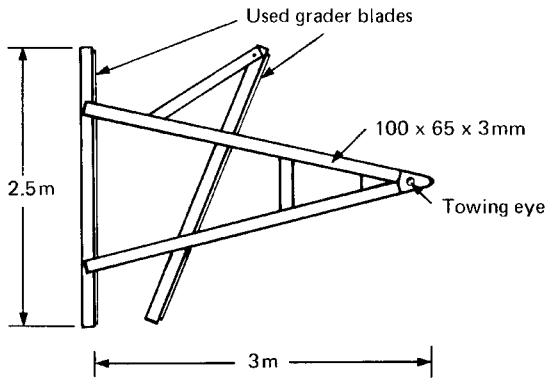
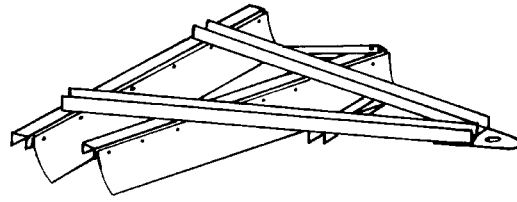
A road drag is a steel frame with beams at an angle that scarifies and remixes the aggregate wearing course (Bergström and Grebacken, 1995).

There are many versions of drags, ranging from simple home-made drags with two or more grader blades bolted to a frame, to factory-made adjustable drags. The drag is generally coupled to a tractor or lorry. See figure 7.24.

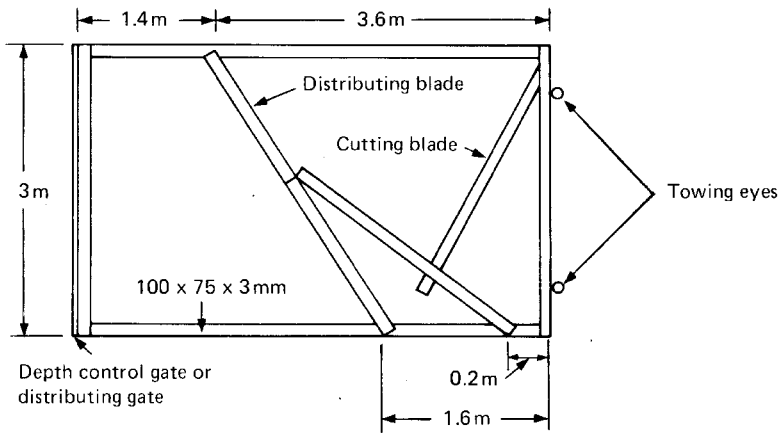
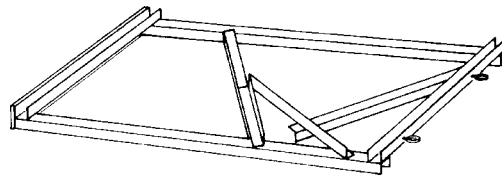


Figure 7.24 Road drag coupled to a tractor (*Maintenance of gravel and earth roads, 1994*).

Drags are normally drawn over the road unconstrained. There are also steerable drags, drags which can be loaded, and drags where the frame is carried on runners and its height can be adjusted to a certain extent. Hubendick (1969) gives a detailed description of how dragging is to be carried out. Examples of some drags are given in figure 7.25.



(a) 'A' - FRAME DRAG UTILISING GRADER BLADES



(b) RECTANGULAR TRIPLE BLADED DRAG

Figure 7.25 Some examples of road drags (Maintenance of unpaved roads, 1985).

7.8 Ditching

Hubendick (1969) states that ditches are the most important part of the road. If there are no ditches, there is nowhere for water to drain into. The result is that the road structure contains too much water, it does not bind together, and has not the bearing capacity it must have. Ditching is therefore important work. The term ditching refers to both new ditches and the clearing of heavily blocked ditches.

Persson (1993) says that ditching must at all times be preceded by consultation with the land owners concerned. In some cases a permit is also required from the Swedish Environmental Protection Agency. An application for such a permit must be submitted to the county executive board. The suitable depth and slopes of a ditch are illustrated in figure 7.26.

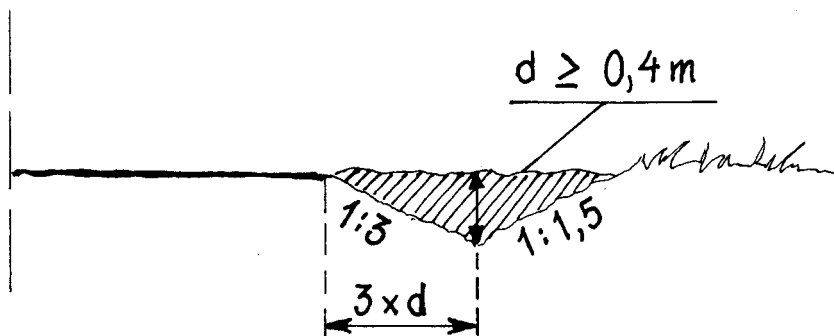


Figure 7.26 Suitable depth and slopes of a ditch (Persson, 1993).

A shallow ditch can be provided to drain surface water from the carriageway where space is limited by plots near the road, under bridges, etc. See figure 7.27. Shallow ditches do not drain the road pavement.

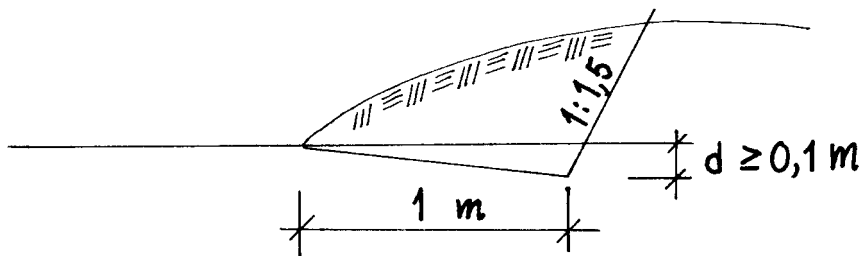


Figure 7.27 Suitable depth and slopes of a shallow ditch (Persson, 1993).

Ditch clearance comprises edge trimming and clearing of the ditch so that it regains its original shape and depth. The frequency at which a ditch must be cleared varies. The average time between ditching operations is about 7 years. Ditches should be inspected and repaired regularly. When a large flow of water may be expected, for instance after a major timber felling operation, it is particularly important that drainage should be in good order.

A road grader is used for normal work on ditches and slopes, and an excavator for more difficult jobs. The grader blade should cut right down to the bottom and draw soil up to the edge of the road.

"Forest roads" (1992), in Swedish, says that bad material removed from ditches should be run to a tip and spread out, or spread out on the ground near the ditch.

In FSB Version (1998), it is stated that environmental impacts must be given special attention when ditches are cleared. Protected flora must not be removed, and care should also be taken of flora on the slopes of the road. It should also be borne in mind that soil removed from ditches may contain heavy metals and other environmentally hazardous substances. Environmentally hazardous material must be disposed of in accordance with the regulations of the county executive board or the municipality. In determining the methods employed in ditching, due consideration must be given to natural resources in the surroundings.

7.9 Removing stones from the road

Stones can work their way up into the road from the road structure. Large stones in the road reduce capacity during grading or dragging. It is more difficult to shape the road. The grader blade is subjected to greater wear. Snow clearance is also impeded. Stones can damage plant and implements and cause accidents. Traffic safety is jeopardised, and trafficability is reduced. When large stones are being hoisted up, warning signs must be displayed. Cavities left in the road by large stones must be made good with suitable material.

The eventual aim of measures is to remove large stones from the road structure. An excavator or wheeled loader equipped with a combigrip are suitable plant for this. See figure 7.28.

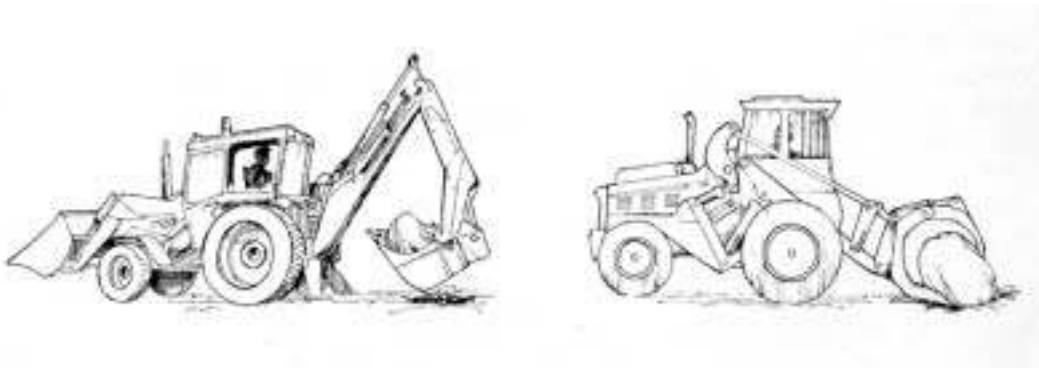


Figure 7.28 Excavator and wheeled loader equipped with combigrip (Persson, 1993).

Persson (1993) describes two methods for removing large stones from the road structure, excavation and blasting.

Excavation means that stones are dug out or broken up with the bucket. The hole is then filled with suitable pavement material. The surface is levelled and compacted with the bucket or blade.

Blasting can be used when individual stones are to be removed. One drawback of blasting is that often only the top of the stone is removed. The remainder can continue to force its way upwards.

If there are many stones in the road and the soil is susceptible to frost action, removal of stones is time consuming and expensive.

Persson (1993) therefore proposes some **preventive measures**. One is to lower the groundwater level by deepening the ditches, so that permanent improvement is achieved.

In very difficult areas one alternative may be to dig out the subgrade. Other conceivable measures are to install an anticapillary layer or insulation. The best method is to remove boulders when the road is constructed.

8

Condition assessment of gravel roads

The purpose of condition assessment is to determine the condition of the road, make predictions and assess the need for maintenance measures. The condition of the road is defined as the surface condition of the road at a certain time. If the condition of the road does not satisfy the specified requirements, measures must be taken to improve the road so that it does satisfy these requirements.

This chapter describes assessment of the condition of roads, primarily by methods used in Sweden but also those employed or suggested in Finland, Canada, USA, New Zealand and Australia. In view of the fact that forest roads account for ca 50% of the total road network in Sweden, standard classes for forest roads are also described.

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8.1 Assessment of the condition of gravel roads in Sweden

Not enough is known of the way the condition of gravel roads changes in time. There is an evident need, generally acknowledged, for a reliable method—either subjective or objective—for the assessment of the condition of a road.

8.1.1 Subjective assessment

Several methods have been developed over the years in Sweden for assessing the condition of gravel roads. The following methods will be described:

- Swedish Road Institute, 1934, in Swedish.
- Andren och Fransson-KTH, 1976.
- Improvement and maintenance of gravel roads, the "FUG scale", 1979, in Swedish.
- DDp scale, 1982, in Swedish.
- Method Specification VVMB106, 1996, of the Swedish National Road Administration, in Swedish.

8.1.1.1 Swedish Road Institute, 1934

In the report (1934) of the Swedish Road Institute, a distinction is made between three different conditions of a gravel road:

- C₁: Gravel roads in best condition in the summer, with even and hard carriageway
- C₂: Gravel roads in the summer which are corrugated or potholed
- C₃: Gravel roads of medium standard in autumn and spring

The condition of the gravel road network in 1934 is set out in table 8.1.

Table 8.1. *Condition of gravel road network in Sweden in 1934 (Report (1934) of Swedish Road Institute).*

| Region | Number of days during the year for a certain road condition | | | |
|-----------------|---|----------------|----------------|----------------|
| | Snow | C ₃ | C ₂ | C ₁ |
| Southern Sweden | 60 | 90 | 70 | 145 |
| Central Sweden | 90 | 90 | 60 | 125 |
| Norrland | 135 | 90 | 45 | 95 |

8.1.1.2 Andren and Fransson-KTH, 1976

In their degree project at KTH (1976), Andren and Fransson developed a model for the classification of gravel roads. The model was based on subjective assessment of three factors, "roughness", "binding ability" and "dusting tendency". Subjective assessment is made on the basis of textual description and photographs. The factors are assessed individually and are then combined into a condition description.

For roughness a scale from A to D is used, where Class A is comparable to the roughness of a paved road. For binding ability, a scale from A to D is used, and

for dusting tendency a scale from A to C. These condition classes are set out in table 8.2. Photographs are not shown in this report.

Andren and Fransson emphasise that the classification method shall be as simple as possible, no measurements or sampling, only visual inspection of the road. As far as can be ascertained, this method has not been used in practice.

Table 8.2 Condition assessment method proposed by Andren and Fransson.

| Condition class | Roughness |
|-----------------|--|
| A | No factors which affect driving comfort, or small roughness, which do not however affect vehicle speed. The road can be compared to the roughness of a paved road. |
| B | Roughness and depressions which affect driving comfort, but not to such an extent that they appreciably affect vehicle speed. Some potholes along the road. Corrugation of minor extent. |
| C | Speed must at times be reduced, pronounced depressions and roughness. Tendency to potholing. Pronounced potholes. Ruts noticeable while driving. |
| D | Carriageway is run down, and driving is very uncomfortable. Extensive potholing. Heavy rutting. Deep corrugations. |
| | Binding ability |
| A | Little or no aggregate on carriageway, there may be loose aggregate at edges. |
| B | Some loose aggregate at road edge, some aggregate windrows on carriageway. |
| C | Banks of aggregate in curves and aggregate windrows along whole carriageway. |
| D | Many pronounced banks of loose aggregate over whole road, lack of certain fractions, excess sand. |
| | Dusting tendency |
| A | Little or no dust is raised. |
| B | Minor dust clouds. |
| C | Pronounced dust clouds. |

8.1.1.3 Improvement and maintenance of gravel roads, "FUG-scale", 1979

Over the period 1979-1982 a joint Nordic road research project was carried out to develop gravel road maintenance, designated "Improvement and maintenance of gravel roads", "FUG". The countries participating in this project were Finland, Iceland, Norway and Sweden.

In the joint Nordic project FUG (1979) and FUG (1983), a system was established for the assessment of gravel roads. Over the project period 1980-81, a number of test roads were selected in each country for maintenance studies and driving tests. Their condition was assessed subjectively in a uniform manner in all the countries. The factors assessed were surface roughness, binding ability and dusting tendency. A scale ranging from 0 to 5, according to a Finnish system, was used for surface roughness. This system is described in Subclause 8.3.1. For binding ability a scale from 0 to 4 was used, and for dusting tendency a scale from 0 to 3. Assessment was performed according to a system tested in Sweden.

This model for assessment is mainly based on Finnish experience of quality inspections. Marks 5, 4 and 3 denote the highest quality that can be attained for each property. Instructions for quality assessment of gravel roads according to the FUG scale are given in table 8.3.

Table 8.3 *Instructions for quality assessment of gravel roads according to the FUG scale (FUG, 1979) and (FUG, 1983).*

| Assessment | Surface roughness |
|------------|--|
| 4.1—5.0 | The surface of the road has retained its shape and is very even and firm. Any roughness do not affect driving comfort. |
| 3.1—4.0 | The surface of the road has generally retained its shape and is very even and firm. There may be one or two depressions. Speed need not be lowered because of roughness. |
| 2.1—3.0 | The surface of the road has generally retained its shape and is mostly even and firm. There may be potholes of minor depressions and other roughness. Depressions and roughness can be avoided or they are of such condition that speed need not be lowered. When overtaking or passing other vehicles or under similar conditions it may be necessary to lower speed. |
| 1.1—2.0 | The road may have been deformed transversely. There may be corrugations. There may be sections with settlements or elevations, indicated by warning signs. Speed must at times be lowered. |
| 0.1—1.0 | The road is in several places deformed transversely. The surface is irregular because of depressions, corrugations and torn-up sections. There are settlements and elevations on the road that cannot be avoided. The road surface demands constant attention while driving, and speed must often be changed. |
| | Binding ability |
| 3.1—4.0 | Little or no loose aggregate on the carriageway, there may be loose aggregate at the edges of the road. |
| 2.1—3.0 | Some loose aggregate on the carriageway, occasional windrows of aggregate on the carriageway. |
| 1.1—2.0 | Banks of aggregate in curves, and windrows of aggregate along whole carriageway. |
| 0.1—1.0 | Pronounced banks of loose aggregate or a lot of loose aggregate over whole carriageway, lack of certain fractions, excess sand. |
| | Dusting tendency |
| 2.1—3.0 | Little or no dust is raised. |
| 1.1—2.0 | Minor dust clouds. |
| 0.1—1.0 | Pronounced dust clouds. |

It is stated in FUG that the following requirements should be satisfied in order that a subjective assessment system may be appropriate:

- Assessment should be easy and reliable since there are many users and their training is variable.
- The difference between the classes should be obvious to both the road management authority and road users.
- There should be good correlation with some objective method, e.g. bump integrator, TÖI (Norwegian Institute of Transport Economics) meter.

8.1.1.4 DDp scale, 1982

In the 1982-86 five-year plan for management activity, an experiment was made in using condition assessments generally based on the FUG scale. Condition assessments are based on a subjective assessment regarding the three factors surface roughness, binding ability and dusting tendency. Three condition classes were found sufficient for practical use. The 5 and 4 grade scales for surface roughness and binding ability in the FUG model are compressed into 3 grade scales. In the effect catalogues, this 3-grade scale is called the DDp scale, and in some other literature the SNRA scale. See table 8.4.

Table 8.4 Condition classes according to the DDp scale.

| Condition class | Surface roughness |
|-----------------------|---|
| Class 1 Good | The road surface has the necessary crossfall and is even and firm. There may be one or two potholes. |
| Class 2 Acceptable | The road surface largely has the necessary crossfall and is mostly even and firm. There are potholes and surface roughness on certain sections. |
| Class 3 Low | The carriageway has poor crossfall and/or is deformed transversely. Large sections of the surface are uneven owing to potholes and corrugations. |
| Binding ability | |
| Class 1 Good | Little or no loose aggregate on the carriageway. Loose aggregate may occur at the edges of the road. |
| Class 2 Acceptable | Loose aggregate occurs on the carriageway to a minor extent. There may be small banks of aggregate along road edges and in curves. |
| Class 3 Low | Pronounced banks of loose aggregate along road edges and in curves. Large scale occurrence of loose aggregate over whole carriageway. |
| Dusting tendency | |
| Class 1 Good | Little or no dust is raised. |
| Class 2 Acceptable | Minor dust clouds are often raised along the road (Where there are buildings along the road. Minor dust clouds are raised in places). |
| Class 3 Low | Pronounced dust clouds are raised along most of the road (Where there are buildings along the road. Pronounced dust clouds are raised in places). |

The DDP scale was used in 1982 to monitor and study a number of gravel roads in the D, H, U, W, Y and Z counties. A total of 34 roads were observed. The total length of road was ca 300 km (Olsson et al., 1983).

Comparison of FUG and DDp scales

Carlsson (1980) carried out objective measurements of surface roughness on gravel roads before grading, a few days after grading and at a time between two grading events. Surface roughness was measured with a specially equipped Volvo 145 which registered the relative vertical movement between the rear axle and the chassis. The signal was evaluated according to the road roughness indicator principle, according to which the upward movements of the rear axle relative to the chassis over a given road section are added and this sum is then divided by the distance driven.

Results were printed out every 300 metres both on punched tape and on a panel in the car. This measuring vehicle is described in detail in VTI reports Nos 49, 83 and 123. Measurements were made at 50 km/h.

The Effect Catalogue (1989) states that, on the basis of Carlsson's surface roughness measurements, it is possible to translate the values of the FUG scale into surface roughness indices in terms of mm/km.

The Effect Catalogue (1989) gives a table in which the FUG scale is compared with the DDp scale and surface roughness indices. See table 8.5.

Table 8.5 Comparison of FUG and DDp scales (Effect Catalogue, 1989).

| | | | | | | |
|-------------------------------|-------|------------|------------|------|------|------|
| Surface roughness | | | | | | |
| Surface roughness index mm/km | 11200 | 9300 | 7400 | 5500 | 3600 | 1700 |
| FUG scale | 0 | 1 | 2 | 3 | 4 | 5 |
| DDp scale | Low | | Acceptable | | Good | |
| Binding ability | | | | | | |
| FUG scale | 0 | 1 | 2 | 3 | 4 | |
| DDp scale | Low | | Acceptable | | Good | |
| Dusting tendency | | | | | | |
| FUG scale | 0 | 1 | 2 | 3 | | |
| DDp scale | Low | Acceptable | Good | | | |

8.1.1.5 Method Specification "VVMB 106, 1996" of Swedish National Road Administration

The present system was introduced in 1990. In this, the three factors surface roughness, binding ability and dusting tendency are amalgamated into two factors, surface roughness and binding ability.

The condition of gravel roads is assessed in accordance with the SNRA Method Specification 106:1996, "Assessment of the condition of gravel roads, functional properties" which is abbreviated VVMB 106. Method Specification 106:1996 supersedes 106:1990.

A gravel road is divided into sections which, by comparison with verbal descriptions and photographs, are judged to belong to a certain condition class. During inspections 100 m sections are assessed at a time with regard to surface roughness and binding ability. The lowest condition class to which at least 10 m of the section can be assigned is considered to hold for the whole 100 m section.

Assessment according to this method is not made under freezing conditions but only when roads are free from snow and ice (May-October). At other times inspections are performed to an extent sufficient for changes in condition to be reliably monitored. There is a proposal for this assessment method to be altered so that it can also be applied during the frozen period.

Condition classes according to VVMB 106

The condition of gravel roads with regard to surface roughness and binding ability is assigned to three classes, good, acceptable and low.

Condition classes regarding surface roughness

Class 1, good

The road surface has the necessary crossfall and is even and firm. There may be one or two potholes; see figure 8.1.

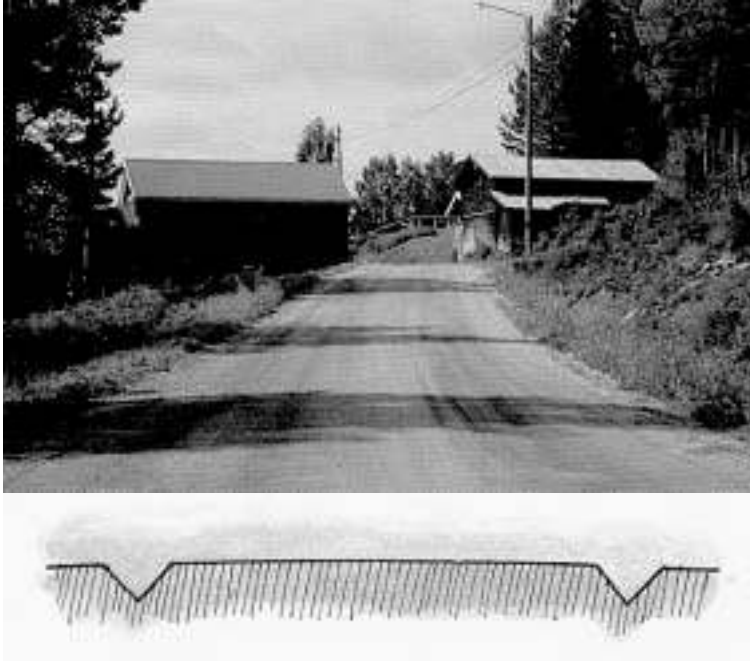


Figure 8.1 Class 1, good.

Class 2, acceptable

The road surface largely has the necessary crossfall and is mostly even and firm. There are potholes and surface roughness on certain sections; see figure 8.2.



Figure 8.2 Class 2, acceptable.

Class 3, low

The carriageway has poor crossfall and/or is deformed transversely. Large sections of the surface are uneven owing to potholes and corrugations; see figure 8.3.

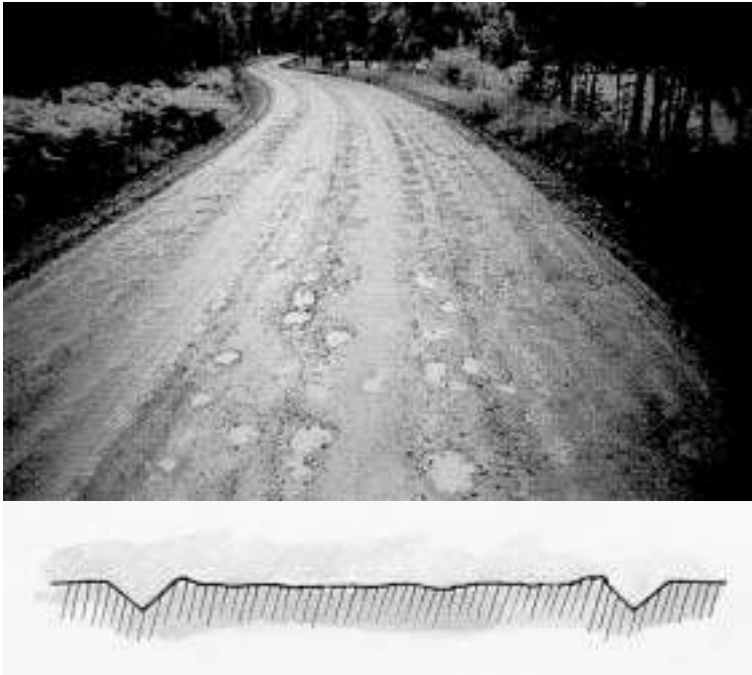


Figure 8.3. Class 3, low.

Condition classes with regard to binding ability**Class 1, good**

Loose aggregate occurs on the carriageway to a slight extent (due to grading there may be loose aggregate at the edges of the road and between ruts). No dust is raised; see figure 8.4.

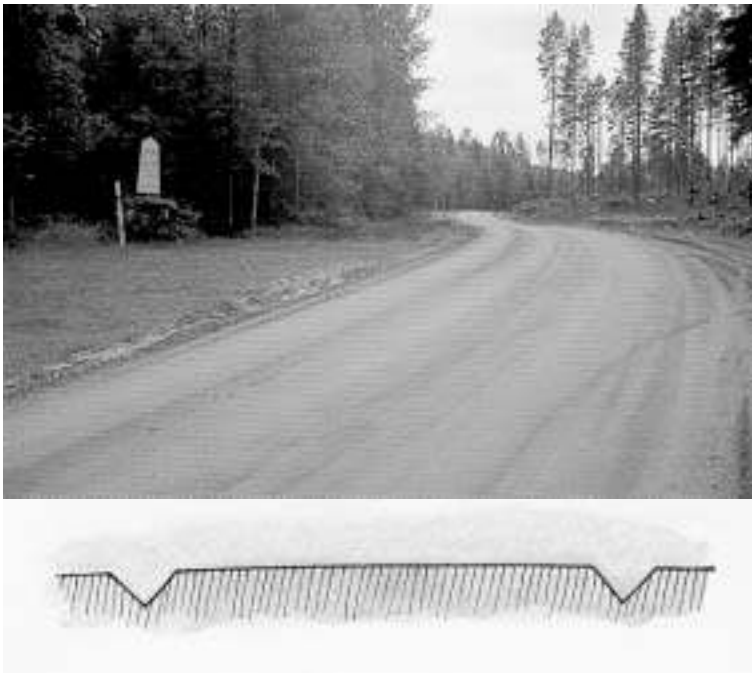


Figure 8.4. Class 1, good.

Class 2, acceptable

Loose aggregate occurs on the carriageway to a minor extent and in small banks along the edges of the road. Minor dust clouds are raised along the road; see figure 8.5.

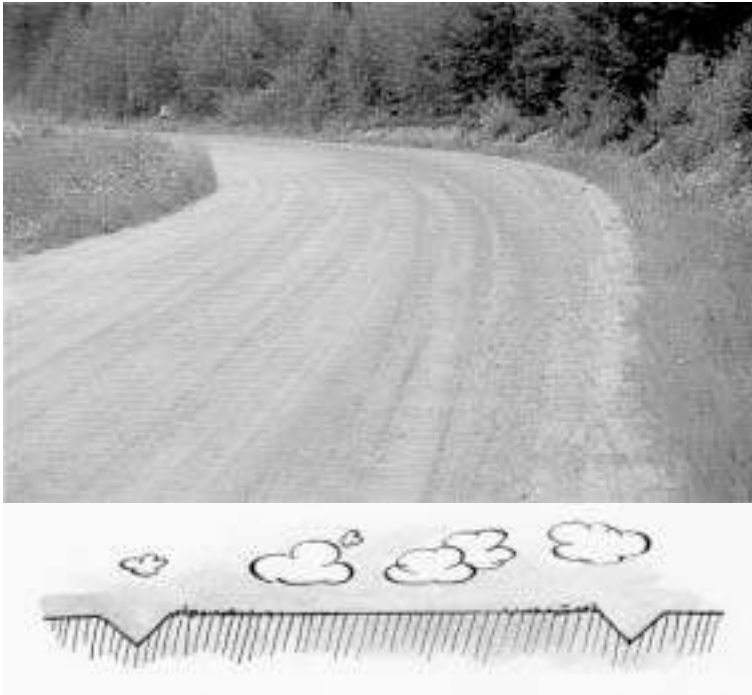


Figure 8.5. Class 2, acceptable.

Class 3, low

Loose aggregate occurs to a large extent over the whole carriageway and in pronounced banks along the edges of the road. Pronounced dust clouds are raised along most of the road; see figure 8.6.

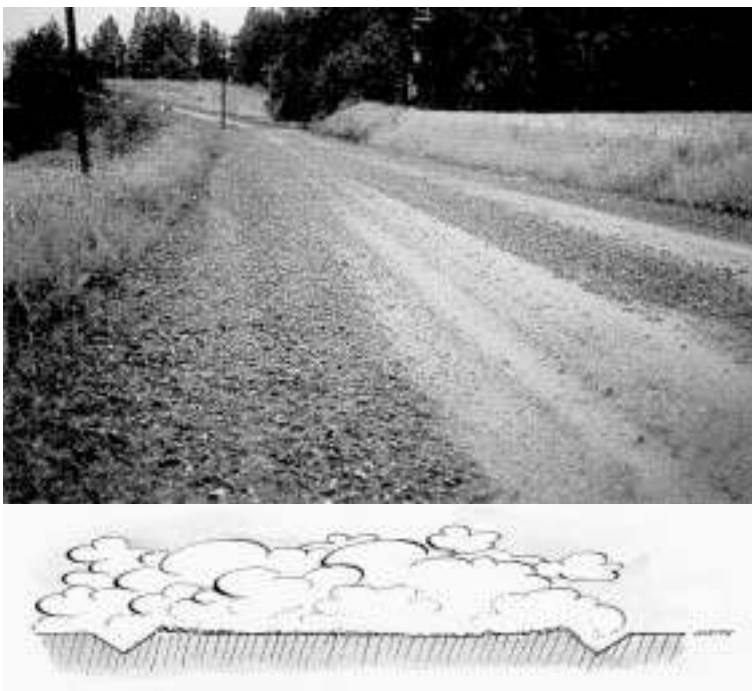


Figure 8.6 Class 3, low.

It is worth noting that the Swedish National Road Administration, West Region, has drawn up a report which contain more photographs describing the three classes of surface roughness and binding ability. (Manual of standard photographs, Gravel Road Maintenance, 1996, in Swedish). When more photographs are available, it is easier to determine what class the road is to be assigned to.

Standard classes

With regard to traffic flow, a road should be assigned to a certain standard class according to table 8.6 (Regulations for Maintenance and Operation, 1990, in Swedish).

In determining the condition that a road must have, consideration should also be given to buildings, public transport and other utility traffic, the distribution of recreational and business journeys, and available economic resources. table 8.6 sets out the three standard classes.

Table 8.6 *Standard classes for management and maintenance of gravel roads.*

| Traffic flow, AADT | Standard classes |
|--------------------|------------------|
| <50 | C |
| 50—124 | B |
| ≥125 | A |

In the West Region, the standard classes have been altered so that C has been replaced by B which is the lowest class in this region. See below. Classes A and have been amalgamated into a Class A.

Traffic flow, AADT_t Standard class

<50 B
>50 A

8.1.2 Objective assessment

It is obviously desirable that gravel roads should be qualitatively evaluated with reference a measurable variable. It has however been found difficult to select a variable that provides all-embracing information regarding the condition of gravel roads. The variable which is most often measured objectively is the longitudinal surface roughness which is expressed in terms of mm/km.

For Swedish gravel roads, surface roughness normally varies from 3000 to 9000 mm/km. Normal values for paved roads are 500-3500 mm/km. ("Data for management planning", 1983).

In order to eliminate human factors which easily give rise to an irregular or systematic spread of the results, a number of equipments have been designed for direct measurement of the condition of a road. Four studies will be described, Magnusson et al. (1977), Carlsson and Öberg (1977), Johansson et al. (1983) and Sjögren (1998).

8.1.2.1 Magnusson et al. 1977

Magnusson et al. (1977) performed a study to measure surface roughness on gravel roads and to find a relationship between roughness and the speed selected by drivers. The experimental part of the study was performed in two stages on 20 test sections each 200 m in length. The first stage was carried out during the thaw period at the end of April while the second was performed at the end of May when thaw had finished and the road had dried. Four meters were employed:

1. PCA Road Meter (Portland Cement Association)
2. GM Profilometer (General Motors)
3. Road Roughness Indicator
4. Friction Test Vehicle (BV11 J)

1. PCA Road Meter

The PCA Road Meter measures longitudinal roughness in the road by registering the movements of the rear axle in relation to the chassis. Registration is performed electromechanically. The results are dependent on the speed.

2. GM Profilometer

This is a car that measures longitudinal roughness in the road by means of a fifth wheel. Both the movements of this wheel in relation to the chassis, and the movements of the chassis, are registered. See figure 8.7.



Figure 8.7 GM Profilometer (Magnusson et al., 1977).

3. Road Roughness Indicator

This is the oldest and simplest measuring equipment which registers the longitudinal roughness of the road. In principle, it comprises a measuring wheel mounted in a relatively heavy frame through a spring and shock absorber system. The equipment which is towed by a car registers vertical movements of the wheel in cm/km or mm/km. The results are highly dependent on the speed. The speed during the tests was 32 km/h; see figure 8.8.

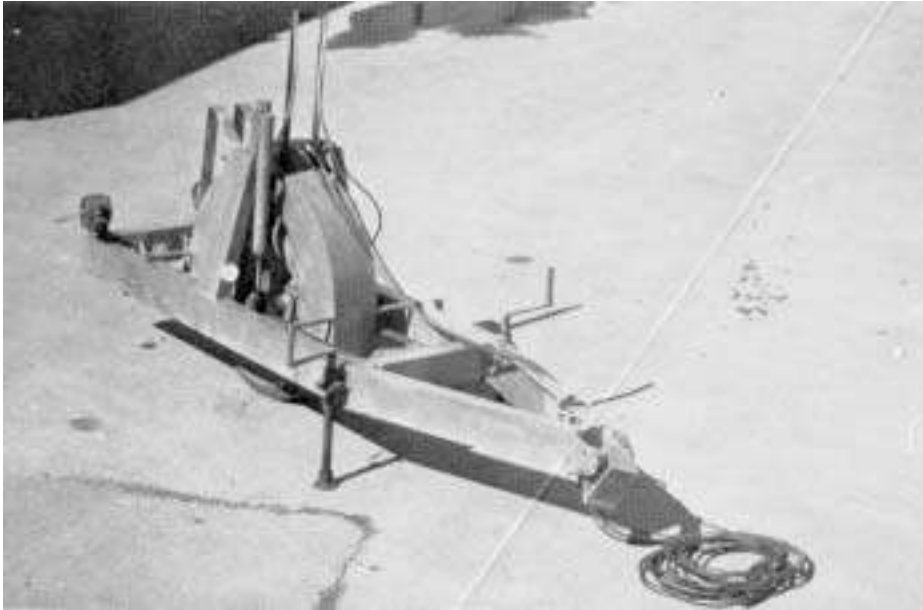


Figure 8.8 Road Roughness Indicator (Magnusson et al., 1977).

4. Friction Test Vehicle

BV11 is a trailer drawn by a car. The trailer was originally designed to measure friction. BV11 is equipped with a differential transformer mounted in such a way that its output signal is a measure of the vertical position of the measuring wheel relative to the frame. This signal is processed in a computing unit mounted in the towing vehicle into an index corresponding to that given by the Road Roughness Indicator or the OCA meter. BV11 is intended to measure both surface roughness and friction. The prototype BV11 shown in figure 8.9 has been fitted with yet another potentiometer for measuring the relative motion between the measuring wheel and the applied load. The object was to find which of the two relative movements provided the best reliability and agreement with assessment results.

For friction measurements it is necessary for the measuring wheel to be braked so that there is some slip. In order to find whether the braking moment might disturb the surface roughness measurements, measurements were made with the wheel both braked and not braked. Results are dependent on the speed. Speeds in the test were 30 and 50 km/h.

The trailer was originally designed for use on a relatively even road, and from the vehicle engineering standpoint it is therefore less satisfactory for use on a very uneven surface.

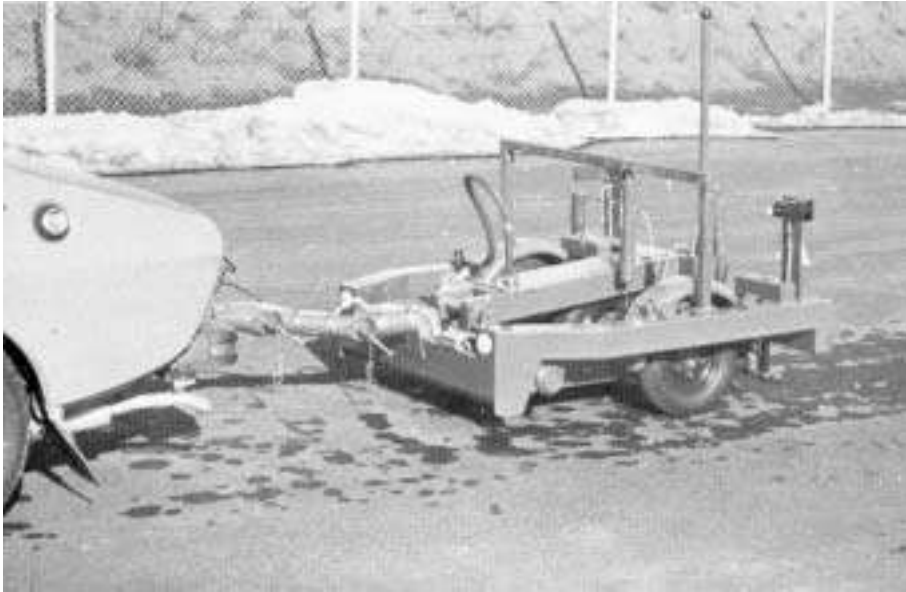


Figure 8.9 Prototype BV11 J (Magnusson et al., 1977).

It is not evident which of the four equipments mentioned in Magnusson et al.'s study is most suitable for measurements of the surface roughness of gravel roads.

8.1.2.2 Carlsson and Öberg, 1977

Carlsson and Öberg (1977) performed a study to measure friction before and after single course gravel surface dressing Y1G on gravel roads. Friction was measured with the VTI friction test vehicle BV11. Friction was measured both before and after a traffic count. Friction was also measured after a change in road conditions, e.g. after rain. On each occasion, measurements were made at the centre of the road and in wheeltracks, in both directions and at two different speeds. These were 30 and 50 km/h in bends and 50 and 70 km/h at the other traffic count points. Surface dressing of the road caused an increase in road friction by 0.1—0.3. Experiences or conclusions relating to the use of BV11 on gravel roads are not given in the report.

8.1.2.3 Johansson et al., 1983

The report Johansson et al. (1983) FUG relates to surface roughness measurements on gravel roads using the following equipments:

1. Road Roughness Indicator
2. TÖI (Norwegian Institute of Transport Economics) meter
3. CHLOE profilometer

1. Road Roughness Indicator

The equipment was used at a speed of 32 km/h. The results exhibit good correlation with the subjective valuation systems that consider surface roughness, e.g. the 5-grade FUG system. See figure 8.10.

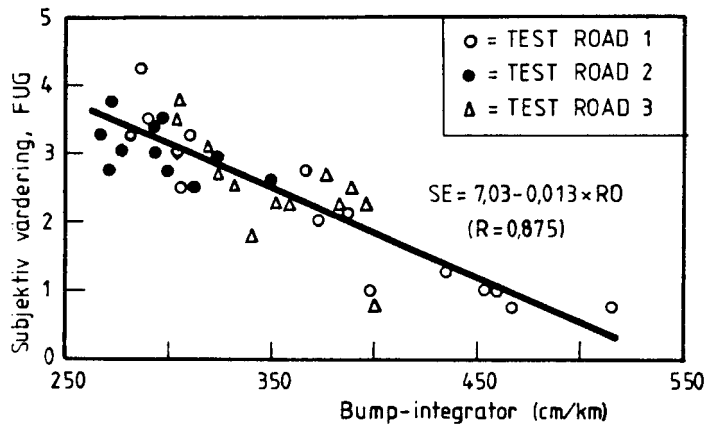


Figure 8.10 Relationship between subjective assessment (FUG) and surface roughness measured with the Road Roughness Indicator on three Finnish gravel roads (Johansson et al., 1983).

Vertical axis- Subjective evaluation

Horizontal axis- Road Roughness Indicator

The report states that similar correlations had been obtained between the Road Roughness Indicator, the TÖI meter and the CHLOE profilometer.

2. TÖI meter

This is an equipment developed by the Institute of Transport Economics (TÖI) in Norway. The equipment can measure rut depth and surface roughness at 50 km/h. See figure 8.11.

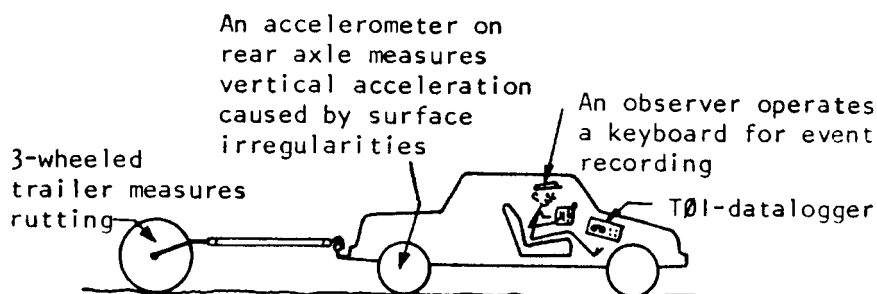


Figure 8.11 General arrangement of TÖI meter (Johansson et al., 1983).

3. CHLOE profilometer

The name CHLOE refers to Huckins, Leathers and Other Engineers, i.e. the team that developed the instrument.

The profilometer comprises a laced beam supported on the towing vehicle and two wheels. The supporting wheel unit incorporates a balance arm mounted in such a way that it is deflected by surface roughness. In the Swedish version the "TRAC" value is calculated. This is considered to have better correlation than the Present Serviceability Index (PSI) with subjective assessments. Measuring speed is quite low, 15 km/h. See figure 8.12.

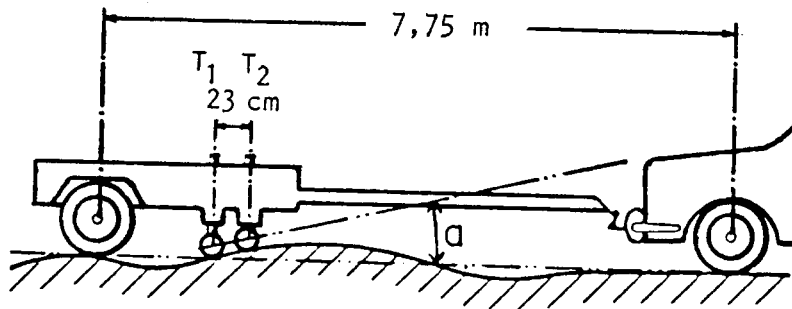


Figure 8.12 General arrangement of CHLOE meter (Johansson *et al.*, 1983).

8.1.2.4 Sjögren, 1998, VTI Laser RST Vehicle

Sjögren (1998) carried out a small number of measurements with the VTI Laser Road Surface Tester. This vehicle is normally used on paved roads to determine their condition. It is a relatively expensive method.

The Laser RST measures, *inter alia*,

- a. The longitudinal profile of the road along two wheeltracks separated by 150 cm. From the longitudinal profile two surface roughness indices, e.g. the International Roughness Index (IRI) and Root Mean Square (RMS), are calculated.
- b. Texture along two wheeltracks
- c. Fine macrotexture
- d. Coarse macrotexture
- e. Megatexture
- f. Longitudinal profile

Sjögren (1998) claims that, with the help of the longitudinal profile in the two wheeltracks and the surface roughness determined from this, and the differences between roughness in the two tracks, it is possible to obtain a measure of the extent of corrugations and potholes. Using the coarse macrotexture, 0.4-50 mm, a measure of the occurrence of loose aggregate can be given.

Sjögren's conclusions are

- In a research context, measurements can be made on gravel roads with the VTI Laser RST. However, several and repeated measurements are needed to determine appropriate presentations and the accuracy of these. What Sjögren means is that the accuracy must be specified for the dimensions to be studied. This can be arrived at by making a measurement series on the correct selection of test roads and comparing the results with traditional assessments.
- However, the use of the Laser RST on gravel roads as a regular measurement method cannot be recommended, owing to the risk of damage to the equipment and also because measurement conditions are difficult due to the presence of dust and water on the surface which may cause the laser camera to make erroneous readings. The risk of damage can be eliminated, but the latter is more difficult to tackle.

- The surface roughness of gravel roads varies more across the road than that of paved roads.
- It is important to measure the entire width of the road.

8.2 Condition monitoring according to GUPP

"Gravel Road Monitoring" (1995), in Swedish, describes a statistical model for where and when an assessment of the condition of the gravel road network is to be made.

Method Specification 106:1996 "Condition assessment of gravel roads, functional properties" and the statistical model "Monitoring of gravel roads" are together denoted "System for monitoring gravel roads" and abbreviated to GUPP.

The monitoring system GUPP is based on experiences obtained during experimental activity in the West Region of the Swedish National Road Administration in the spring, summer and autumn of 1994. Roads to be monitored were selected in time and space according to one of the two selection models:

- A. The regional selection model
- B. The local selection model

A. The regional selection model

According to this model, the purpose of monitoring is to determine whether condition is better or worse than a certain minimum standard. This monitoring forms the basis for reports to the decision support system abbreviated to BESS. The condition of gravel roads in a road network during the frostfree period is obtained by statistical data processing ("Gravel Road Monitoring", 1995). The way this statistical data processing is performed is described briefly, but not clearly, in the report "Monitoring of Gravel Roads".

B. The local selection model

Monitoring can be used to verify contractors' work. In this case, statistical data processing gives the condition of gravel roads in different geographical areas during the frostfree period, and also the monthly variation in condition on a regional level.

The term geographical area refers to the area for which management and maintenance work has been procured. These areas are also called contract areas. Under the monitoring system, the contractor carries out his own condition assessments, and the road management authority performs spot inspections at its discretion. Today, GUPP is applied in only a few regions, and reports are not sent to BESS.

Selection in time and space

During the frostfree period of the year, every gravel road must be assessed on at least one occasion during every period of either ten or two weeks. The time between two assessments must be not less than nine and not more than eleven weeks when the regional model is applied, and not less than one and not more than three weeks when the local model is used.

At the time of each assessment, the gravel road is to be assessed in places selected at random. Gravel roads shorter than 1 km are not included in the monitoring system. For gravel roads longer than 10 km there shall be at least 2 assessment objects selected at random, plus one more assessment object per every 10 km or part thereof in addition to the first 10 km. Three alternatives are given for the way random selection is to be made. The assessment object is a section of gravel road that covers the selected points. The three alternatives are:

Alternative 1

Points on the gravel road are selected from a table of random numbers. This table is designed so that points far too close to one another are avoided.

Alternative 2

An ordinary table of random numbers or a random number generator is used to determine the points. This may at times result in some crowding of points, but this is statistically correct.

Alternative 3

The points are stratified. The gravel road is divided into the same number of sections as the number of objects to be selected. The lengths of these sections must be equal. One point in each section is then selected using a table of random numbers or a random number generator.

If the producer makes the inspections, the road management authority shall make random checks. The times the authority makes its checks should closely coincide with the producer's inspections. The producer is therefore obliged to inform the authority in good time, e.g. a few days, before each inspection as to which objects will be assessed and the time of such assessments.

Reports on condition measurements and assessments are to be made using the "Gravel road inspection sheet"; see Appendix No 2.

8.3 Assessment of the condition of gravel roads abroad

Systematic tests in this areas have been made in several countries. The way the condition of gravel roads is assessed in Finland, Canada, USA, New Zealand and Australia is described below. The methods applied for condition assessment, and the scales used, vary both between countries and regions.

8.3.1 Finland

About 42% of the 75,000 km of State road network in Finland consists of gravel roads. Traffic mileage on gravel roads is ca 7% (Männistö and Tapio, 1990). Traffic mileage on gravel roads in Sweden is 1.32%. See Chapter 4.

For the assessment of the condition of gravel roads, the most important information in the road register is that relating to bearing capacity and road length at risk of frost damage. The road register gives e.g. the length of gravel roads, year of construction, functional class and standard maintenance class, measures taken on the road, traffic volume, traffic mileage and tonne mileage, road width, lighting, speed limits, number of accidents and accident frequency (Jämsä and Kankare, 1980).

Subjective assessment

The condition of the wearing course is assessed visually according to the assessment scale set out below. This assessment takes no account of occasional frost damage. Assessment is primarily based on surface roughness, binding ability, dusting tendency and crossfall (Routine road maintenance management and monitoring at the Finnish National Road Administration, 1994).

Both verbal descriptions and example photographs aid assessment. Assessment scales, condition classes and condition descriptions are set out in table 8.7. With regard to surface roughness, the Finnish condition classes are very similar to the FUG scale. See table 8.3 for comparison.

Table 8.7 Condition classes in Finland (Johansson et al, 1983).

| Rating | Condition Class | Description |
|---------|-----------------|---|
| 4.1-5.0 | 5 | The surface or the road has retained its shape and is very even and firm. Any possible unevenness does not affect driving pleasure. |
| 3.1-4.0 | 4 | The surface or the road has generally retained its shape and is even and firm. A few small depressions may exist here and there. No dust is apparent. Driving speed does not have to be lowered because of unevenness. |
| 2.1-3.0 | 3 | The road has retained its shape in general and is mostly even and firm. There may be occasional small depressions and other unevenness. The road is a little dusty. Any depressions or bumps in the road can be avoided or they do not require slowing down. It may be necessary to slow down when meeting a car or allowing someone to pass. |
| 1.1-2.0 | 2 | The cross-sectional profile of the road may have changed some. There is some washboard surface. There may be a few signs that warn about depression or bumps. There is a moderate amount of dust. Driving speed has to be slowed occasionally and the driver has to watch for unevenness. |
| 0.1-1.0 | 1 | The cross-sectional profile of the road has changed in many places. The surface is uneven and looks like a washboard. The road contains bumps and depressions that cannot be avoided. It contains an abundant amount of dust. The driver must continuously survey the surface and vary his/her driving speed. |

Jämsä (1983) and Johansson et al (1983) say that assessments and monitoring are carried out in five stages:

Stage 1: Assessment of the description to which the condition most closely corresponds.

Stage 2: If the condition of the road, on average, corresponds to the description, or if it is slightly better or worse than the description, the assessment is adjusted as necessary.

Stage 3: The road section is generally assessed as a whole, but it may be necessary to divide it up into subsections.

Stage 4: For each standard class there is a target in the form of a minimum limit for the condition of the wearing course, in terms of the scales in the table above.

In Finland there are five standard classes for gravel roads. The highest is standard class 3, and the lowest standard class 7. See table 8.8.

Stage 5: If the condition drops below the minimum limit of the target, then, if weather conditions permit, the necessary measures must be taken to raise the standard. See table 8.8.

Table 8.8 *Targets for minimum standards in the standard classes.*

| AADT | Standard class | Target (minimum limit) |
|-------------|-----------------------|-------------------------------|
| -100 | 7 | 1.5 |
| 101—200 | 6 | 2.0 |
| 201—500 | 5 | 2.4 |
| 501—1500 | 4 | 2.8 |
| 1501—6000 | 3 | 3.3 |

The difference between the Finnish and Swedish models is that in the Finnish model the limits are different for measures to be taken depending on standard class, while the Swedish model has the same limits irrespective of traffic. In the Swedish model it is the time within which measures must be taken after the standard has dropped below the lower limit which depends on standard class (Standard project, 1979, in Swedish).

8.3.2 Canada

In their "Manual for condition rating of gravel surface roads", Chong and Wrong (1989) describe a method for condition assessment.

The method is based on subjective assessment of three types of primary distress. Each of these includes other secondary damage. These primary and secondary distresses are as follows:

1. Surface defects

- 1.a Loose aggregate
- 1.b Dust
- 1.c Potholes
- 1.d Breakup

2. Surface deformation

- 2.a Corrugations
- 2.b Rutting
- 2.c Flat or reverse crown
- 2.d Distortion

3. Shoulder distress manifestations

- 3.a Excessive height
- 3.b Ponding
- 3.c Overgrowth

Two terms are used to describe defects. One is "Severity", the other "Density" which indicates the extent of damage. Severity has three levels, slight, moderate and severe. Density also has three levels, intermittent, frequent and extensive.

Verbal descriptions and example photographs aid assessments. During visual assessments a straightedge is used to measure e.g. the depth and width of defects.

Chong and Wrong propose what operation and maintenance measures should be taken depending on the results of assessments. table 8.9 shows the measures needed for different levels of rutting. The following example gives a detailed idea of how rutting and the measures that are needed are assessed. figure 8.13, 8.14 and 8.15 show the three levels of rutting, slight, moderate and severe.



Figure 8.13 *Slight rutting.*

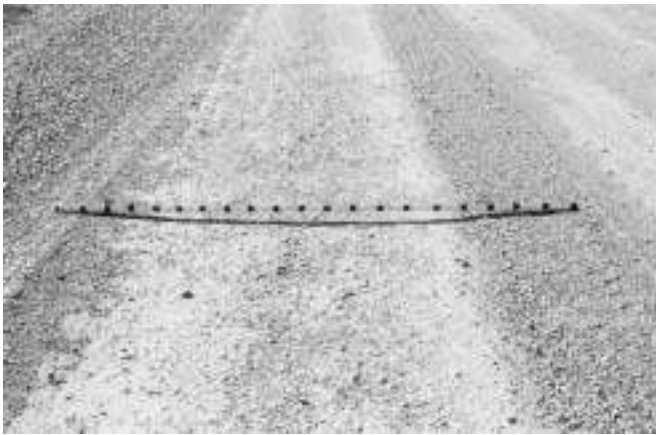


Figure 8.14 *Moderate rutting.*



Figure 8.15 *Severe rutting.*

Table 8.9 *Management and maintenance measures needed for different levels of rutting.*

| Treatments | | |
|------------|--------------|---|
| Evaluation | | Suggested Maintenance Treatment Alternatives |
| Severity | Density | |
| Slight | Intermittent | • No action |
| | Frequent | • No action |
| | Extensive | • No action |
| Moderate | Intermittent | • No action |
| | Frequent | • Grading and rolling |
| | Extensive | • Grading and rolling |
| Severe | Intermittent | • Grading with addition of gravel and rolling |
| | Frequent | • Grading with addition of gravel and rolling |
| | Extensive | • Grading with addition of gravel and rolling • Rehabilitation candidate |

The condition of entire road sections is then assessed according to a 100-degree assessment scale. See table 8.10. On the basis of this scale, there is a breakdown into five classes, 80-100, 60-79, 40-59, 20-39, 0-19.

Table 8.10 *The hundred-degree assessment scale (Chong and Wrong, 1989).*

| Description | PCR | Recommended maintenance |
|---|--------|--|
| Roadway surface well shaped with well-defined shoulder between roundings. No surface distress manifestations, just a slight classification for dust and loose gravel. No frost heave or soft spots when evaluation is made in late spring. Good drainage for surface run-off on roadway and shoulder. | 80-100 | Routine maintenance. |
| Roadway surface well shaped with shoulder between roundings. Some distress manifestations in slight to moderate class such as dust, loose gravel, potholes, etc. There may be a few soft spots of frost heaving when evaluation is made in late spring. Good drainage for surface run-off on roadway and shoulder. | 60-79 | Routine maintenance. Dust control may be necessary for residential areas. |
| Mixture of properly shaped roadway surface and improperly shaped areas. Shoulder distress manifestations such as ponding and overgrowth evident between roundings in slight to moderate class. Various surface distress manifestations present such as washboarding, potholes, etc., in slight to moderate class. Localised breakup may be present. | 40-59 | Increased routine maintenance necessary. Addition of gravel and dust control additives become necessary. |
| Majority of roadway surface improperly shaped. Shoulder distress manifestations in moderate to sever class. Various roadway surface distress manifestations making travel unpleasant because of washboarding, dust, potholes, distortion, etc. Localised breakup areas. | 20-39 | Maintenance with addition of gravel necessary. Dust control a must for residential areas. Some portion may be need rehabilitation. |
| Flat to reveres crown, sever roadway surface distress such as washboarding, loose gravel, potholes, etc. Very rough on vehicles from severe distortion and breakup areas. Severe shoulder distress trapping surface water at all times. Little or no gravel due to severe windrow of loose gravel, on roadway surface. | 0-19 | Rehabilitation necessary |

Dobson and Postill (1983) present in their study a method for standard classification of gravel roads. Roads are assigned in view of their "Quality of Service" to three classes; see Table 8.11. Standard classification is based on AADT and the proportion of heavy vehicles, road width, visibility conditions, driving comfort and availability during the year.

Table 8.11 *The three standard classes.*

| | Quality-of-service Characteristic | Class 1 | Class 2 | Class 3 |
|---|-----------------------------------|--|---|---|
| 1 | ADT | 250-400 | 100-300 | 0-150 |
| | Trucks (%) | 13 | 13 | 13 |
| 2 | Road Width (m) | > 6.7 | 4.9-6.7 | 4.9 |
| 3 | Visibility | | | |
| | Passing sight distance (m) | 488 | 335 | 244 |
| | Stopping sight distance (m) | 107 | 84 | 61 |
| 4 | Ease of passage | Rutting, corrugation, and potholes are not tolerated | Slight rutting, corrugation, and potholes allowed | Rutting, corrugation, and potholes corrected seasonally |
| 5 | All-season travel | Open year round | Open year round | Seasonal closures allowed |

Dobson and Postill made 400 vehicles the upper limit for AADT since they consider that roads with AADT in excess of 400 ought to be paved. According to Dobson and Postill, management and maintenance activity can be planned and performed better when their classification is employed. They also add that this classification makes macroeconomic estimates possible.

8.3.3 USA

About 50% of the American road network is unpaved. Traffic flow on gravel roads varies from 50 to 400 AADT (Han, 1992).

"Gravel-PASER Manual, Pavement Surface Evaluation and Rating GPM" (1994) describes a method for condition assessment of gravel roads in USA. The method is based on subjective assessment. Five road properties or distresses are used to describe condition. All defects are described in words and with photographs. Proposals for remedial measures are also given. The five properties and defects are:

1. Crown
2. Drainage
3. Gravel wearing course
4. Surface deformation
5. Surface defects

1. Crown

The term crown also describes crossfall and the height of the centre of the road above the edges. There are three levels, excellent crown, poor grading and poorly graded crown.

2. Drainage

The condition of both ditches and culverts is assessed with the help of photographs and descriptions. There are four levels, excellent drainage, acceptable drainage, poor drainage and no drainage.

3. Gravel wearing course

The thickness and quality of the gravel wearing course are assigned to three levels, excellent gravel wearing course, acceptable gravel wearing course and little or no gravel wearing course.

4. Surface deformation

Surface deformation may be rutting, corrugation or potholes.

4.1: There are two levels of rutting, rutting only in wheeltracks and extensive rutting combined with very poor drainage.

4.2: There are two levels of corrugation, moderate and significant corrugation.

4.3: There are three levels of potholes, few potholes, series of moderate potholes and extensive potholes which covers almost the whole carriageway. Potholes on bridges is also described.

5. Surface defects

In conjunction with defects, dusting and loose aggregate are described as follows:

5.1: Unexpectedly, dust is given only one level which is lot of dust. There should be another level, e.g. no dust.

5.2: Loose aggregate is broken down into two levels:

Loose aggregate occurs extensively over almost the whole carriageway (level 1) and extensive banks along the road edges (level 2).

GPM gives a table for assessing the condition of the wearing course with respect to the above five properties and defects. With the help of photographs and verbal descriptions, the road is assigned to five condition classes. The scale 1—5 is used, with 5 as excellent. See table 8.12.

Table 8.12 *The five condition classes (GPM, 1989).*

| | Rating | Visible distress | Treatment measures |
|---|---------------|---|--|
| 5 | Excellent | No distress. Dust controlled. Excellent surface conditions and ride quality. | Little or no maintenance needed. |
| 4 | Good | Dust under dry conditions. Moderate loose aggregate. Slit washboarding. | Routine maintenance may be needed. |
| 3 | Fair | Good crown 3"-6". Ditches present on more than 50% of roadway. Gravel wearing course is mostly adequate but additional aggregate may be needed at a few locations to help correct washboarding or isolated potholes and ruts. Some culvert cleaning needed. Moderate washboarding (1"-2" deep), over 10%-25% of the area. Moderate dust, partial obstruction of vision. None or slight rutting (less than 1" deep). An occasional small potholes (less than 2" deep). Some loose aggregate (2" deep). | Regrading necessary to maintain. Needs some ditch improvement and culvert maintenance |
| 2 | Poor | Little or no roadway crown (less than 3"). Adequate ditches on less than 50% of roadway. Portions of the ditches may be filled, overgrown and/or show erosion. Some areas (25%) with little or no aggregate. Culverts partially full of debris. Moderate to severe washboarding (over 3" deep) over 25% of area. Moderate rutting (1"-3") over 10%-25% of area. Moderate potholes (2"-4") over 10%-25% of area. Severe loose aggregate (over 4"). | Needs additional aggregate. Minor ditch construction and culvert maintenance also required. |
| 1 | Failed | No roadway crown or road is bowl shaped with extensive ponding. Little if any ditches. Filled or damaged culverts. Severe rutting (over 3" deep), over 25% of the area. Severe potholes (over 4" deep), over 25% of area. Many areas (over 25% of the area) with little or no aggregate. | Needs complete rebuilding and or new culverts. |

Every condition class in table 8.12 is accompanied by a general description of the condition of the road, and some measures are proposed depending on the defects described above. For instance, the general description of Condition Class 2 is that speed is low and often less than 40 km/h.

In their report, Eaton and Beaucham (1992) describe a method for condition assessment. The method is based on subjective assessment and presents an "unsurfaced road condition index" URCI. This has a scale ranging from 0 to 100, and the road condition according to this is the same as that given in "pavement condition index" PCI for paved roads. Standard classes and condition classes are briefly described in the following.

Standard classes for gravel roads according to Eaton and Beaucham are set out in table 8.13.

Table 8.13 *Standard classes.*

| Standard class | ADT, number of vehicles per day | URCI |
|----------------|---------------------------------|--------|
| 1 | ≥200 | 70-100 |
| 2 | 100—199 | 55-70 |
| 3 | 50—99 | 40-55 |
| 4 | 0—49 | 25-40 |

For **condition assessment** there are two types of inspection. One is "windshield inspection" and the other a detailed inspection.

Windshield inspection is carried out from a car driven at ca 40 km/h depending on road condition and speed limit. The road is not divided into sections, but the car drives over the whole length of the road. This inspection is performed every season, four times a year.

Eaton and Beaucham recommend that the detailed inspection should be carried out every year at the same time. The inspection should be made when the road is in the best possible condition. An inspection should not be made during the thaw period.

For a **detailed inspection**, a gravel road is divided into sections which, by referring to photographs, are judged to belong to a certain standard class with respect to seven different types of distress. Sections 35-80 m long are assessed at a time.

The seven **distresses** used for assessment are as follows:

1. Wrong crossfall
2. Insufficient drainage
3. Corrugations
4. Dust
5. Potholes
6. Rutting
7. Loose aggregate

Distress is described under three headings,

- a. Brief description of distress, its causes and the consequences if no action is taken.
- b. Method of measuring the distress.

A straightedge 1.2 m long is used to measure the depth, area and width of the distresses.

c. Levels of the severity of distresses:

1. Low severity (L)
2. Medium severity (M)
3. High severity (H)

The seven types of distress are illustrated in figure 8.16-8.22 (Eaton and Beaucham, 1992).

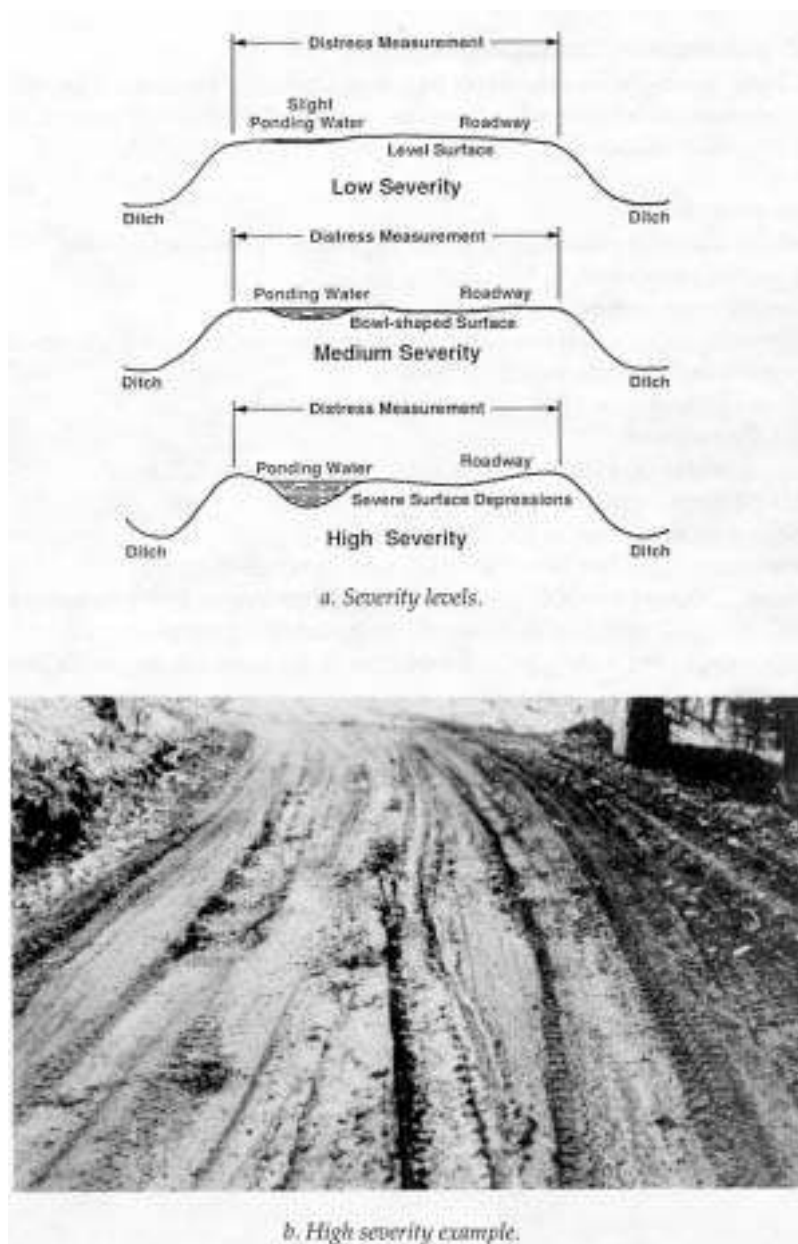


Figure 8.16 The three levels for assessment of crossfall (Eaton and Beaucham, 1992).

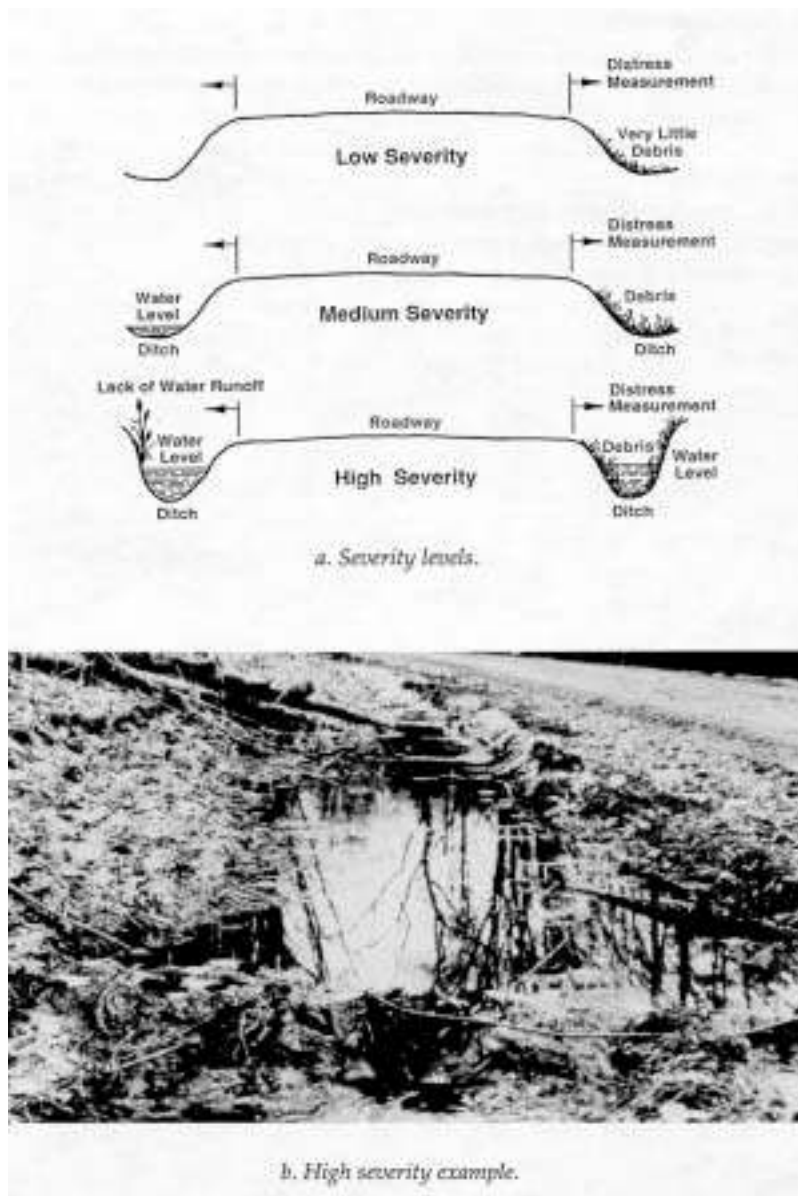


Figure 8.17 The three levels for assessment of drainage (Eaton and Beaucham, 1992).

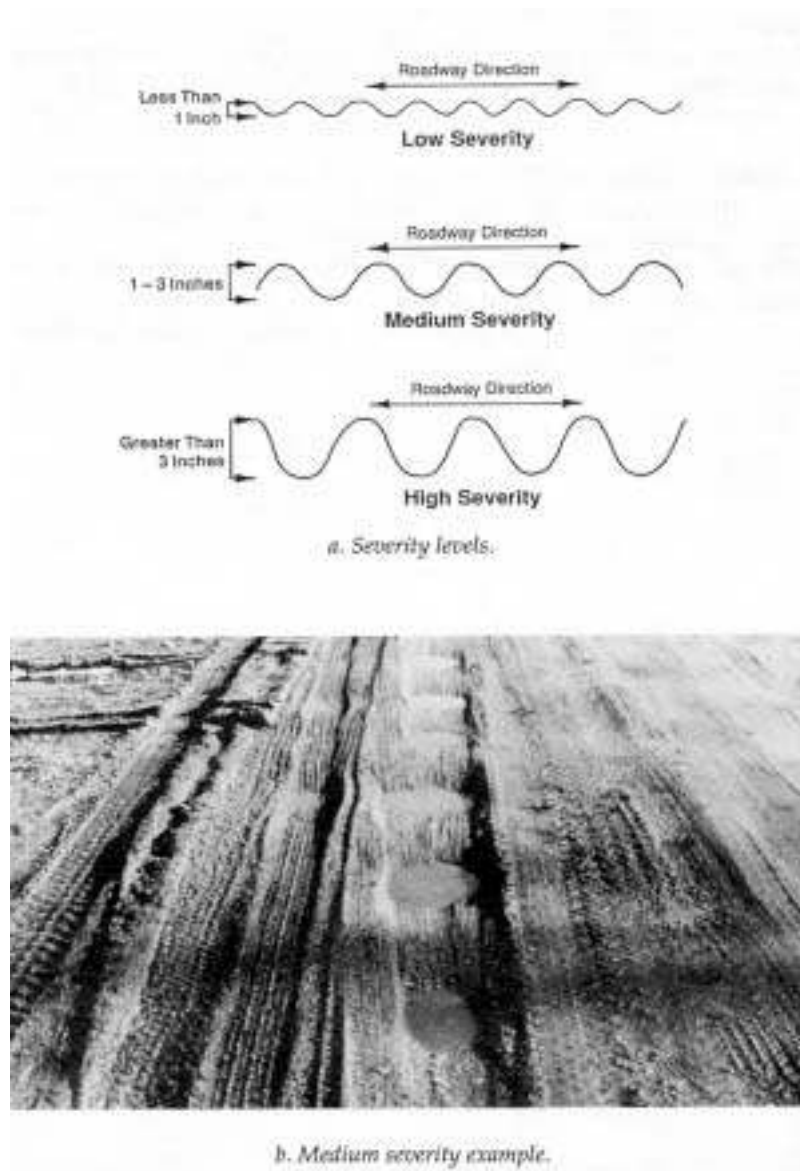
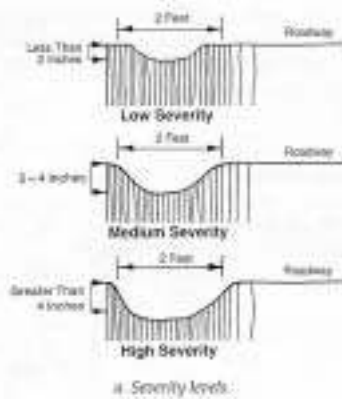


Figure 8.18 *The three levels for assessment of corrugation (Eaton and Beaucham, 1992.)*



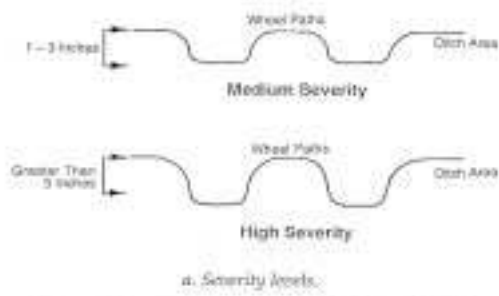
b. High severity example.

Figure 8.19 The three levels for assessment of dusting (Eaton and Beaucham, 1992).



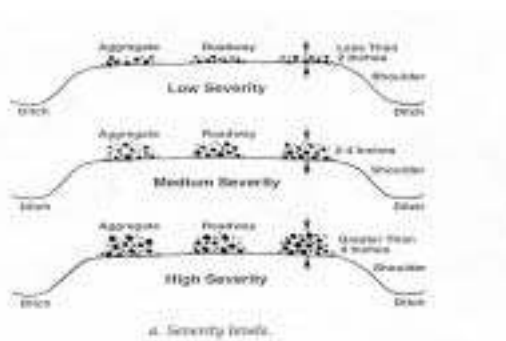
b. High severity example.

Figure 8.20 The three levels for assessment of potholing (Eaton and Beaucham, 1992).



b. Low severity example.

Figure 8.21 The three levels for assessment of rutting (Eaton and Beaucham, 1992).



b. Low severity example.

Figure 8.22 The three levels for assessment of loose aggregate (Eaton and Beaucham, 1992).

The inspection report is made on a special form; see Appendix No 3. The form has two tables which must be filled in. One contains information regarding degrees of severity L, M or H. The other table is headed URCI Calculation. URCI is calculated in four steps. These are not described here.

After URCI has been calculated for the whole road, the condition class to which the road is assigned is assessed. The relationship between URCI and the condition classes is set out in figure 8.23.

| URCI | RATING |
|------|-----------|
| 100 | Excellent |
| 85 | Very Good |
| 70 | Good |
| 55 | Fair |
| 40 | Poor |
| 25 | Very Poor |
| 10 | Failed |
| 0 | |

Figure 8.23 The URCI scale (Eaton and Beaucham, 1992).

Priorities to different road sections are assigned using a Maintenance Priority Graph. This is based on a combination of URCI and traffic volume AADT. The maintenance priority graph is reproduced in figure 8.24.

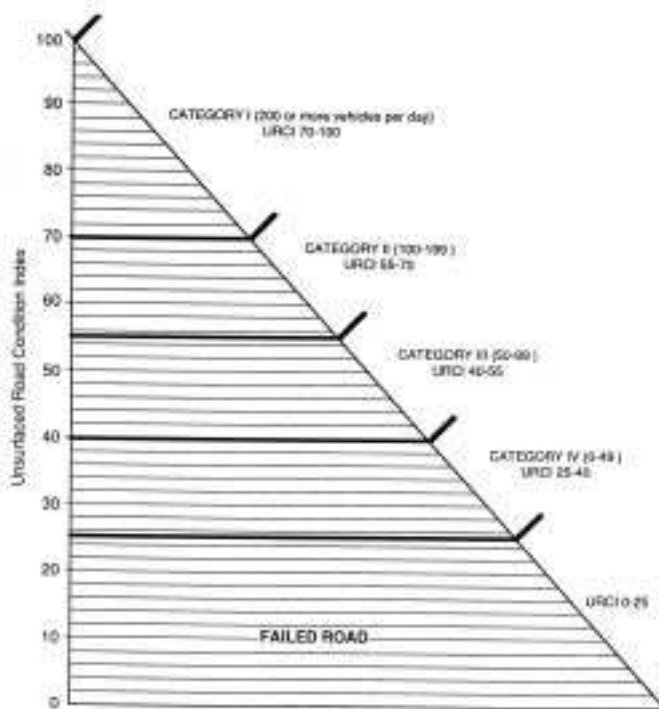


Figure 8.24 Maintenance priority graph (Eaton and Beaucham, 1992).

All roads in the network can then be assigned to three priority classes, low, medium and high priority. The class the road is assigned to is determined by:

- Standard class
- Budget availability
- Local conditions

Roads with e.g. a lower URCI and a higher AADT should have a higher priority. Depending on defects, recommendations are also made as to the management and maintenance measures that need be taken. For each standard class there is a target in the form of a lower limit for the condition of the wearing course according to the scale presented in figure 8.24.

8.3.4 Australia and New Zealand

Australia has more than 500,000 km unpaved roads, gravel roads and earth roads, that represent about 65% (1993) of the total road network of 800,000 km (Foley and Cropley, 1996). Many of the roads lack aggregate. They are only graded earth roads. 42% (1995) of the New Zealand road network is made up of gravel roads (Foley and Cropley, 1996).

"A guide to the visual assessment of pavement condition" (1987) states that damage to unpaved roads, i.e. gravel and earth roads, is to be divided into three primary groups.

1. Deformation D
2. Surface Texture S
3. Potholes HO

The first two groups are subdivided into other secondary defects. Secondary defects are denoted by two letters.

1. Deformation D
 - 1.a Erosion channels DN
 - 1.b Corrugation DC
 - 1.c Rutting DR
 - 1.d Shoving DS (Plastic bulging of surface)
2. Surface Texture S
 - 2.a Coarse texture ST
 - 2.b Loose material SL

A 1.2 m straightedge is used to measure the depth, area and width of the various defects. The length and width of e.g. corrugation ridges and ruts can also be measured with the straightedge. The length of road affected is also judged. All defects are photographed. table 8.14 describes the measurements made in conjunction with condition assessments.

Table 8.14 *Measurements made in conjunction with condition assessments.*

| | Distress | Attributes |
|----------|--------------------------|---|
| 1 | Deformation D | |
| | Channel (scour) DN | Depth of channel (mm) Length of affected road (m) |
| | Corrugations DC | Max. depth (mm) Crest-to-crest spacing (mm) Length of affected road (m) |
| | Rutting DR | Max. depth (mm) Length of affected road (m) |
| | Shoving DS | Depth from high point under a 1.2 m straight edge Area affected (m ²) |
| 2 | Surface Texture S | |
| | Loose material SL | Thickness of loose material (mm) Situation, as surface layer or mound Length of affected road (m) |
| | Coarse texture ST | Projection of aggregate, proud of average pavement surface (mm) Area affected (m ²) |
| 3 | Potholes HO | Depth (mm) Area of potholes (m ²) Number of holes |

It is seen from "Unsealed Roads Manual-Guidelines to Good Practice" (1993) that condition assessments can be based on the following five points:

1. Visible defects, i.e. the above defects deformation, surface texture and potholes.
2. Thickness of gravel wearing course
3. Effectiveness of drainage system
4. Geometrical shape
5. Traffic safety, e.g. lack of road signs.

The report proposes an inspection form to be used for assessment and reporting.

In his handbook, "Unsealed Roads-A Manual of Repair and Maintenance for Pavements", Ferry (1986) describes the system used in New Zealand for assessing gravel and earth roads. The condition of the wearing course is assessed according to the following five-degree scale. Assessment is mainly based on the surface roughness of the road. See table 8.15.

Table 8.15 *The five condition classes (Ferry, 1986).*

| Rating No | Road condition |
|-----------|--|
| 5 | Surface has correct shape and is smooth and firm. Any slight blemish does not affect driving. |
| 4 | Shape is generally maintained and surface is even and firm. There are some occasional single potholes or unevenness. Driving speeds can be maintained despite defects. |
| 3 | Shape is generally maintained and surface is mostly even and firm. There are some defects and dust nuisances in dry weather. Driving speeds and other vehicle operations such as passing are to a slight extent affected by the presence of defects. |
| 2 | Cross-section has changed somewhat. There are significant defects such as corrugations, potholes or ruts. Dust problem exists in dry weather. Driving speeds are below optimum and some drivers are taking action to evade defects. |
| 1 | Cross-section is substantially out of the shape. There are plenty of corrugations, potholes or uneven areas on the carriageway. Dust is a nuisance in dry weather. Driving speeds badly affected. |

8.4 Standard classes for forest roads

Forestry in Sweden has a very great economic role. Many people live on income from forestry and forest products, and forests are extensively utilised. The forest roads constructed in forest districts are important for large scale forest utilisation.

The total value of forest roads in Sweden is SEK 10-15 milliard. The annual management costs for forest roads amount to about SEK 800 million.

Forest roads are used for:

- Haulage of timber.
- Forestry services.
- Transport routes for tourism and recreation.
- Transport of personnel and equipment for defence and fire fighting.

8.4.1 Standard classes for forest roads in Sweden

In Sweden, standard classes for forest roads and ordinary gravel roads are assessed differently. Ordinary gravel roads are assessed according to "Rules for Management and Maintenance", Regulations for Maintenance and Operation (1990) with regard to AADT. Forest roads are classified on the basis of other properties and methods.

In Sweden, the standard of forest roads is assessed by geometric design and bearing capacity.

It is geometric design that determines trafficability, while bearing capacity is of critical significance for availability during the year.

8.4.1.1 Geometric standard classes

In view of geometric shape, a distinction is made between the following classes (Forest roads: service, maintenance and upgrading, 1992, in Swedish):

Road class 1: Single lane permanent road with wearing course of crushed aggregate. Design speed is normally 60 km/h. This class is primarily intended for specially important roads where there are relatively high demands regarding speed, e.g. the longest forest roads or combined roads where traffic other than forest traffic is also of great extent.

Road class 2: Single lane permanent road with wearing course of crushed aggregate. Design speed is normally 40 km/h. This class is primarily intended for major forest roads.

Road class 3: Single lane permanent road with wearing course of crushed aggregate or graded natural aggregate. Design speed is normally 30 km/h. This class is intended for roads with low demand regarding speed.

Road class 4: Single lane permanent road that has no proper wearing course. Design speed is normally 20 km/h. Engineering design is based on assumption that road standard is not maintained by continuous maintenance measures. Road is put in order prior to each period of use. Roads in this class are considered to have a life much shorter than roads in Classes 1-3.

Road class 5: Single lane road which cannot normally carry vehicle combinations longer than 18 m. Width of carriageway is ca 3 m.

Road class 6: Simplest possible road which cannot normally carry vehicles with trailers.

Classes 1-4 all have a carriageway width of 3.5 m and shall otherwise be designed for traffic comprising the same vehicle type. Comprehensive improvements shall not under any circumstances produce a standard lower than Class 4. Newly constructed roads shall always have a standard corresponding to Classes 1-4. Road classes 5 and 6 are only included to assign a standard to existing low class roads.

The most common **geometric defects** of forest roads are:

- Narrow exits
- Insufficient, small and few, turning places
- Narrow carriageways
- Insufficient increase in width in horizontal bends
- Ditches blocked by vegetation
- Poor crossfall

Owing to the low geometric standard, mainly in the southern parts of Sweden, many areas cannot be reached with 24 m vehicles, and timber must be transhipped. Drivers are forced to leave the lorry trailer out on the major road and to enter the narrow roads with only the lorry itself. The trailer normally carries twice as much as the lorry, and three trips are therefore usually necessary before the combination can be coupled up and the journey can continue. This assembly operation normally takes 2-4 hours.

8.4.1.2 Bearing capacity standard

The term bearing capacity refers to the ability of a road to support loads during different parts of the year. Depending on road standard, bearing capacity varies during the year. Some roads must be able to carry traffic during the whole year, others only during the winter (Forest roads: service, maintenance and upgrading, 1992).

The design of forest roads, including those of lowest standard (Road Class 4) is based on a typical vehicle of:

Total length: 24 m

Total width: 2.6 m

Total height: 4.5 m

Overall weight: 60 tonnes

Axle/bogie load: 10/18 tonnes on roads

Axle load on bridges: 14 tonnes

Bogie load on bridges: 18-22 tonnes

From the standpoint of **bearing capacity**, roads are assigned to four classes with respect to the part of the year during which it is normally assumed that heavy traffic can use the road without seriously damaging it. All roads must have sufficient bearing capacity for vehicles with 10 tonnes axle load and 18 tonnes bogie load. The four availability classes are as follows:

Availability Class A: The road shall be able to carry lorry and car traffic during the whole year.

Availability Class B: The road shall be able to carry lorry traffic during the whole year except during the thaw period. It shall be able to carry cars during the whole year.

Availability Class C: The road shall be able to carry lorry traffic during the whole year, except during the thaw period and prolonged rainy periods. The road shall be able to carry cars during the whole year except during the thaw period.

Availability Class D: On the whole, the road shall be able to carry lorry traffic only when the road structure is frozen. The road shall be able to carry cars during the summer also.

8.4.1.3 Combinations of geometric classes and bearing capacity classes

The geometric classes and bearing capacity classes can be combined into standard classes as in table 8.16 (Forest roads: Service, Maintenance and Upgrading, 1992).

Table 8.16 Division into standard classes (Roadplan 80, 1982, in Swedish).

| General standard | Satisfactory gravel carriageway | | Carriageway with no proper wearing course, temporary road | | Some older roads | |
|---|---------------------------------|----|---|----|--------------------------|---------|
| Availability | Normal design speed, km/h | | | | Availability for | |
| | 60 | 40 | 30 | 20 | 18m vehicle combinations | Lorries |
| Lorry and car traffic during whole year | 1A | 2A | 3A | 4A | 5A | |
| Lorry traffic all year except during thaw. Car traffic all year | 1B | 2B | 3B | 4B | 5B | |
| Lorry traffic all year except during thaw and prolonged rain. Car traffic all year except during thaw | 1C | 2C | 3C | 4C | 5C | 6C |
| Lorry traffic mainly in winter. Car traffic in summer also | - | - | - | 4D | - | 6D |

The most common class for forest roads in Sweden is Class 3C. The class to be chosen in different situations is mainly a matter of planning the road network, which is dependent on forestry, transport and highway economic factors.

8.4.2 Standard classes for forest roads in Canada

In Canada, a system called the **ALSAT-L SYSTEM** is applied (Paterson et al, 1975). The letters stand for the following:

AL = design Axle Load (kips), 1 kip = 4.4 kN

S = Speed (km/h)

A = Availability within the year

T = Traffic volume (passenger/day of the design axle)

L = road Life (years)

A road may be classified as e.g. 18K-30-A-250.05, i.e. the road carries 250 vehicles per day with an axle load of 18 kip (80 kN) at a speed of 30 km/h. A denotes availability in all weathers except during the thaw period. The life is 5 years.

9

Planning and evaluation of operation and maintenance measures

Planning of operation and maintenance measures and compliance with competition legislation are discussed in this chapter. Evaluation of the cost effectiveness of operation and maintenance activity and nationaleconomic estimates have also been studied, as well as the relationship between operation and maintenance measures and their traffic economic effects in the form of vehicle costs, traffic safety and trafficability. A study is also made of the willingness to pay of road users.

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9.1 Planning of operation and maintenance activity

In planning maintenance work on gravel roads, attention should be paid to the criteria for condition assessment, the choice of roads to be maintained, prioritising of roads to be subjected to remedial treatment, choice of operation and maintenance measures. A core issue in maintenance planning is the condition class to be achieved.

Planning must relate to the entire road network so that the correct priorities may be decided on. There should be available a maintenance system to provide assistance in maintenance planning.

In their report, Eaton and Beaucham (1992) present a complete system for the classification and condition assessment of gravel roads and the planning of operation and maintenance. The main points of this system are:

1. Identification of the road network
2. Division of the road network into different standard classes
3. Condition assessment and division of the road network into different condition classes
4. Assignment of priorities to different road sections
5. Assessment of the need for operation and maintenance measures
6. Calculation of costs with reference to purely business economics aspects
7. Management of data

This method has been used in practice and, according to Eaton and Beaucham, has been found quite good for planning operation and maintenance measures. Items 2 "Standard classes" and 3 "Condition classes" are described briefly in Chapter 8.

Different forms of maintenance strategies, based on experience, can be seen. Bäckman et al. (1998) give some examples of strategies that can be applied to gravel roads.

- Only acute maintenance
- Worst first
- Utilisation of coordination benefits
- Regular maintenance intervals
- Reduction of use and thus maintenance

Bäckman et al. (1998) add however that it is very unusual for a road management authority to fully concentrate on one of these strategies, even though the first two, only acute maintenance and worst first, are not uncommon due to the lack of economic resources.

9.1.1 Compliance with competition legislation in operation and maintenance

The Swedish National Road Administration (SNRA) is the State agency responsible for road planning, construction, operation and maintenance on the State road network. The authority also has sectorial responsibility for traffic safety and environment. For operation and maintenance there is a 3 year planning budget which has remained nominally unchanged for several years.

It is worth noting that in 1990 the Swedish parliament passed a resolution that all State activity shall be thrown open to competition. In 1997, State roads were divided into ca 145 geographical areas, and 107 of these, covering 70,000 km, are subject to competitive tendering. At present (1999), ca 99% of the geographical areas are subject to competition.

The party who commissions operation and maintenance work is called the principal or the road management authority. The party who carries out operation and maintenance work is called producer or contractor. Those carrying out operation and maintenance of gravel roads are Production SNRA profit centre, Skanska, NCC, PEAB and other local companies; see table 9.1.

Table 9.1 *Market percentages in terms of km of road and number of geographical areas opened to competition in 1997 (Wikström in the course "Operation and maintenance of Traffic Facilities-KTH, 1997, in Swedish).*

| Producer | Percentage of roads (km) open to competition | Number of geographical areas open to competition |
|-----------------|--|--|
| SNRA Production | 68 | 70.5 |
| Skanska | 13 | 13.5 |
| NCC | 10 | 12 |
| PEAB | 6 | 8 |
| Others, LBC etc | 3 | 3 |
| Totals | 100 | 107 |

The **procurement model** for operation and maintenance services is based on orders being expressed in terms of products and services. Quality shall be expressed in terms of standard and service levels. Specifications of functional or standard requirements shall be applied as far as possible. The forms of contract applied by the National Swedish Road Administration are:

- Divided contract
- General contract
- Design and construct contract
- Design, construct and maintain contract

The **Basic Management Package** is formulated in such a way that the road management authority shall, throughout the year, feel confident that it discharges its responsibility for road management by making the producer responsible for carrying out acute and routine measures without any action on the part of the authority (Wikström in the course "Operation and maintenance of Traffic

Facilities-KTH, 1997). The basic management package also comprises, inter alia, winter road management, traffic signs, rest areas and pavement repairs.

According to Danielson (1997) in the course "Operation and maintenance of Traffic Facilities-KTH", **important criteria for competition** are as follows:

- A. In procurement, free and genuine competition shall apply in the short and long term.
- B. Procurement shall be correct, unambiguous and calculable.
- C. Results shall be measurable.
- D. Standard shall be consistent for all road classes irrespective of how and when procurement was undertaken.

A. Free and genuine competition

Forms of procurement shall be such as to ensure that the previous public monopoly is not replaced by a private monopoly because a producer becomes established in a geographical area and makes it of no interest for other producers to compete. There must also be an interest for the road management area during both low and high periods in the business cycle. Since parts of operation and maintenance activity had not previously been open to competition, various measures may initially have to be taken to allow producers to build up new competence.

B. Correct procurement

There must be methods to describe the worst standard that will be accepted and the standard to aim for. Knowledge of the normal frequency of measures is also required in order that the tender shall be calculable.

C. Measurable results

Methods of measuring the results of a measure have been developed over a long time for certain types of activity, e.g. surfacings. There is a great need of objective result measurement for other measures. One example may be gravel road maintenance where conditions often change rapidly. It is important that it should be possible to measure the worst condition that is accepted before remedial action must be taken.

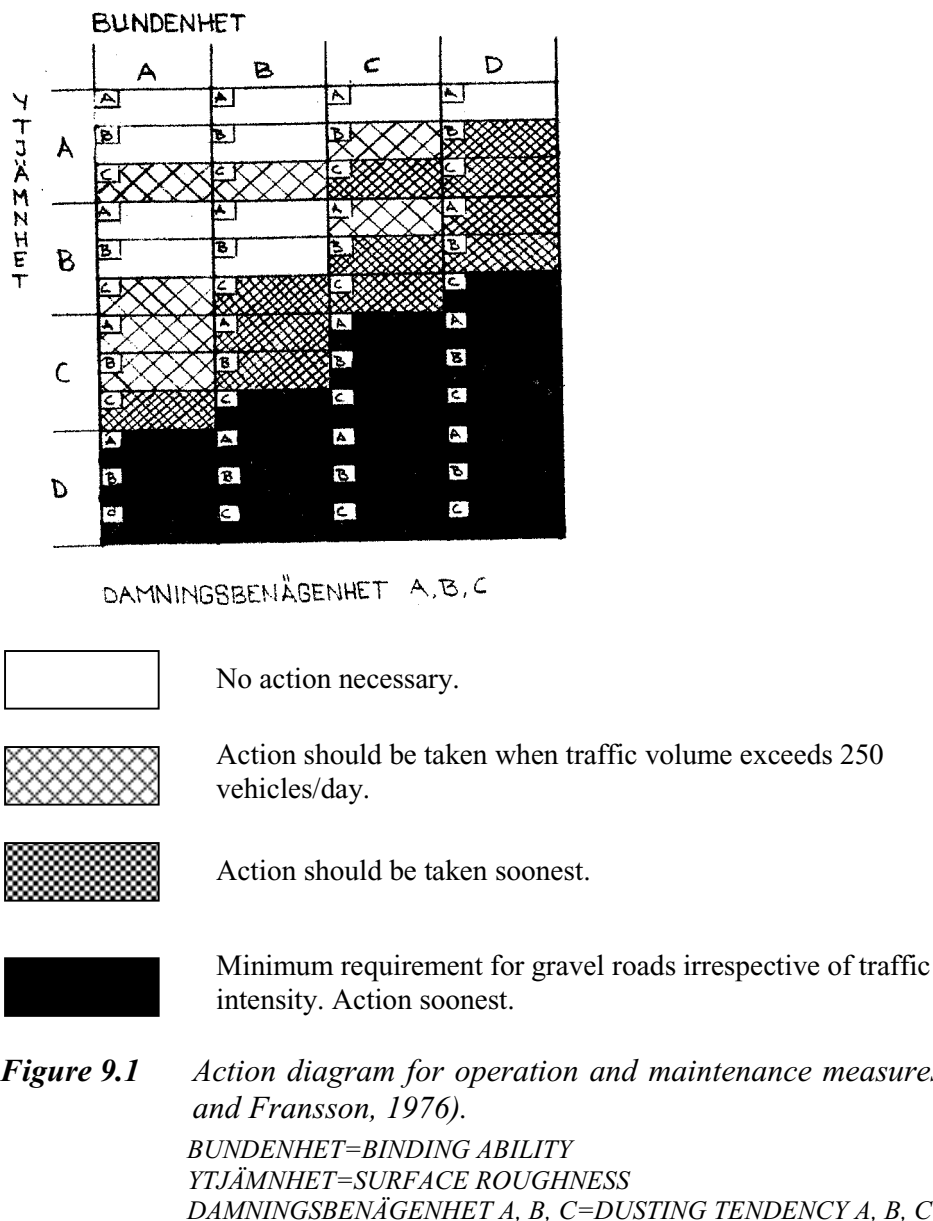
D. Consistent standard

Since grant allocations may vary from year to year, procurement must incorporate such flexibility that the standard required can be adjusted easily depending on the availability of funds.

9.1.2 Choice of operation and maintenance measures

Operation and maintenance measures are chosen so as to achieve the optimum results for customers, the road management authority and other interested parties.

In their degree project, Andren and Fransson (1976) developed a method for classifying gravel roads with respect to the factors surface roughness, binding ability and dusting tendency. The method and the criteria employed are described in Subclause 8.1.1.2. With respect to these criteria, an action diagram was constructed showing whether or not a certain measure is necessary. See figure 9.1.



Andren and Fransson also drew up a relationship between running speed and the number of vehicles that have passed since remedial action was taken on the gravel road. The relationship shows that the maintenance cycle of a road, i.e. the period between two consecutive measures such as grading, may be said to comprise three stages, an initial stage when the road has binding ability, a stationary stage when the condition of the road is reasonably unchanged, and a decline stage during which deterioration is manifested by a drop in mean speed. On the roads studied in the degree project, it was found that the mean speed was 55-65 km/h at points where the condition became unacceptable after ca 6000-10,000 vehicle passages.

In their report, Beckemeyer and McPeak (1995) present a figure for the choice of operation and maintenance measures; see figure 9.2. The figure is based on the URCI scale; see Subclause 8.3.3.

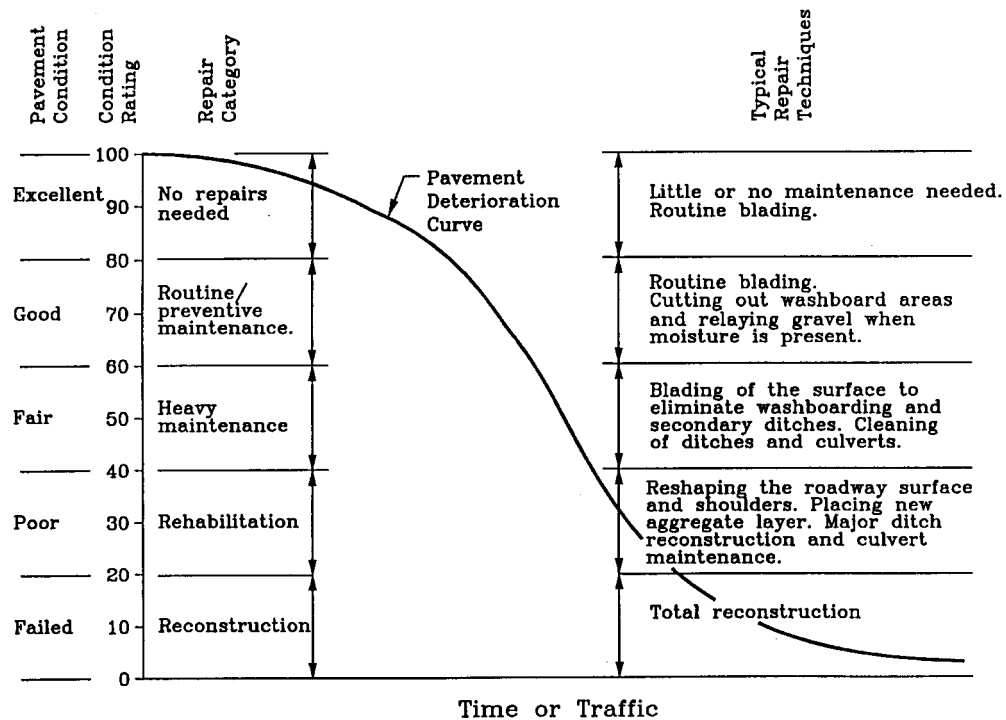


Figure 9.2 Relationship between gravel road condition and maintenance measures.

9.2 Economic evaluations in operation and maintenance

The term economic planning is defined as economic management of limited resources, i.e. utilisation of resources in such a way that the greatest possible yield is obtained. This applies regardless of whether the economic calculation is made in view of the interests of a company or society. What makes these calculations different is the purpose for which they are made. If they are made for a company, the goal is generally to ensure that profits are as high as possible, i.e. the endeavour is to maximise the difference between costs and revenues. In principle, the same also applies in nationaleconomic calculations where consideration must be given to the costs and revenues of society and an endeavour made to minimise the costs and maximise the revenues of society.

However, the business economic calculation considers only the direct effects, not the external effects such as negative impacts on the environment which are not a business economic cost. In a nationaleconomic calculation all the effects of a road are considered, regardless of whether or not they are expressed in monetary terms.

9.2.1 Effects of operation and maintenance measures

In order that the cost effectiveness of operation and maintenance may be assessed, knowledge of the operation and maintenance measures and their effects is needed. Changes in the condition of gravel roads are assumed to vary periodically, as shown in the schematic diagram in figure 9.3 (Effect Calculation Models, 1986, in Swedish).

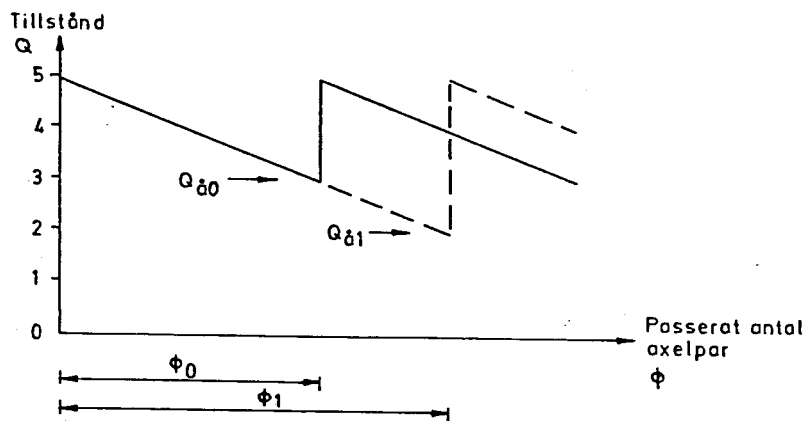


Figure 9.3 Assumed change in the condition of gravel roads.

Vertical axis-Condition

Horizontal axis-No of two-axle units passing

The relationships between effects in the following are based on a scale for condition classification used in the joint Nordic project "Improvement and maintenance of gravel roads FUG". The relationship between this scale and the DDp scale was described in Subclause 8.1.1.4.

Both surface roughness and binding ability influence vehicle costs. Surface roughness affects tyre wear, maintenance, repairs and depreciation. In contrast, fuel consumption is affected only by binding ability.

Road user costs consist mainly of three elements:

- A. Traffic safety
- B. Trafficability (speed and riding comfort)
- C. Vehicle costs (fuel consumption, tyre wear, maintenance and repair, depreciation)

A. Traffic safety

As a rule, roads with a gravel wearing course have low geometric standard. Speeds on these roads are lower than on paved roads.

In the Effect Catalogue-Operation and maintenance measures (1989), in Swedish, it was claimed that it is reasonable to assume that a change from a gravel road to a paved road entails a positive traffic safety effect. Whether such a trend also applies when the surface condition of gravel roads is improved by grading is very difficult to ascertain. However, it would seem to be a reasonable assumption that greater surface roughness and better binding ability may have a positive effect owing to more comfortable driving and lower incidence of loose aggregate. At the same time, the increase in speed has a negative effect on traffic safety. On the whole, therefore, it is somewhat uncertain whether any traffic safety effect can be attributed to a change in the surface condition of gravel roads.

B. Trafficability

In conjunction with trafficability, both speed and driving comfort are evaluated.

B.1 Speed

Running speed on a newly graded road is low because the road has not yet developed binding ability. As binding ability increases, speed rises. Surface roughness then deteriorates owing to traffic, precipitation etc, and binding ability is reduced. However, the drop in speed caused by this is generally moderate.

From the Effect Catalogue-Operation and maintenance measures (1989) it is seen that, on the basis of a number of investigations, deterioration by one surface roughness class in the FUG scale appears to entail a drop in speed by about 1.5 km/h.

In "Effect Calculation models" (1986) it is stated that the change in trip time consumption due to a change in the standard of gravel road management can be calculated from the following equation:

$$\Delta T = BMT * 30 * BMDT * \frac{1}{2} * (1/v_{\dot{a}1} - 1/v_{\dot{a}0}) * L$$

ΔT = difference in trip time consumption between the standards studied (veh.h/year)

BMT = period when road is free from snow and ice (months)

BMDT= mean daily traffic during period when road is free from snow and ice (two-axle units/day), can be put at 1.1*AADT

$v_{\dot{a}1}, v_{\dot{a}0}$ = running speed at the condition prevailing ($Q_{\dot{a}0}, Q_{\dot{a}0}$) when action is taken

L = road length (km)

The speeds $v_{\dot{a}1}, v_{\dot{a}0}$, at the conditions prevailing when action, is taken can be read in figure 9.4.

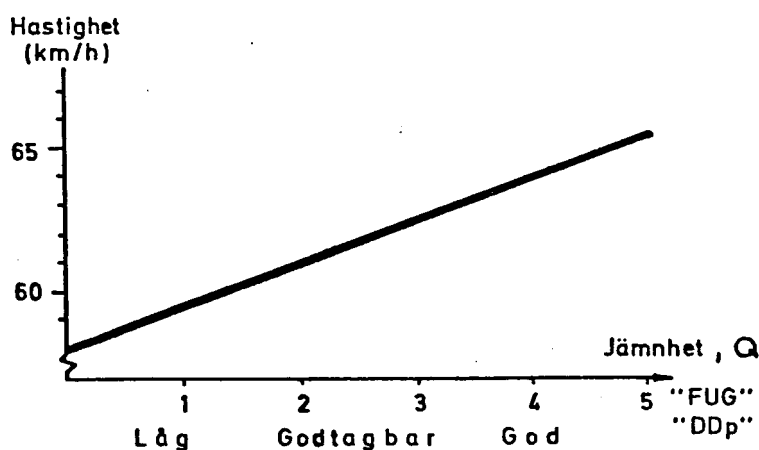


Figure 9.4 Relationship between mean speed and surface roughness.

Vertical axis- Speed

Horizontal axis- Surface roughness, Low, Acceptable, Good

No properly designed tests with the aim of ascertaining the relationship between speed and the surface condition of gravel roads have been made in Sweden.

B.2 Riding comfort

In Sweden, Fäldner (1988) has made an investigation to estimate road users' willingness to pay for the increase in comfort resulting from driving on a paved road instead of a gravel road. This investigation comprises about a thousand interviews.

Fäldner's investigation suggests that:

- Vehicle costs and driving comfort are the most important factors for the choice of road for short trips in the countryside. These are followed by travel time and traffic volume
- The comfort factor of the greatest importance is the condition of the road
- The values placed on different comfort factors vary greatly between individuals
- For some individuals, beautiful nature, danger due to elk and desolation have a great influence on the choice of road. However, it is only a small proportion of individuals who are affected to a considerable degree by these factors.

It is stated in the Effect Catalogue-Operation and maintenance measures (1989) that in the Swedish investigation it was also found that the value placed on the difference in riding comfort between a good and a bad gravel road was of the order of SEK 10/vehicle hour.

In Finland, a study was made to find the propensity of motorist to choose a good but longer paved road instead of an uneven but shorter gravel road, a paved uneven road or a road under reconstruction, in order find the cost of lack of comfort. A riding comfort value was obtained (Effect Catalogue-Operation and maintenance measures, 1989).

The value obtained in the Swedish investigation is in quite good agreement with that in the Finnish investigation. Figure 9.5 sets out the relationship between riding comfort and surface roughness.

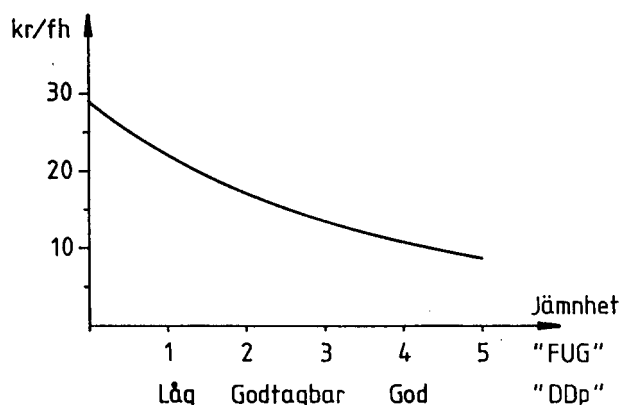


Figure 9.5 Relationship between riding comfort and surface roughness (Effect Catalogue "Operation and maintenance measures", 1989).

Vertical axis- SEK/veh.h

Horizontal axis- Surface roughness, Low, Acceptable, Good

C. Vehicle costs

There are four components:

- Fuel consumption
- Tyre wear
- Maintenance and repairs
- Depreciation

"Vehicle operation costs on unsealed roads" (1994), abbreviated VOC, describes a small literature study to find how these four components are influenced by surface roughness.

VOC (1994) quotes Curtayne et al. (1987), according to which the relationship between these four components and surface roughness on gravel roads, for buses, is as set out in table 9.2 and figure 9.6. It is however not clear how "increase in roughness" was determined.

Table 9.2 Relationship between the four components and surface roughness of gravel roads for buses.

| VOCs components | Average contribution to total cost (%) | Increase in VOC related to increase in roughness (%) |
|-------------------------|--|--|
| Fuel consumption | 25 | 5 |
| Tyre wear | 10 | 120 |
| Maintenance and repairs | 40 | 40 |
| Depreciation | 25 | 30 |

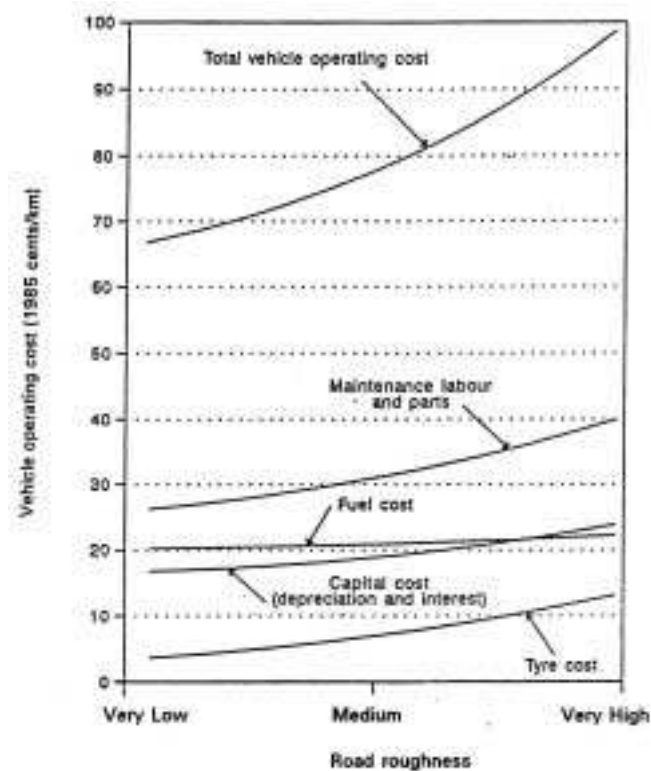


Figure 9.6 Relationship between the four components and surface roughness of gravel roads for buses (VOC, 1994).

The conclusions of VOC are that the differences in vehicle costs between unpaved and paved roads are not more than 5%.

In the Effect Catalogue-Operation and maintenance measures (1989) it is stated that the percentage breakdown of costs for a car travelling at a speed of 70-90 km/h on paved roads is as set out in table 9.3.

Table 9.3 *Percentage breakdown of vehicle costs over the four components.*

| Cost item | Percentage |
|---|------------|
| Fuel cost | about 40 |
| Tyres | about 10 |
| Maintenance, repairs | about 35 |
| Depreciation, driven distance dependent | about 5 |
| Depreciation, time dependent | about 10 |

A brief description of fuel consumption, tyre wear, maintenance and repairs and depreciation is given below.

C.1 Fuel consumption

It appears from VOC (1994) that fuel consumption accounts for 25% of vehicle costs. VOC summarises the results of a number of studies and states that the differences in fuel consumption between unpaved and paved roads are 0-8%.

Measurements of how surface roughness and binding ability influence fuel consumption have been made on a number of gravel roads in central Sweden between 1980 and 1981 by Carlsson (1980). These investigations were part of the joint Nordic project "FUG".

The measurements show that the clearly documented increase in evenness resulting from grading a gravel road does not appear to influence fuel consumption. On the other hand, increase in binding ability appears to reduce fuel consumption.

Sävenhed (1986) and (1987) has studied how fuel consumption is affected and changed when a gravel road remains ungraded over an entire summer. Reference sections were a number of gravel roads which were graded to the normal extent.

The results show that the increase in evenness due to grading appears to influence fuel consumption by only 1-3%. Loss of binding ability in the road surface causes a 3-5% increase in fuel consumption. A clearly higher fuel consumption was measured when the road surface was wet.

It is entirely logical that greater loss of binding ability should increase fuel consumption, since lower incidence of loose material on the surface would reduce rolling resistance.

Sävenhed (1986) points out that fuel consumption immediately after grading is higher than a week after grading. According to Sävenhed, the reason is that the road is compacted by traffic which makes the surface hard and even.

Carlsson (1980) also made a subjective assessment of the surface roughness, binding ability and dusting tendency of gravel roads.

In the Effect Catalogue-Operation and maintenance measures (1989) the significance of binding ability for fuel consumption, according to Carlsson's (1980) investigation, is summarised in table 9.4. Measurements were made on five different occasions.

Table 9.4 Significance of binding ability for fuel consumption.

| Assessed binding ability as per FUG scale | DDp scale | Fuel consumption (%) | | |
|--|------------|----------------------|---------|---------|
| | | 50 km/h | 60 km/h | 70 km/h |
| 3—4, dry | Good | 100 | 100 | 100 |
| 2—3, dry | Acceptable | 101 | 104 | 103 |
| 1—2, newly graded | Low | 115 | 115 | 116 |
| 1—2, wet | Low | 116 | 118 | 120 |
| 0—1, very wet | Low | 125 | 129 | 128 |

In Norway, TÖI (Institute of Transport Economics) has measured fuel consumption on dry and wet gravel carriageways. It was found that fuel consumption on wet gravel carriageways was about 5% higher than in dry conditions. If this figure is applied to the Swedish measurement results for the last two surface roughness classes, increases in fuel consumption for different binding ability standards and a dry carriageway can be estimated as in table 9.5 (Effect Catalogue-Operation and maintenance measures, 1989).

Table 9.5 Significance of binding ability for fuel consumption on dry carriageways.

| Binding ability | | Fuel consumption (%) |
|-----------------|------------|----------------------|
| FUG scale | DDp scale | |
| 3—4 | Good | 100 |
| 2—3 | Acceptable | 103 |
| 1—2 | Low | 110 |
| 0—1 | Low | 120 |

C.2 Tyre wear

Tyre wear accounts for 10% of vehicle costs (VOC, 1994). Many investigations have been made which show that tyre wear on gravel roads is considerably higher than on paved roads. According to the Effect Catalogue-Operation and maintenance measures (1989), on the basis of a literature study TÖI (1981) has concluded that tyres wear down twice as rapidly on gravel roads than on paved roads. Tyre manufacturers, e.g. Goodyear, have produced an index that shows tyre life on different wearing courses. See table 9.6.

Table 9.6 Tyre life on different types of road (*Effect Catalogue-Operation and maintenance measures, 1989*).

| Condition of wearing course | Relative life, % |
|-----------------------------|------------------|
| Motorway | 100 |
| Good paved road | 80 |
| Very good gravel road | 70 |
| Good gravel road | 66 |
| Poor gravel road | 57 |
| Very poor gravel road | 50 |

"Effect Catalogue" (1989) tabulates a relationship between tyre wear and surface roughness; see table 9.7.

Table 9.7 Relationship between tyre wear and surface roughness.

| Surface roughness | | Tyre wear, % |
|-------------------|-----------------|--------------|
| | | |
| FUG scale | DDp scale | |
| - | Even paved road | 88 |
| 4—5 | Good | 100 |
| 3—4 | Good | 106 |
| 2—3 | Acceptable | 115 |
| 1—2 | Low | 123 |
| 0—1 | Low | 140 |

C.3 Maintenance and repairs

VOCs (1994) states that maintenance and repairs account for 40% of vehicle costs. The costs of repair, maintenance and depreciation have in many investigations been presented together since they all affect one another. In Effect Catalogue (1989) it is claimed that the average gravel road gives rise to ca 50% higher maintenance and repair costs than a paved road. With this assumption as the basis, the effect of the surface standard can be estimated as in table 9.8. It is however not clear how this estimate was arrived at.

Table 9.8 Effect of surface roughness standard on maintenance and repair costs (*Effect Catalogue, 1989*).

| Surface roughness | | Maintenance and repair costs (%) |
|-------------------|------------|----------------------------------|
| | | |
| FUG scale | DDp scale | |
| 4—5 | Good | 100 |
| 3—4 | Good | 122 |
| 2—3 | Acceptable | 144 |
| 1—0 | Low | 165 |
| 0—1 | Low | 187 |

C.4 Depreciation

According to VOCs (1994), depreciation accounts for 25% of vehicle costs. "Effect Catalogue" (1989) states that depreciation on the average gravel road is ca 25% higher than on a corresponding paved road. It is claimed that, with this

assumption as the basis, the effect of surface roughness standard on depreciation can be estimated as in table 9.9.

Table 9.9 *Effect of surface standard on depreciation (Effect Catalogue, 1989).*

| Surface roughness | | Depreciation, % |
|-------------------|-----------------|-----------------|
| FUG scale | DDp scale | |
| - | Even paved road | 85 |
| 4-5 | Good | 100 |
| 3-4 | Good | 103 |
| 2-3 | Acceptable | 107 |
| 1-2 | Low | 110 |
| 0-1 | Low | 113 |

Overall evaluation of the effect of operation and maintenance measures on vehicle costs

On the basis of the data regarding the various components, it is possible to calculate an overall index for vehicle costs on gravel roads of different standards.

"Effect Catalogue" (1989) states that vehicle costs on a normal gravel road are SEK 0.85/vehicle km. Such a gravel road is characterised by surface roughness of 3-4 and binding ability of 2-3 according to the FUG scale. This gives the vehicle costs for a perfect gravel road as SEK 0.77/veh.km. Vehicle costs for variable surface roughness and binding ability standards are calculated using the correction factors set out in table 9.10.

Table 9.10 *Correction factors for vehicle costs for variable standards of surface roughness and binding ability.*

| Binding ability | | Surface roughness | | | | | |
|-----------------|------------|-------------------|------|------------|------|------|------|
| | | FUG scale | 4—5 | 3—4 | 2—3 | 1—2 | 0—1 |
| | | DDp scale | Good | Acceptable | Low | | |
| FUG scale | DDp scale | | | | | | |
| 3-4 | Good | | 1.00 | 1.09 | 1.17 | 1.26 | 1.35 |
| 2-3 | Acceptable | | 1.01 | 1.10 | 1.19 | 1.27 | 1.36 |
| 1-2 | Low | | 1.04 | 1.12 | 1.21 | 1.30 | 1.39 |
| 0-1 | Low | | 1.08 | 1.16 | 1.25 | 1.34 | 1.43 |

According to "Effect Calculation models" (1986), a change in vehicle costs (SEK/year) due to a change in surface conditions can be calculated from the following equation:

$$\Delta F = BMT * 30 * BMDT * f_0 * \frac{1}{2} * (1/k_{a1} - 1/k_{a0}) * L; \text{ where}$$

ΔF = change in vehicle costs (SEK/year)

BM = period when roads are free from snow and ice (months)

BMDT = mean daily traffic (No of two-axle units/day) during snow and ice free period, may be put at 1.1 * AADT

f_0 = vehicle costs in perfect conditions, may be put at SEK 0.75/veh.km. In the Effect Catalogue, this value is SEK 0.77/veh.km

k_{a0}, k_{a1} = vehicle cost index in the condition prevailing when action is taken

L = length of road (km)

The vehicle cost index k_{a0} , k_{a1} as a function of road condition Q is plotted in figure 9.7. B denotes binding ability.

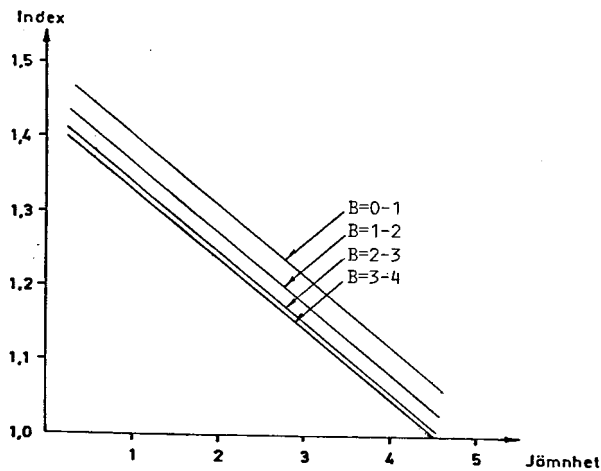


Figure 9.7 Vehicle cost index for different standards of binding ability and surface roughness (*Effect Calculation models, 1986*).

Vertical axis-Index

Horizontal axis-Surface roughness

9.2.2 Nationaleconomic evaluation

An essential requirement for a nationaleconomic calculation is that the decision-maker should be in possession of information regarding the willingness of those affected to pay for a certain measure.

According to economic welfare theory, it is theoretically possible to arrive at a payment or compensation in monetary terms that precisely offsets the benefits or disbenefits of the effects of a measure. An endeavour is made to consider all effects, which are expected to arise in conjunction with operation and maintenance activity, in monetary terms where this is possible. If the sum of the positive effects, "benefits", is higher than that of the negative effects, "costs", this can be interpreted as a gain for society.

At least two types of cost are generally studied in conjunction with a nationaleconomic analysis of the cost effectiveness of maintenance measures, namely maintenance costs and road user costs.

Maintenance costs increase if a higher standard is chosen. Road user costs decrease at the same time.

Road user costs in the form of vehicle costs, traffic safety and trafficability can be evaluated in monetary terms. The other effects, mainly environmental impacts, must often be assessed subjectively.

No proper comprehensive nationaleconomic calculations have been made with reference to gravel road maintenance. On the other hand, it is very usual for different maintenance measures to be compared and assessed with respect to business economic aspects.

In deciding on maintenance measures, an attempt should be made to try to find an optimum solution that takes many different factors into consideration. In looking for this optimum solution, the long term costs of maintaining a certain quality level should be compared with the benefits that can be gained with this quality level. Dobson and Postill (1983) note that, from a nationaleconomic standpoint, gravel roads with AADT>400 should be provided with some sort of paving.

Olsson et al (1987) monitored the standard of some selected gravel roads in Malmöhus and Älvsborg counties. In conjunction with this project, a nationaleconomic assessment was made and the condition of the different gravel roads was evaluated using the DDp scale.

Olsson et al. calculated the annual road user costs, maintenance costs and total costs during the period when roads were free from snow and ice. Calculations were made only with respect to surface roughness, and on the assumption that the surface condition of a gravel road changes linearly between grading events. Other assumptions made for the calculation were as follows:

| | |
|--------------------------------------|--|
| Traffic | 100 vehicles/day |
| Proportion of lorry traffic | 10% |
| Snow and ice free period | 9 months/year |
| Maintenance costs during this period | SEK 3000/km annually for at least Surface Standard 2 |

Maintenance costs during the period when roads were free from snow and ice were calculated for different minimum standards with reference to the cost of maintenance for a road of a given condition. The calculated costs were corrected with respect to value added tax (VAT) in order to be nationaleconomically correct.

It is however not clear how costs are obtained for a minimum standard other than minimum standard 2, since one of the assumptions was that maintenance costs during the snow and ice free period were SEK 3000/km annually at minimum surface standard 2. The results of calculations by Olsson et al. are plotted in figure 9.8, 9.9 and 9.10.

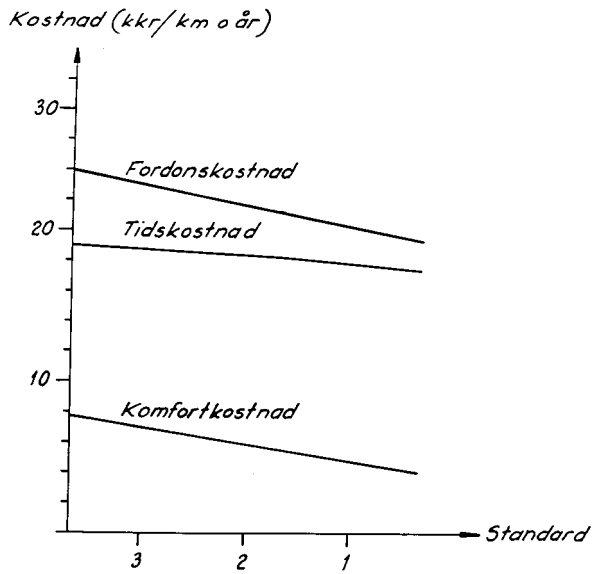


Figure 9.8 Road user costs (Olsson et al., 1987).

Vertical axis-Cost (SEK1000/km/year)

Horizontal axis-Standard

Fordonskostnad=Vehicle cost

Tidskostnad=Time cost

Komfortkostnad=Comfort cost

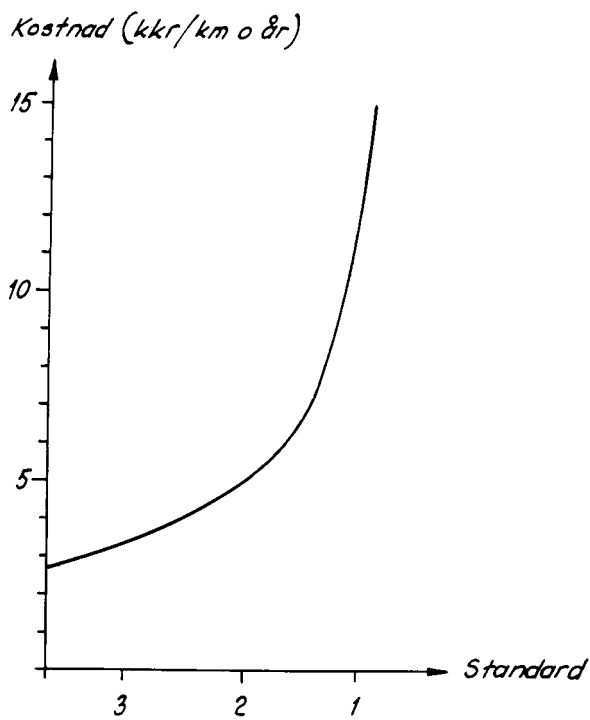


Figure 9.9 Maintenance costs (Olsson et al., 1987).

Vertical axis-Cost (SEK1000/km/year)

Horizontal axis-Standard

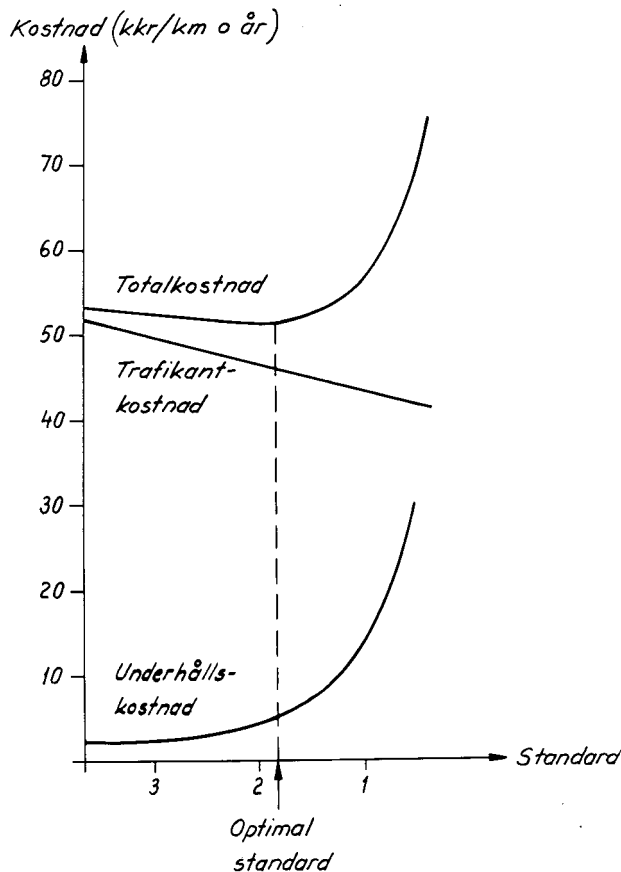


Figure 9.10 Total costs (Olsson et al., 1987).
 Vertical axis-Cost (SEK1000/km/year)
 Horizontal axis-Standard
 Totalkostnad=Total cost
 Trafikantkostnad=Road user cost
 Underhållskostnad=Maintenance cost
 Optimal standard=Optimum Standard

The results of Olsson et al. suggest that total costs will be least at a minimum standard just below 2; see figure 9.10. It is also evident from the figure that nationaleconomic costs rise very steeply if a standard higher than the optimum is selected, while nationaleconomic costs rise more moderately if a standard lower than the optimum is decided on.

9.2.3 Willingness to pay of road users

Ruckertz and Forsström (1991) have probably made the only study of the value road users place on different surface standards on different types of road. These road user values were estimated with reference to road users' willingness to pay. Willingness to pay is expressed in terms of how much road users are prepared to pay for a better road surface standard.

The study is based on a relatively new statistical method—stated preference. Stated preference is ascertained by presenting individuals with a number of alternative choices. Using this method, monetary values can be estimated for both existing and hypothetical measures. The road alternatives investigated were a wide (13 m) paved road, a narrow (6-9 m) paved road, and a gravel road. Since the primary

objective of a willingness to pay study is to estimate the values road users place on different road surface standards, a factor that gives a reasonable description of the surface condition of the three road types is required. The factor chosen in the study is surface roughness. The surface roughness of the gravel road is broken down into four levels:

Level 1: A simple surfacing of Y1G type has been applied to the gravel road, which means better tyre grip, no dusting and more relaxed driving than on a gravel surface. There may be one or two roughness places, especially during the thaw period. A speed of 70-90 km/h can be maintained on straight sections.

Level 2: The gravel road is even and firm. There may be one or two potholes. A speed of 70 km/h can be maintained on straight sections.

Level 3: The gravel road is even in places. There may be potholes over short sections. In most cases a speed of 70 km/h can be maintained on straight sections. It may be necessary to lower speed somewhat when there are many depressions.

Level 4: Longer sections of deep potholes are usual. Where there are the most roughness, the driver has the feeling of driving over a washboard. A speed of 50-60 km/h can be maintained on some sections. Speed must however be steeply reduced in some places.

Levels 2, 3 and 4 may be likened to the SNRA condition classes good, acceptable and low with reference to surface roughness, but without speed restrictions.

In order that the values placed by road users on the different road conditions may be estimated, a cost factor is also required in addition to the surface standard factor. The cost item chosen in this study was petrol price per litre. Variations in petrol price occur by changes in taxation, which are assumed to have a direct coupling to road maintenance.

In order to find whether the place of residence of the persons interviewed has an effect on the values, the sample was divided into four strata; Norrland, Central Sweden, Southern Sweden and Metropolitan Regions (Stockholm, Göteborg and Malmö). The results of the study regarding gravel roads are set out in table 9.11. The terms Norrland, Central Sweden and Southern Sweden were not defined in the study.

Table 9.11 Willingness to pay (SEK/l) in four strata in Sweden (Ruckertz and Forsström, 1991).

| Places | Improvement from standard 2 to 1 | Improvement from standard 3 to 1 | Improvement from Standard 4 to 1 |
|----------------------|----------------------------------|----------------------------------|----------------------------------|
| Norrland | 0.16 | 1.13 | 3.9 |
| Central Sweden | 0.10 | 1.21 | 4.12 |
| Southern Sweden | 0.06 | 0.74 | 3.32 |
| Metropolitan Regions | 0.02 | 0.79 | 3.44 |
| Whole country | 0.07 | 0.96 | 3.69 |

The above results show that road users place quite a high value on an improvement of the road network. Willingness to pay is highest for an improvement from Level 4 (washboard) to Level 1 (Y1G). The average value placed on this improvement is ca SEK 3.7/l. One remarkable result is that road users appear to be uninfluenced by the difference between a newly graded gravel road and one with Y1G.

Ruckertz and Forsström (1991) point out, however, that this result is not statistically verified.

In order to find what the customers of the National Swedish Road Administration think of the roads and of the way the Administration carries out its duties, the Administration has on several occasions commissioned market survey institutes to carry out road user investigations. Other interested parties apart from SNRA have also considered it of interest to make such investigations.

Reference is made below to four investigations of attitudes regarding gravel roads. These are: All these investigations are in Swedish.

- A. Public attitudes to roads in Sweden (SNRA, October 1981)
- B. Customer attitudes to the road management authority in Gävleborg County (Informations Psykolog AB, January 1989)
- C. Road maintenance in Western Norrland (FL Marknadsfakta AB, 1989)
- D. Views on SNRA-An attitude survey among road users in Västerbotten (Stig Johan Wiklund and students, 1990)

A. Public attitudes to roads in Sweden (SNRA, October 1981)

The National Swedish Road Administration and Statistics Sweden carried out a comprehensive survey among the public to obtain a decision base for prioritising measures in the road system. Those interviewed awarded marks to the condition of gravel roads. The results are set out in table 9.12.

Table 9.12 *Marks awarded by interviewees to the condition of gravel roads.*

| Percentage % | Mark awarded |
|--------------|--------------|
| 3 | Very good |
| 12 | Good |
| 37 | Fairly good |
| 32 | Fairly poor |
| 10 | Poor |
| 6 | Very poor |

B. Customer attitudes to the road management authority in Gävleborg County (InformationsPsykolog AB, January 1989)

The survey related to e.g. views on road management in Gävleborg County. 83% consider that gravel roads shall be even and have no potholes. 36% want to have fewer potholes in the carriageway of a paved road.

C. Road maintenance Western Norrland (FL Marknadsfakta AB, 1989)

If those interviewed had the chance to reallocate, reduce or increase, the resources for road maintenance in Västernorrland County, 22% would increase resources for poor gravel roads. 20% would increase resources for regravelling and grading on gravel roads.

D. Views on SNRA – an attitude survey among road users in Västerbotten (Stig Johan Wiklund and students, 1990)

If those interviewed had the chance to reallocate the resources of SNRA for road maintenance in Västerbotten, 45-55% would increase resources for gravel road management, while 1017% would reduce resources.

10

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Appendix No 1

Lengths of different wearing course types on the State road network in the different counties over the period 1990-1997 and the percentages of the total State road lengths in the counties accounted for by these wearing course types.

Stockholm (AB)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|------|-----|------|---------------|------|------------|------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 3261 | 272 | 8.34 | 118 | 3.62 | : | 0.00 | 1 | 0.03 | 2868 | 87.95 |
| 1991 | 3047 | 241 | 7.91 | 134 | 4.40 | : | 0.00 | 1 | 0.03 | 2669 | 87.59 |
| 1992 | 3049 | 226 | 7.41 | 145 | 4.76 | : | 0.00 | 1 | 0.03 | 2675 | 87.73 |
| 1993 | 3068 | 197 | 6.42 | 174 | 5.67 | : | 0.00 | 1 | 0.03 | 2694 | 87.81 |
| 1994 | 3077 | 161 | 5.23 | 159 | 5.17 | : | 0.00 | 1 | 0.03 | 2754 | 89.50 |
| 1995 | 3113 | 128 | 4.11 | 76 | 2.44 | : | 0.00 | 1 | 0.03 | 2906 | 93.35 |
| 1996 | 3138 | 85 | 2.71 | 59 | 1.88 | : | 0.00 | 1 | 0.03 | 2991 | 95.32 |
| 1997 | 3138 | 85 | 2.71 | 26 | 0.83 | : | 0.00 | 1 | 0.03 | 3024 | 96.37 |

Uppsala (C)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|------|---------------|------|------------|------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 2933 | 602 | 18.46 | 243 | 7.45 | : | 0.00 | 31 | 0.95 | 2057 | 70.13 |
| 1991 | 2955 | 602 | 19.76 | 243 | 7.98 | : | 0.00 | 31 | 1.02 | 2079 | 70.36 |
| 1992 | 2976 | 587 | 19.25 | 258 | 8.46 | : | 0.00 | 31 | 1.02 | 2100 | 70.56 |
| 1993 | 2985 | 534 | 17.41 | 300 | 9.78 | : | 0.00 | 31 | 1.01 | 2120 | 71.02 |
| 1994 | 2977 | 530 | 17.22 | 296 | 9.62 | : | 0.00 | 40 | 1.30 | 2131 | 71.58 |
| 1995 | 3015 | 530 | 17.03 | 296 | 9.51 | : | 0.00 | 40 | 1.28 | 2149 | 71.28 |
| 1996 | 3013 | 530 | 16.89 | 296 | 9.43 | : | 0.00 | 40 | 1.27 | 2147 | 71.26 |
| 1997 | 3013 | 524 | 16.70 | 302 | 9.62 | : | 0.00 | 40 | 1.27 | 2147 | 71.26 |

Södermanland (D)

| Year | Tot. length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|-------------|--------|-------|-----|------|---------------|------|------------|------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 2708 | 543 | 20.05 | 205 | 7.57 | : | 0.00 | 3 | 0.11 | 1957 | 72.27 |
| 1991 | 2733 | 542 | 19.83 | 182 | 6.66 | : | 0.00 | 3 | 0.11 | 2006 | 73.40 |
| 1992 | 2733 | 531 | 19.43 | 187 | 6.84 | : | 0.00 | 3 | 0.11 | 2012 | 73.62 |
| 1993 | 2731 | 516 | 18.89 | 203 | 7.43 | : | 0.00 | 3 | 0.11 | 2009 | 73.56 |
| 1994 | 2777 | 512 | 18.44 | 206 | 7.42 | : | 0.00 | 3 | 0.11 | 2056 | 74.04 |
| 1995 | 2791 | 512 | 18.34 | 206 | 7.38 | : | 0.00 | 3 | 0.11 | 2070 | 74.17 |
| 1996 | 2832 | 512 | 18.08 | 205 | 7.24 | : | 0.00 | 3 | 0.11 | 2112 | 74.58 |
| 1997 | 2832 | 512 | 18.08 | 205 | 7.24 | : | 0.00 | 3 | 0.11 | 2112 | 74.58 |

Östergötland (E)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|-------|---------------|------|------------|------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 4621 | 1316 | 28.48 | 519 | 11.23 | : | 0.00 | 2 | 0.04 | 2783 | 60.23 |
| 1991 | 4681 | 1271 | 27.15 | 594 | 12.69 | : | 0.00 | 2 | 0.04 | 2813 | 60.09 |
| 1992 | 4701 | 1219 | 25.93 | 617 | 13.12 | : | 0.00 | 2 | 0.04 | 2862 | 60.88 |
| 1993 | 4702 | 1096 | 23.31 | 678 | 14.42 | : | 0.00 | 2 | 0.04 | 2925 | 62.21 |
| 1994 | 4706 | 1082 | 22.99 | 683 | 14.51 | : | 0.00 | 2 | 0.04 | 2938 | 62.43 |
| 1995 | 4706 | 1002 | 21.29 | 695 | 14.77 | : | 0.00 | 2 | 0.04 | 3006 | 63.88 |
| 1996 | 4731 | 987 | 20.86 | 705 | 14.90 | : | 0.00 | 2 | 0.04 | 3037 | 64.19 |
| 1997 | 4731 | 981 | 20.74 | 705 | 14.90 | : | 0.00 | 2 | 0.04 | 3043 | 64.32 |

Jönköping (F)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|-------|---------------|------|------------|------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 4393 | 1195 | 27.20 | 603 | 13.73 | 0 | 0.00 | 310 | 7.06 | 2283 | 51.97 |
| 1991 | 4406 | 1104 | 25.06 | 649 | 14.73 | 0 | 0.00 | 291 | 6.60 | 2361 | 53.59 |
| 1992 | 4424 | 1041 | 23.53 | 704 | 15.91 | 0 | 0.00 | 259 | 5.85 | 2419 | 54.68 |
| 1993 | 4457 | 890 | 19.97 | 778 | 17.46 | 0 | 0.00 | 238 | 5.34 | 2551 | 57.24 |
| 1994 | 4524 | 841 | 18.59 | 813 | 17.97 | 0 | 0.00 | 224 | 4.95 | 2646 | 58.49 |
| 1995 | 4538 | 770 | 16.97 | 848 | 18.69 | 0 | 0.00 | 224 | 4.94 | 2696 | 59.41 |
| 1996 | 4550 | 746 | 16.40 | 851 | 18.70 | 0 | 0.00 | 223 | 4.90 | 2730 | 60.00 |
| 1997 | 4567 | 735 | 16.09 | 861 | 18.85 | 0 | 0.00 | 223 | 4.88 | 2748 | 60.17 |

Kronoberg (G)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|-------|---------------|------|------------|------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 3615 | 1092 | 30.21 | 372 | 10.29 | 77 | 2.13 | 354 | 9.79 | 1719 | 47.55 |
| 1991 | 3616 | 1036 | 28.65 | 389 | 10.76 | 105 | 2.90 | 354 | 9.79 | 1731 | 47.87 |
| 1992 | 3616 | 922 | 25.50 | 482 | 13.33 | 120 | 3.32 | 348 | 9.62 | 1743 | 48.20 |
| 1993 | 3636 | 817 | 22.47 | 575 | 15.81 | 120 | 3.30 | 346 | 9.52 | 1777 | 48.87 |
| 1994 | 3632 | 731 | 20.13 | 576 | 15.86 | 120 | 3.30 | 344 | 9.47 | 1852 | 50.99 |
| 1995 | 3628 | 687 | 18.94 | 607 | 16.73 | 114 | 3.14 | 329 | 9.07 | 1891 | 52.12 |
| 1996 | 3628 | 652 | 17.97 | 636 | 17.53 | 114 | 3.14 | 329 | 9.07 | 1897 | 52.29 |
| 1997 | 3664 | 647 | 17.66 | 636 | 17.36 | 114 | 3.11 | 326 | 8.90 | 1941 | 52.97 |

Kalmar (H)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|-------|---------------|------|------------|------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 4058 | 651 | 16.04 | 461 | 11.36 | : | 0.00 | 106 | 2.61 | 2839 | 69.96 |
| 1991 | 4013 | 623 | 15.52 | 471 | 11.74 | : | 0.00 | 90 | 2.24 | 2829 | 70.50 |
| 1992 | 4034 | 550 | 13.63 | 575 | 14.25 | : | 0.00 | 75 | 1.86 | 2834 | 70.25 |
| 1993 | 4034 | 460 | 11.40 | 687 | 17.03 | : | 0.00 | 79 | 1.96 | 2808 | 69.61 |
| 1994 | 4033 | 418 | 10.36 | 698 | 17.31 | : | 0.00 | 75 | 1.86 | 2842 | 70.47 |
| 1995 | 4034 | 346 | 8.58 | 737 | 18.27 | : | 0.00 | 74 | 1.83 | 2877 | 71.32 |
| 1996 | 4033 | 340 | 8.43 | 742 | 18.40 | : | 0.00 | 74 | 1.83 | 2877 | 71.34 |
| 1997 | 4030 | 339 | 8.41 | 742 | 18.41 | : | 0.00 | 74 | 1.84 | 2875 | 71.34 |

Gotland (I)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|-------|---------------|------|------------|------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 1489 | 338 | 22.70 | 346 | 23.24 | : | 0.00 | 10 | 0.67 | 788 | 52.92 |
| 1991 | 1489 | 279 | 18.74 | 344 | 23.10 | : | 0.00 | 15 | 1.01 | 844 | 56.68 |
| 1992 | 1488 | 170 | 11.42 | 340 | 22.85 | : | 0.00 | 15 | 1.01 | 956 | 64.25 |
| 1993 | 1489 | 100 | 6.72 | 337 | 22.63 | : | 0.00 | 15 | 1.01 | 1030 | 69.17 |
| 1994 | 1485 | 37 | 2.49 | 317 | 21.35 | : | 0.00 | 15 | 1.01 | 1109 | 74.68 |
| 1995 | 1486 | 1 | 0.07 | 317 | 21.33 | : | 0.00 | 15 | 1.01 | 1146 | 77.12 |
| 1996 | 1486 | 1 | 0.07 | 317 | 21.33 | : | 0.00 | 15 | 1.01 | 1146 | 77.12 |
| 1997 | 1486 | 1 | 0.07 | 317 | 21.33 | : | 0.00 | 15 | 1.01 | 1146 | 77.12 |

Blekinge (K)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|-------|---------------|------|------------|-------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 1539 | 167 | 10.85 | 240 | 15.59 | 57 | 3.70 | 156 | 10.14 | 919 | 59.71 |
| 1991 | 1522 | 134 | 8.80 | 238 | 15.64 | 68 | 4.47 | 161 | 10.58 | 921 | 60.51 |
| 1992 | 1536 | 103 | 6.71 | 241 | 15.69 | 105 | 6.84 | 161 | 10.48 | 926 | 60.29 |
| 1993 | 1545 | 76 | 4.92 | 247 | 15.99 | 118 | 7.64 | 149 | 9.64 | 955 | 61.81 |
| 1994 | 1545 | 59 | 3.82 | 249 | 16.12 | 124 | 8.03 | 149 | 9.64 | 964 | 62.39 |
| 1995 | 1551 | 46 | 2.97 | 242 | 15.60 | 129 | 8.32 | 151 | 9.74 | 983 | 63.38 |
| 1996 | 1552 | 46 | 2.96 | 242 | 15.59 | 129 | 8.31 | 151 | 9.73 | 984 | 63.40 |
| 1997 | 1552 | 46 | 2.96 | 242 | 15.59 | 129 | 8.31 | 151 | 9.73 | 984 | 63.40 |

Kristianstad (L)₁

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|------|-----|------|---------------|------|------------|-----|------------|------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 3679 | 545 | 14.8 | 444 | 12.1 | : | 0.00 | 193 | 5.2 | 2493 | 67.8 |
| 1991 | 3689 | 545 | 14.8 | 441 | 12.0 | : | 0.00 | 176 | 4.8 | 2523 | 68.4 |
| 1992 | 3683 | 542 | 14.7 | 441 | 12.0 | : | 0.00 | 176 | 4.8 | 2520 | 68.4 |
| 1993 | 3718 | 474 | 12.7 | 505 | 13.6 | : | 0.00 | 175 | 4.7 | 2560 | 68.9 |
| 1994 | 3719 | 413 | 11.1 | 539 | 14.5 | : | 0.00 | 175 | 4.7 | 2588 | 69.6 |
| 1995 | 3736 | 342 | 9.2 | 538 | 14.4 | : | 0.00 | 175 | 4.7 | 2677 | 71.7 |
| 1996 | 3747 | 342 | 9.1 | 538 | 14.4 | : | 0.00 | 175 | 4.7 | 2688 | 71.7 |
| 1997 | | | | | | | | | | | |

¹⁾ Kristianstad until 96. Skåne + Kristianstad from 97 onwards had got the name Skåne

Skåne (M)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|------|------|------|---------------|------|------------|-----|------------|------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 4268 | 807 | 18.9 | 508 | 11.9 | : | 0.00 | 6 | 0.1 | 2898 | 67.9 |
| 1991 | 4135 | 770 | 18.6 | 473 | 11.4 | : | 0.00 | 6 | 0.1 | 2839 | 68.7 |
| 1992 | 4147 | 755 | 18.2 | 424 | 10.2 | : | 0.00 | 6 | 0.1 | 2918 | 70.4 |
| 1993 | 4191 | 570 | 13.6 | 575 | 13.7 | : | 0.00 | 6 | 0.1 | 2996 | 71.5 |
| 1994 | 4191 | 475 | 11.3 | 614 | 14.7 | : | 0.00 | 6 | 0.1 | 3052 | 72.8 |
| 1995 | 4214 | 397 | 9.4 | 611 | 14.5 | : | 0.00 | 6 | 0.1 | 3156 | 74.9 |
| 1996 | 4214 | 376 | 8.9 | 610 | 14.5 | : | 0.00 | 6 | 0.1 | 3178 | 75.4 |
| 1997 | 7977 | 718 | 9.0 | 1149 | 14.4 | : | 0.00 | 181 | 2.3 | 5881 | 73.7 |

Halland (N)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-----|-----|------|---------------|------|------------|------|------------|------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 2968 | 282 | 9.5 | 475 | 16.0 | 14 | 0.47 | 1012 | 34.1 | 1203 | 40.5 |
| 1991 | 2984 | 280 | 9.4 | 471 | 15.8 | 14 | 0.47 | 1007 | 33.7 | 1212 | 40.6 |
| 1992 | 2996 | 266 | 8.9 | 485 | 16.2 | 14 | 0.47 | 1003 | 33.5 | 1228 | 41.0 |
| 1993 | 2981 | 218 | 7.3 | 539 | 18.1 | 14 | 0.47 | 980 | 32.9 | 1215 | 40.8 |
| 1994 | 3053 | 209 | 6.8 | 546 | 17.9 | 14 | 0.46 | 973 | 31.9 | 1282 | 42.0 |
| 1995 | 3053 | 200 | 6.6 | 550 | 18.0 | 14 | 0.46 | 971 | 31.8 | 1289 | 42.2 |
| 1996 | 3095 | 200 | 6.5 | 548 | 17.7 | 14 | 0.45 | 968 | 31.3 | 1314 | 42.5 |
| 1997 | 3093 | 197 | 6.4 | 549 | 17.7 | 14 | 0.45 | 962 | 31.1 | 1320 | 42.7 |

V. Götaland (O)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|------|---------------|------|------------|-------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 2659 | 305 | 11.47 | 109 | 4.10 | : | 0.00 | 266 | 10.00 | 1979 | 74.43 |
| 1991 | 2873 | 272 | 9.47 | 111 | 3.86 | : | 0.00 | 265 | 9.22 | 2234 | 77.76 |
| 1992 | 2883 | 251 | 8.71 | 112 | 3.88 | : | 0.00 | 250 | 8.67 | 2270 | 78.74 |
| 1993 | 2895 | 233 | 8.05 | 124 | 4.28 | : | 0.00 | 237 | 8.19 | 2301 | 79.48 |
| 1994 | 2897 | 212 | 7.32 | 130 | 4.49 | : | 0.00 | 246 | 8.49 | 2309 | 79.70 |
| 1995 | 2912 | 204 | 7.01 | 129 | 4.43 | : | 0.00 | 246 | 8.45 | 2333 | 80.12 |
| 1996 | 2911 | 184 | 6.32 | 136 | 4.67 | : | 0.00 | 243 | 8.35 | 2348 | 80.66 |
| 1997 | 2928 | 183 | 6.25 | 137 | 4.68 | : | 0.00 | 246 | 8.40 | 2360 | 80.60 |

Älvsborg (P)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|-------|---------------|------|------------|------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 5184 | 1501 | 28.95 | 618 | 11.92 | : | 0.00 | 442 | 8.53 | 2623 | 50.60 |
| 1991 | 5220 | 1404 | 26.90 | 647 | 12.39 | : | 0.00 | 432 | 8.28 | 2737 | 52.43 |
| 1992 | 5220 | 1363 | 26.11 | 649 | 12.43 | : | 0.00 | 406 | 7.78 | 2802 | 53.68 |
| 1993 | 5215 | 1340 | 25.70 | 719 | 13.79 | : | 0.00 | 396 | 7.59 | 2760 | 52.92 |
| 1994 | 5223 | 1321 | 25.29 | 723 | 13.84 | : | 0.00 | 385 | 7.37 | 2794 | 53.49 |
| 1995 | 5240 | 1304 | 24.89 | 742 | 14.16 | : | 0.00 | 380 | 7.25 | 2814 | 53.70 |
| 1996 | 5260 | 1270 | 24.14 | 734 | 13.95 | : | 0.00 | 376 | 7.15 | 2880 | 54.75 |
| 1997 | 5254 | 1264 | 24.06 | 736 | 14.01 | : | 0.00 | 375 | 7.14 | 2879 | 54.80 |

Skaraborg (R)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|-------|---------------|------|------------|------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 4068 | 798 | 19.62 | 438 | 10.77 | : | 0.00 | 298 | 7.33 | 2534 | 62.29 |
| 1991 | 4075 | 794 | 19.48 | 441 | 10.82 | : | 0.00 | 297 | 7.29 | 2543 | 62.40 |
| 1992 | 4085 | 740 | 18.12 | 464 | 11.36 | : | 0.00 | 291 | 7.12 | 2590 | 63.40 |
| 1993 | 4080 | 697 | 17.08 | 466 | 11.42 | : | 0.00 | 289 | 7.08 | 2628 | 64.41 |
| 1994 | 4082 | 668 | 16.36 | 470 | 11.51 | : | 0.00 | 288 | 7.06 | 2656 | 65.07 |
| 1995 | 4082 | 658 | 16.12 | 467 | 11.44 | : | 0.00 | 283 | 6.93 | 2674 | 65.51 |
| 1996 | 4095 | 642 | 15.68 | 469 | 11.45 | : | 0.00 | 282 | 6.89 | 2702 | 65.98 |
| 1997 | 4093 | 632 | 15.44 | 476 | 11.63 | : | 0.00 | 282 | 6.89 | 2703 | 66.04 |

Värmland (S)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|-------|---------------|------|------------|-------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 4803 | 1473 | 30.67 | 492 | 10.24 | : | 0.00 | 814 | 16.95 | 2024 | 42.14 |
| 1991 | 4804 | 1457 | 30.33 | 501 | 10.43 | : | 0.00 | 812 | 16.90 | 2034 | 42.34 |
| 1992 | 4804 | 1439 | 29.95 | 492 | 10.24 | : | 0.00 | 778 | 16.19 | 2095 | 43.61 |
| 1993 | 4805 | 1403 | 29.20 | 517 | 10.76 | : | 0.00 | 771 | 16.05 | 2114 | 44.00 |
| 1994 | 4802 | 1390 | 28.95 | 529 | 11.02 | : | 0.00 | 770 | 16.03 | 2113 | 44.00 |
| 1995 | 4818 | 1377 | 28.58 | 541 | 11.23 | : | 0.00 | 771 | 16.00 | 2129 | 44.19 |
| 1996 | 4814 | 1372 | 28.50 | 537 | 11.15 | : | 0.00 | 768 | 15.95 | 2137 | 44.39 |
| 1997 | 4816 | 1372 | 28.49 | 537 | 11.15 | : | 0.00 | 768 | 15.95 | 2139 | 44.41 |

Örebro (T)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|-------|---------------|------|------------|------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 2811 | 831 | 29.56 | 332 | 11.81 | : | 0.00 | 124 | 4.41 | 1523 | 54.18 |
| 1991 | 2949 | 883 | 29.94 | 331 | 11.22 | : | 0.00 | 110 | 3.73 | 1625 | 55.10 |
| 1992 | 2945 | 874 | 29.68 | 322 | 10.93 | : | 0.00 | 108 | 3.67 | 1641 | 55.72 |
| 1993 | 2961 | 806 | 27.22 | 373 | 12.60 | : | 0.00 | 108 | 3.65 | 1674 | 56.53 |
| 1994 | 2965 | 800 | 26.98 | 376 | 12.68 | : | 0.00 | 107 | 3.61 | 1682 | 56.73 |
| 1995 | 2978 | 772 | 25.92 | 395 | 13.26 | : | 0.00 | 107 | 3.59 | 1704 | 57.22 |
| 1996 | 2980 | 765 | 25.67 | 399 | 13.39 | : | 0.00 | 106 | 3.56 | 1710 | 57.38 |
| 1997 | 2984 | 761 | 25.50 | 398 | 13.34 | : | 0.00 | 106 | 3.55 | 1719 | 57.61 |

Västmanland (U)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|-------|---------------|------|------------|------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 2522 | 521 | 20.66 | 469 | 18.60 | : | 0.00 | 24 | 0.95 | 1508 | 59.79 |
| 1991 | 2522 | 521 | 20.66 | 459 | 18.20 | : | 0.00 | 24 | 0.95 | 1518 | 60.19 |
| 1992 | 2524 | 521 | 20.64 | 459 | 18.19 | : | 0.00 | 24 | 0.95 | 1520 | 60.22 |
| 1993 | 2536 | 487 | 19.20 | 494 | 19.48 | : | 0.00 | 24 | 0.95 | 1531 | 60.37 |
| 1994 | 2536 | 487 | 19.20 | 494 | 19.48 | : | 0.00 | 24 | 0.95 | 1531 | 60.37 |
| 1995 | 2572 | 485 | 18.86 | 493 | 19.17 | : | 0.00 | 24 | 0.93 | 1570 | 61.04 |
| 1996 | 2572 | 485 | 18.86 | 492 | 19.13 | : | 0.00 | 24 | 0.93 | 1571 | 61.08 |
| 1997 | 2574 | 485 | 18.84 | 492 | 19.11 | : | 0.00 | 24 | 0.93 | 1573 | 61.11 |

Dalarna (W) (Kopparberg)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|------|---------------|------|------------|-------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 5080 | 1153 | 22.70 | 469 | 9.23 | : | 0.00 | 1286 | 25.31 | 2003 | 39.43 |
| 1991 | 4993 | 1138 | 22.79 | 459 | 9.19 | : | 0.00 | 1272 | 25.48 | 1940 | 38.85 |
| 1992 | 5004 | 1130 | 22.58 | 459 | 9.17 | : | 0.00 | 1246 | 24.90 | 1977 | 39.51 |
| 1993 | 4998 | 1086 | 21.73 | 494 | 9.88 | : | 0.00 | 1227 | 24.55 | 1992 | 39.86 |
| 1994 | 4998 | 1063 | 21.27 | 494 | 9.88 | : | 0.00 | 1186 | 23.73 | 2038 | 40.78 |
| 1995 | 5003 | 1061 | 21.21 | 493 | 9.85 | : | 0.00 | 1155 | 23.09 | 2084 | 41.66 |
| 1996 | 5002 | 1061 | 21.21 | 492 | 9.84 | : | 0.00 | 1167 | 23.33 | 2088 | 41.74 |
| 1997 | 5001 | 1030 | 20.60 | 492 | 9.84 | : | 0.00 | 1196 | 23.92 | 2107 | 42.13 |

Gävleborg (X)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|-------|---------------|------|------------|-------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 3584 | 536 | 14.96 | 374 | 10.44 | : | 0.00 | 845 | 23.58 | 1829 | 51.03 |
| 1991 | 3581 | 538 | 15.02 | 382 | 10.67 | : | 0.00 | 851 | 23.76 | 1810 | 50.54 |
| 1992 | 3580 | 531 | 14.83 | 366 | 10.22 | : | 0.00 | 874 | 24.41 | 1809 | 50.53 |
| 1993 | 3582 | 499 | 13.93 | 361 | 10.08 | : | 0.00 | 906 | 25.29 | 1816 | 50.70 |
| 1994 | 3577 | 455 | 12.72 | 338 | 9.45 | : | 0.00 | 963 | 26.92 | 1821 | 50.91 |
| 1995 | 3600 | 454 | 12.61 | 326 | 9.06 | : | 0.00 | 996 | 27.67 | 1824 | 50.67 |
| 1996 | 3597 | 426 | 11.84 | 322 | 8.95 | : | 0.00 | 1028 | 28.58 | 1821 | 50.63 |
| 1997 | 3596 | 426 | 11.85 | 307 | 8.54 | : | 0.00 | 1039 | 28.89 | 1824 | 50.72 |

Västernorrland (Y)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|------|---------------|------|------------|-------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 5190 | 1998 | 38.50 | 268 | 5.16 | : | 0.00 | 1459 | 28.11 | 1465 | 28.23 |
| 1991 | 5128 | 1984 | 38.69 | 266 | 5.19 | : | 0.00 | 1448 | 28.24 | 1430 | 27.89 |
| 1992 | 5974 | 1986 | 33.24 | 264 | 4.42 | : | 0.00 | 1444 | 24.17 | 1431 | 23.95 |
| 1993 | 5125 | 1973 | 38.50 | 263 | 5.13 | : | 0.00 | 1453 | 28.35 | 1436 | 28.02 |
| 1994 | 5127 | 2000 | 39.01 | 253 | 4.93 | : | 0.00 | 1354 | 26.41 | 1520 | 29.65 |
| 1995 | 5124 | 1990 | 38.84 | 253 | 4.94 | : | 0.00 | 1358 | 26.50 | 1523 | 29.72 |
| 1996 | 5123 | 1990 | 38.84 | 243 | 4.74 | : | 0.00 | 1355 | 26.45 | 1535 | 29.96 |
| 1997 | 5134 | 1969 | 38.35 | 238 | 4.64 | : | 0.00 | 1335 | 26.00 | 1592 | 31.01 |

Jämtland (Z)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|------|---------------|------|------------|-------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 5974 | 2683 | 44.91 | 587 | 9.83 | : | 0.00 | 591 | 9.89 | 2113 | 35.37 |
| 1991 | 5966 | 2658 | 44.55 | 514 | 8.62 | : | 0.00 | 565 | 9.47 | 2229 | 37.36 |
| 1992 | 5974 | 2577 | 43.14 | 504 | 8.44 | : | 0.00 | 536 | 8.97 | 2357 | 39.45 |
| 1993 | 5991 | 2491 | 41.58 | 385 | 6.43 | : | 0.00 | 504 | 8.41 | 2611 | 43.58 |
| 1994 | 5989 | 2395 | 39.99 | 421 | 7.03 | : | 0.00 | 562 | 9.38 | 2611 | 43.60 |
| 1995 | 5996 | 2364 | 39.43 | 397 | 6.62 | : | 0.00 | 627 | 10.46 | 2608 | 43.50 |
| 1996 | 5995 | 2328 | 38.83 | 382 | 6.37 | : | 0.00 | 661 | 11.03 | 2624 | 43.77 |
| 1997 | 5994 | 2322 | 38.74 | 377 | 6.29 | : | 0.00 | 667 | 11.13 | 2618 | 43.68 |

Västerbotten (AC)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|-------|---------------|------|------------|-------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 9241 | 4046 | 43.78 | 652 | 7.06 | : | 0.00 | 2953 | 31.96 | 1590 | 17.21 |
| 1991 | 9251 | 4015 | 43.40 | 652 | 7.05 | : | 0.00 | 2972 | 32.13 | 1612 | 17.43 |
| 1992 | 9251 | 3962 | 42.83 | 654 | 7.07 | : | 0.00 | 3016 | 32.60 | 1619 | 17.50 |
| 1993 | 4248 | 3876 | 91.24 | 725 | 17.07 | : | 0.00 | 3015 | 70.97 | 1632 | 38.42 |
| 1994 | 9238 | 3781 | 40.93 | 791 | 8.56 | : | 0.00 | 3045 | 32.96 | 1621 | 17.55 |
| 1995 | 9251 | 3739 | 40.42 | 815 | 8.81 | : | 0.00 | 3039 | 32.85 | 1658 | 17.92 |
| 1996 | 9253 | 3696 | 39.94 | 841 | 9.09 | : | 0.00 | 3057 | 33.04 | 1659 | 17.93 |
| 1997 | 9251 | 3682 | 39.80 | 852 | 9.21 | : | 0.00 | 3058 | 33.06 | 1659 | 17.93 |

Norrbotten (BD)

| Year | Total length | Gravel | | Y1G | | Sealed Gravel | | Oil Gravel | | Bituminous | |
|------|--------------|--------|-------|-----|-------|---------------|------|------------|-------|------------|-------|
| | km | km | % | km | % | km | % | km | % | km | % |
| 1990 | 8724 | 3490 | 40.00 | 642 | 7.36 | : | 0.00 | 3304 | 37.87 | 1288 | 14.76 |
| 1991 | 8713 | 3452 | 39.62 | 688 | 7.90 | : | 0.00 | 3308 | 37.97 | 1265 | 14.52 |
| 1992 | 8713 | 3418 | 39.23 | 734 | 8.42 | : | 0.00 | 3305 | 37.93 | 1256 | 14.42 |
| 1993 | 8713 | 3304 | 37.92 | 840 | 9.64 | : | 0.00 | 3333 | 38.25 | 1236 | 14.19 |
| 1994 | 8720 | 3306 | 37.91 | 848 | 9.72 | : | 0.00 | 3311 | 37.97 | 1255 | 14.39 |
| 1995 | 8725 | 3250 | 37.25 | 936 | 10.73 | : | 0.00 | 3267 | 37.44 | 1272 | 14.58 |
| 1996 | 8727 | 3231 | 37.02 | 946 | 10.84 | : | 0.00 | 3263 | 37.39 | 1287 | 14.75 |
| 1997 | 8723 | 3225 | 36.97 | 948 | 10.87 | : | 0.00 | 3260 | 37.37 | 1290 | 14.79 |

Appendix No 3

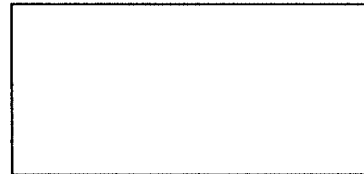
Unsurfaced road inspection sheet

Branch _____ Date _____
 Section _____ Inspector _____
 Sample Unit _____ Area of Sample _____

DISTRESS TYPES

- 81. Improper Cross Section (linear feet)
- 82. Inadequate Roadside Drainage (linear feet)
- 83. Corrugations (square feet)
- 84. Dust
- 85. Potholes (number)
- 86. Ruts (square feet)
- 87. Loose Aggregate (linear feet)

SKETCH



DISTRESS QUANTITY AND SEVERITY

| Type | | 81 | 82 | 83 | 84 | 85 | 86 | 87 |
|-----------------------|---|----|----|----|----|----|----|----|
| Quantity and Severity | L | | | | | | | |
| | M | | | | | | | |
| | H | | | | | | | |

URCI CALCULATION

| Distress Type | Density | Severity | Deduct Value | REMARKS: |
|----------------------|----------|----------|--------------|----------|
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| | | | | |
| Total Deduct Value = | | | | |
| q = | | | | |
| URCI = | RATING = | | | |