Norwegian Public Roads
Administration

Manual **198e**

Guidelines

Cold Bitumen Stabilized Base Courses

Guidelines to Standard no.018 Road Construction

11.99

Norwegian Public Roads Administration

Cold Bitumen Stabilized Base Courses

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Preface

The present document is a translation of the original guidelines written in Norwegian in 1997.
These guidelines are dealing with cold bitumen stabilized base courses. The guidelines cover mix design, production, laying as well as compaction. The following people have participated in the working group for these guidelines:

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The cold mix technology is steadily developing. Therefore, it may be necessary to revise these guidelines within a few years. Questions and comments to these guidelines can be directed to:

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1 Introduction

These guidelines deal with the use of cold mixes as base course. The term cold mix refers to the fact that aggregates are cold during production. The binder in a cold mix may be foamed bitumen or bitumen emulsion. Furthermore, cold mixes can be produced by in-situ milling stabilization or in plants. Cold mixes may be used for construction of new roads as well as for rehabilitation and maintenance.

The first cold mix project in Norway was carried out in 1983. The volume has steadily increased, and in 1997 about 1.3 million m^2 of road was stabilized by in-situ milling, whereas plant mixing constituted a volume of 50,000-100,000 tons which equals approximately 250,000-500,000 m^2 if laid in 10 cm thickness.

The major advantages of cold mixes are low costs, simple production equipment and the use of local and «low quality» materials. The use of cold mixes are also environmentally beneficial, because heating of aggregates is not needed and due to short hauling distances.

1.1 Selection of Rehabilitation and Maintenance Measures

The overall objective when selecting rehabilitation and maintenance measures should be to minimize the total costs to the society. The alternative that has the lowest annual costs should be selected. This evaluation should include road user costs, investment costs and maintenance costs. When two alternatives have similar annual costs, the alternative with the lower investment costs should be favored.

When estimating pavement service life, previous history (service life of previous surfacings), the age and condition of the road section in question should be taken into consideration. In addition to traffic, the following factors will affect pavement service life: road and shoulder widths, drainage conditions, climate, frost, maintenance, thickness and bearing capacity of the pavement structure. Consideration should also be given to the influence of possible increases in allowable axle loads on pavement service life.

Repaving of roads with low bearing capacity has generally resulted in short pavement service life. Therefore, repaving has often yielded a low benefit/cost ratio compared to more extensive measures (strengthening).

1.2 Costs

Costs of production, laying and use of cold mixes depend on a number of factors:

- available production equipment
- production capacity and quantities produced
- prices of raw materials
- hauling distances
- available aggregates (from the existing road or materials quarry)

Transportation
Until recently, removing of hot mix plants has been a complicated, costly and demanding task that requires high production volumes to be economical. Consequently hot mix plants are usually centrally located. Transportation costs on projects in outlying areas will therefore often be high.

Cold bitumen stabilized materials are produced by in-situ milling, or in simple mobile plants located close to the construction site, see Chapter 3. This reduces or eliminates the need for haulage with favorable effects on the environment. Cold mix production can to a large extent be based on the use of local and «low quality» materials thereby reducing haulage costs. Cold mixes are therefore often competitive costwise in areas located far from hot mix plants.

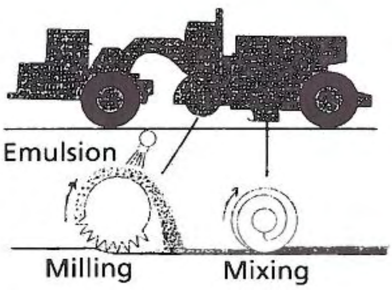


Figure 1.1 In-situ milling

In-situ Milling and Stabilization
In-situ milling and stabilization facilitates strengthening and adjustment of surface deformations and unevenness without adversely affecting the superelevation. This reduces costs, see Chapter 6.5 “In-situ Milling”.

Maintenance
Maintenance costs and the frequency of pavement renewal needed on a given road section depends on a number of factors including the quality of base layer materials. Cold bitumen stabilized materials have (similar to hot mixes) a favorable structural capacity, high stability and low moisture susceptibility compared to unbound materials. This can provide a good basis for long service life and low maintenance costs.

1.3 Environment and Resource Exploitation

Table 1.1 gives an overview of various environmental factors associated with the production and laying of hot and cold mixes.

Compared to the production of hot mixes, cold bitumen stabilized mixes have the following environmental advantages:
- the production process is less energy demanding
- production close to the construction site reduces haulage needs and consequently also noise, dust and exhaust emissions.
- in-situ milling yields environmental gains by recycling of materials. This reduces the need for binder addition and use of virgin aggregates.

Table 1.1 Environmental Factors with Hot and Cold Mixes

Environmental factors	Hot mix 1)	Cold mix 1)
Energy consumption	-	+
Smoke & exhaust fumes	-	+
Reuse/resource exploitation	-	+
Noise/dust	+	+
Emulsion flow(runoff)	+	- 2)
Abration dust	+	- 3)

1) Includes both production and laying
2) Emulsion flow (runoff) may occur with Eg and Ep. The problem should be handled during mix design.
3) Cold mixes should normally be used on low volume roads with minimal wear from studded tires.

Emulsion Flow

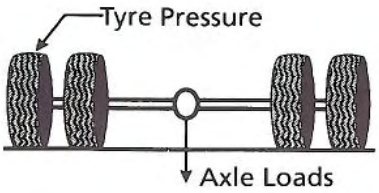
With materials based on bitumen emulsion, excessive flow of emulsion can be a problem, see Chapter 2 "Mix Types". This can occur at the plant, during haulage or after laying. Special consideration should be given to the risk of polluting adjacent rivers, streams or lakes, or when the plant location necessitates transportation through urban areas. So far there are no approved laboratory methods to assess the emulsion flow problem. At the start of a job with gravel emulsion there must be adequate readiness to handle any sullying by the spreading of sand.

Requirements on Reuse

A number of countries have adopted provisions to recycle and reuse construction materials. So far, Norway has no such directives. An anti-pollution act, however, states that "Waste materials shall be handled to minimize damage and adverse effects and reuse undertaken when justified out of consideration to the environment, resources and economics". The share that will be reused is therefore expected to increase in the future.

2 Mix Types

2.1 General



Figur 2.1 Axle load and tyre pressure

Unbound Base Course Materials
The deterioration of the Norwegian road system has increased. This is due to increased traffic volumes, allowable axle loads, air pressure in truck tires or very often the use of low quality unbound base course.

On roads with an unbound base course of poor quality, repaving alone will often not lead to any noteworthy increase in the pavement service life. In such cases, recycling of the gravel base course by milling and binder addition can cause a significant increase in the pavement service life.

Definition
Cold bitumen stabilized base course materials are characterized by aggregates that are cold and damp during the production process, which takes place at plants or on the construction site.

Material Types
The following material types are discussed in these guidelines:

- gravel emulsion (Eg)
- emulsion treated macadam (Ep)
- foamed gravel (Sg)
- bitumen stabilized gravel (Bg)
- recycled asphalt (Gja)

Advantages
Cold bitumen stabilized base course materials have a number of advantages over unbound base course materials such as crushed gravel (Gk) or crushed rock (Fk):

- higher structural coefficient
- higher stability during critical periods such as the spring thaw period
- reduced moisture susceptibility and capillarity because of the binding of the fines

Cold mixes may be used for both rehabilitation purposes and new pavement structures. Bitumen stabilized materials will normally have a low structural capacity in the initial period subsequent to laying, and it often takes 1-2 years before the materials (Eg, Sg, and Bg) have developed full strength. The binder will, however, bind the fines and make the materials less moisture susceptible also during the curing period. Further, see Chapter 3.2, "Terms for Use of Cold Bitumen Stabilized Materials".

"Bitumen Treated Gravel"
For Eg, Sg and Bg a minimum of 3% (residual) is required, see Chapter 4.6.4 "Binder Content". One can also add lesser quantities of binder: 1.5-3%. In such cases the material is called bitumen treated gravel and cannot be denoted Eg, Sg or Bg. The intention of adding such small quantities of binder is to bind fines and reduce moisture susceptibility. The structural coefficient is therefore of lesser significance. The material can be produced either through plant mixing or by milling stabilization at the construction site. The use of «bitumen treated gravel» must be assessed carefully in each individual case.

Applications
Eg, Sg, Bg and Ep are used as lower and/or upper bases course, see Table 2.1. Eg and Sg can also be used as temporary surfacings during the construction stage or as keying or leveling material. Gja can be used as a temporary surfacing for low volume roads.

Binder
The binder in cold mixes may be bitumen emulsion, foamed bitumen or bitumen emulsion and cement, or in some cases also bitumen emulsion and special filler types.

Bitumen emulsion is bitumen emulsified in water. Bitumen emulsion is denoted BE followed by a number indicating the proportion of bitumen. For cold base course materials, BE60, BE65 or BE70 are used. A letter after the number indicates the rate of curing; R: Rapid, M: Medium, S: Slow. For choice of curing rates see Chapter 2.2, 2.4, 2.5 and 2.6, where the different types of materials are discussed.

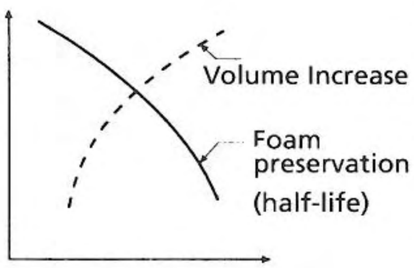


Figure 2.2 Foaming

Foamed Bitumen (Sb) is produced by adding 2-5% water to a warm bitumen. This provides a volume increase corresponding to 10-20 times the original volume of the bitumen. The large volume makes it easier to distribute the relatively small quantities of binder in the aggregate. The water addition must be adapted so that a good distribution of the bitumen in the material is attained. More water will result in a greater volume increase, but with the foam being preserved for a shorter period of time, see Figure 2.2. In most cases addition of 3% water is a good choice.

Standard
018

Figure 2.3 Standard no. 018

Requirements in Standard no. 018

In Manual no. 018 there are requirements for cold bitumen stabilized materials related to:

1) Material Properties
   - Aggregates (mechanical strength, flakiness, amount of crushed material)
   - Binder (type and amount)
   - Grading

2) Production Process:
   - Compaction
   - Homogeneity
   - Evenness or roughness

These guidelines present supplementary information on the above-mentioned requirements.

Recommended AADT Limits

Cold bitumen stabilized base course of type Eg or Sg is recommended for traffic volumes ,as measured by annual average daily traffic (AADT), up to 3,000 and 5,000 in the upper and lower base course, respectively. The corresponding limits for Bg are 1,500 and 3,000, see Table 2.1 and Standard no. 018. One has, however, had good experiences with cold mixes for higher traffic volumes.

Table 2.1 Recommended AADT Limits for Cold Bitumen

Type of Material	Upper Base Course	Lower Base Course
Crushed Gravel	300 1)	1500 1)
Crushed Gravel	1500	5000
Foamed Gravel (Sg) Gravel Emulsion (Eg)	3000	5000
Emulsion Treated Macadam (Ep)	3000	5000
Bitumen Stabilized Gravel (Bg)	1500	3000
Recycled Asphalt (Gja)	2)	2)

1) Gk is not permitted for trunk roads, see Standard no. 018.
2) No AADT limits are given for recycled asphalt (Gja) as these depend on the properties of the material which must be documented in each particular case.

In comparison, crushed gravel (Gk) is used for traffic volumes (AADT) up to 300 and 1500 for the upper and lower base course levels, respectively, while the corresponding limits for crushed rock (Fk) are 1,500 and 5,000.

2.2 Gravel Emulsion (Eg)

Definition

Gravel emulsion (Eg) consists of aggregates and bitumen emulsion. The largest particle size is normally 16, 22 or 32 mm. There are no requirements for the proportion of crushed materials. For recommendations concerning grading, see Chapter 4.3.3. Eg is produced at plants or in mix pavers, see Chapter 3.

Binder

Penetration grades B180 and B370 are normally used for making emulsion. Soft bitumen MB6000 and MB12000 have also been applied. Rapid (R), medium (M) or slow (S) curing emulsions should be assessed depending upon mineralogy, grading, production equipment and technique.

Adhesion Agents

Emulsions contain emulsifiers which work as adhesion agents. Addition of adhesion agents beyond this is in such cases not necessary.

Traffic

Cold bitumen stabilized base course (Eg) is recommended for traffic volumes , as measured by annual average daily traffic (AADT), up to 3,000 and 5,000 in the upper and lower base courses, respectively, see Table 2.1. One has, however, had good experiences with Eg for higher traffic volumes.

Laying of Wearing Course and Protective Spreading

Eg is generally more sensitive to precipitation during and just after laying, as compared to Sg. This is connected to the bitumen emulsion containing more water than foamed bitumen. Under dry conditions, however, Eg often has a higher initial strength than Sg. The reason is better binder coating for Eg shortly after construction as compared to Sg.

Under favorable weather conditions, it can be advantageous if the Eg layer is open to traffic for about one week before laying of the wearing course, among other reasons because of the water evaporation. Where there is a risk of excessive emulsion flow, one should spread sand or filler immediately after laying.

2.3 Foamed Gravel (Sg)

Definition

Foamed Gravel (Sg) is made from aggregates and foamed bitumen. For recommendations concerning gradation, see Chapter 4.3.3.

Binder
Foamed bitumen is usually produced by bitumen type B180-B370, or soft bitumen type MB6000 to MB12000. For safety and environmental reasons the flash point of the softener in the MB types of binder should be verified.

Adhesion Agent
With the production of Sg, an active adhesion agent of an approved type and amount should be added. Sg is produced at plants, or alternatively in a mix paver, see Chapter 3, "Production Equipment".

Traffic
Sg is recommended for traffic volumes, as measured by annual average daily traffic (AADT), up to 3,000 and 5,000 for upper and lower base course, respectively, see Table 2.1. One has, however, had good experiences with Sg for higher traffic volumes.

Laying of Wearing Course
The wearing course can be laid immediately after laying of the base course. Under favorable weather conditions it can be advantageous to have the Sg layer opened to traffic for a few days (2-3) before laying the wearing course.

Foamed gravel is usually less susceptible to precipitation in the initial period subsequent to laying than gravel emulsion. Sg has however often a lower initial strength than Eg. The reason is a poorer binder coverage for Sg than Eg in the initial period after laying.

2.4 Bitumen Stabilized Gravel (Bg)

Definition
Bg is produced at the construction site, by the milling and stabilization of the existing gravel base course. This may also involve milling of existing bituminous layers or unbound imported materials, see Chapter 3 "Production Equipment".

Homogeneity
Plant mixed materials normally provide a more even quality than does milling at the site, because one has more control over aggregate gradation, moisture content and adhesion agent addition. Bg is thus given a lower structural coefficient in Manual no. 018, compared to plant mixed materials, see Table 4.7. This has to be compensated with a greater layer thickness as compared to plant mixed materials (Eg, Sg).

Binder
The binder in Bg can be foamed bitumen or bitumen emulsion. Foamed bitumen and bitumen emulsion are usually produced with

penetration grades B180 or B370, or soft bitumen of the type MB6000 to MB12000. With the use of emulsions, the choice of curing rate, rapid (R), medium (M), or slow (S), is assessed based on mineralogy, grading, production equipment and technique.

Adhesion Agent

When using foamed bitumen, an active adhesion agent of an approved type and amount should be added. If an emulsion is being used, it is in most cases not necessary to add an adhesion agent because the emulsifier itself normally also works as an adhesion agent.

Traffic

Cold bitumen stabilized base course type Bg is recommended for traffic volumes, as measured by annual average daily traffic (AADT), up to 1,500 and 3,000 for the upper and lower base course respectively, see Table 2.1 and Standard no. 018. One has, however, had good experiences with Bg for higher traffic volumes.

Laying of Wearing Course

Bg can be sensitive to heavy rainfall in combination with traffic during the first days subsequent to laying.

The wearing course should normally be laid within a few days after laying of the base course. Should the base course be left to lie open, it can prove expedient to seal (with for example BE50R) and subsequently spread a layer of unbound protective material on top. Alternatively, one can lay a surface treatment. Any damage to the base course must be repaired before laying the wearing course.

2.5 Emulsion Treated Macadam (Ep)

Definition

Emulsion treated macadam (Ep) consists of bitumen stabilized stone and gravel. Emulsion treated macadam is produced at plants or with mix pavers.

Binder

Typically bitumen for the production of emulsions for Ep is B180 to B370, or soft bitumen type MB3000 to MB10000. The type of binder (grade) should be selected on the basis of the mix design, see Chapter 4. The curing rate of the emulsion, rapid (R) or medium (M), should be assessed based on mineralogy, grading, production equipment and technique.

Traffic

The recommended AADT (Annual average daily traffic) limits for use of Ep in upper and lower base course is 3,000 and 5,000 respectively, see Table 2.1 and Standard no.018. One has, however, had good experiences with Ep for higher traffic volumes.

Spreading of protective materials
Fine grained unbound materials should be spread on top of the Ep layer immediately after laying to reduce damage from construction traffic or regular traffic and to avoid excessive emulsion flow in the event of heavy showers.

2.6 Recycled Asphalt

Definition
The term Gja is used for cold or hot recycled materials. Gja may be produced at plants or by in-situ recycling.

Recycling
Annually large amounts of milled materials and asphalt flakes are produced in Norway. Recycling of these materials may be beneficial environmentally, technically and financially.

Applications
Recycled asphalt (Gja) may be used as a lower or upper base course, see Table 2.1. Gja can also be laid as a wearing course on gravel roads. However, the combination of a thin and rigid wearing course on a weak base course should be avoided.

Material Requirements and AADT Limits
There are no specific requirements for Gja in Manual no. 018 as related to grading curve, binder content and AADT (annual average daily traffic) limitations,see Table 2.1.

Binder and Additives
For cold recycling, bitumen emulsion is normally used. Foamed bitumen can be an alternative for fines contents (< 2 mm) greater than 25%.

The binder type (grade) is selected so that the material acquires good workability and evenness after laying. Normally B180-MB10000 is used, but soft bitumen type MB6000 can also be used. Usually 1-3% binder (residual) is added, depending on mix design. Special additives can be used.

3 Production Equipment

3.1 General

Cold bitumen stabilized mixes may be produced at plants or by in-situ milling. For new roads, bitumen stabilized materials are normally produced at plants. These can be stationary or mobile. For reconstruction of existing roads the materials are produced at plants, in a mix paver or through stabilization by in-situ milling.

Cold bitumen stabilized base course materials are produced as shown in Table 3.1. Eg, Ep and Sg are produced at plants or with mix pavers, while Bg is produced by in-situ milling of materials in the existing road, also together with imported materials. Gja can be produced at plants or by recycling on site.

Table 3.1 Cold Bitumen Stabilized Base Course Materials and Associated

Mix Type	Plant Mixing or Mix Paver	In-situ Milling
Eg	Yes	No
Ep	Yes	No
Sg	Yes	No
Bg	No	Yes
Gja	Yes	Yes

Selection of Mix Type and Production Equipment
The selection of mix type and production equipment depends on:

- available equipment (type)
- costs (production, transportation and laying)
- production capacity and production volume
- hauling distances
- available types of aggregate
- properties and composition of mixes
- former experience with various mixes

3.2 Terms for Use of Cold Bitumen Stabilized Materials

Drainage

Cold bitumen stabilized materials have a relatively low initial strength. The fines, however, are bound and the mix is accordingly less moisture susceptible than corresponding materials without binder, see Chapter 2 "Mix Types". Additionally, the structural coefficient increases quickly as the material gradually is being cured and the moisture content reduced. To ensure this, the stabilized material has to be well drained. In case of excessive moisture contents, the structural coefficient will not increase as anticipated. Therefore the drainage has to be good. This pertains to Sg, Eg, Ep and Bg. Dense gravel emulsion (Eg or Bg) is more vulnerable in such situations than foamed gravel (Sg or Bg).

Drainage can in principle be ensured by:

- having an open graded layer (lower base course or subbase course) under the bitumen stabilized layer.
- production of an open graded bitumen stabilized layer.
- ditches or drainage pipes on both sides of the road.

The need for a draining layer under the bitumen stabilized layer must be considered on the basis of properties of the bitumen stabilized layer (draining properties, material type and binder content), climate, draining properties of other layers in the pavement structure and drainage conditions at the site. In most cases, however, a well drained layer of at least 5-10 cm is recommended under the bitumen stabilized layer.

Seasonal Preferences

It is advantageous to produce and lay cold bitumen stabilized materials early in the summer, so that there is enough warmth and traffic on the stabilized layer. This will promote a favorable development of strength in the mix before frost sets in and before the next spring thaw.

When laying late in the season, or in parts of the country where long warm periods are rare, it can be beneficial to wait one year or more before a permanent wearing course is laid. For roads with little or moderate traffic, temporary seal or surface treatment can be laid on top of the cold bitumen stabilized base course.

3.3 Stabilization by in-situ Milling

Objective
The objective of milling is to stabilize existing unbound base course materials through the addition of bitumen emulsion or foamed bitumen. The mix produced by in-situ milling is designated as bitumen stabilized gravel (Bg), see Chapter 2, "Mix types".

Method
Stabilization can take place through the milling of the existing bituminous and unbound layers. Addition of extra materials before milling can also be appropriate, see Chapter 6.5.3.

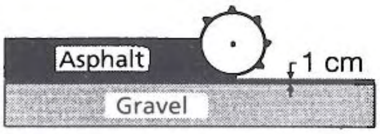


Figure 3.1 Plane Milling

Alternatively, bituminous layers can be removed in a separate plane milling operation. The milling depth should in such cases be adapted to retain a thin bituminous layer of approximately 1 cm. In this way the recycled material will not be "contaminated" with unbound base course materials. For further details on in-situ milling and stabilization, see also Chapter 6.5.

Milling Equipment
There are two types of milling machines; machines used for plane milling and machines for deep lift stabilization. Stabilization machines are optimized for the milling stabilization of unbound base course, while plane milling machines work best with plane milling of asphalt.

The use of stabilization machines for milling of thick (< approx. 4 cm) and hard asphalt layers, can lead to slow progress and low profitability, as well as a poor quality of milled materials, see Chapter 6.5.2 "In-situ Milling and Stabilization or Plane Milling of Old Asphalt Pavements". Only stabilizing machines are discussed further in these guidelines.

The milling width for stabilizing machines varies from approximately 2.2 meters to 4.4 meters, depending on type of machine. The maximum milling depth is usually 20-40 cm. However, the milling depth with the stabilization of existing gravel base courses is typically 10-15 cm (7-20 cm in special cases).

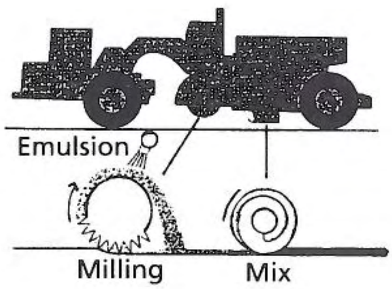


Figure 3.2 Example of a Stabilization Mill

Milling machines for stabilization can be equipped with one or two drums. Dual drum machines normally provide more homogeneous mix after one pass. The homogeneity is also related to the rate of progression; slow progression as a rule gives better quality and homogeneity than higher rates of progression.

Also there are milling machines which lay out the stabilized material in a windrow. With the help of a conveyor belt, the mix is then lifted into a paver. Alternatively, the windrow can be leveled with a grader.

Aeration
Should the moisture content of the material become too high after milling and stabilization, aeration of the mix should be considered in order to obtain an optimum moisture content. A high moisture content can, for example, be caused by rainy weather during laying. Aeration is carried out by dry milling the material without addition of binder, processing with a grader or by letting the mix dry up on the road before compacting. Aeration is laborious and makes the process more costly. Laying in rainy weather conditions with subsequent aeration should therefore be avoided.

3.4 Plant Mixing

3.4.1 General

Production Equipment
The following production equipment is used in Norway:

- free fall mixer
- vertical mixer
- pugmill with or without split material flow

Aggregates
Production normally takes place with the use of materials from the material quarry or recycled materials. Existing base course materials can be used, but must be hauled from the road to the production site. This is costly, and therefore the latter method is not used.

Properties
For differences between cold mixes produced by plant mixing (Sg, Bg) and in-situ stabilized materials (Bg), see Chapter 2.4 "Bitumen Stabilized Gravel (Bg)".

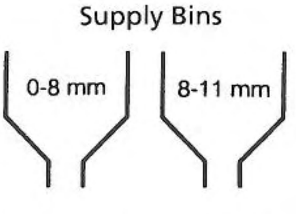


Figure 3.3 Example of Fractioning

3.4.2 Fractioning

It is recommended to use two or more fractions when producing cold mixes by plant mixing. Fractioning contributes to better homogeneity. The following fractions are typical: 0-4 mm, 0-6 mm, 0-8 mm, 4-11 mm, 6-11 mm, 6-16 mm, 8-11 mm, etc. Experiences show that it can be difficult to split damp aggregates using sieves finer than 4 mm.

The choice of fractions to be stabilized or screened out and used for other purposes depends on:

- available production equipment

- laying method
- production volume
- mix types
- thickness of coating and maximum stone size
- evenness
- traffic
- other potential applications for screened fractions.

Also see Chapter 2, "Mix Types", with regard to recommended AADT limitations, choice of binder type and Chapter 4.3.3 "Assessment of Aggregates" for recommended grading.

Example
If the aggregates consist of 0-100 mm fractions, it can prove expedient to:
- screen out material larger than 20 mm and use this as subbase material.
- produce a bitumen stabilized base course material of the 0-20 mm fraction.

Aggregate materials of less than 20 mm can be split into two fractions before stabilization, e.g. 0-8 and 8-20 mm.

3.4.3 Free Fall Mixer

The free fall mixer consists of a mixing chamber with interior sieves and spraying bars, see Figure 3.4. Gravel materials are fed into the top of the free fall mixer via a conveyor belt and split into two fractions, usually 0-6 mm, and + 6 mm. Spraying of binder takes place through three spraying bars, placed under the sieves. The amount of bitumen is adjusted depending upon the amount of aggregate materials which pass through the different sieves. Separate spraying of binder on the fine and coarse fractions ensures that also the coarse fractions get binder. This can otherwise be a problem when binder is added to unsorted materials. The binder can be foamed bitumen or bitumen emulsion.

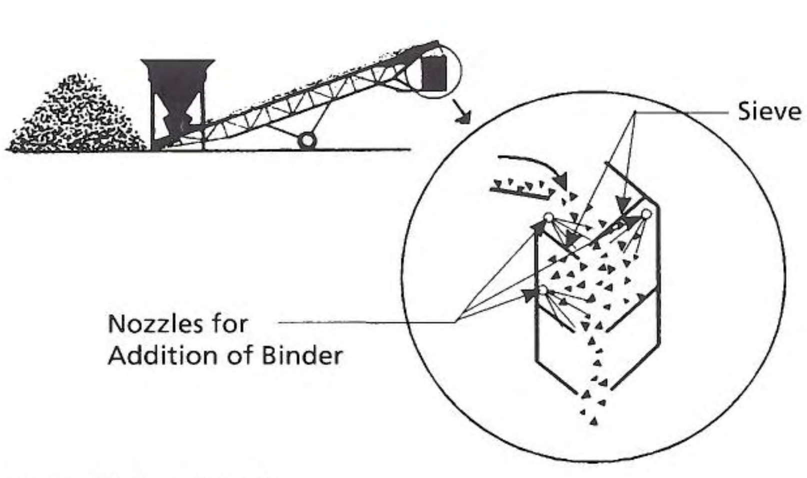


Figure 3.4 Free Fall Mixer

3.4.4 Vertical Mixer

The vertical mixer consists of a mixing chamber with interior mixing arms and mixing blades, see Figure 3.6. The equipment can be classified as a combined gravity mixer and a mechanical pugmill. The binder (bitumen emulsion or foamed bitumen) is added through spraying bars mounted on up to three different levels in the mixer.

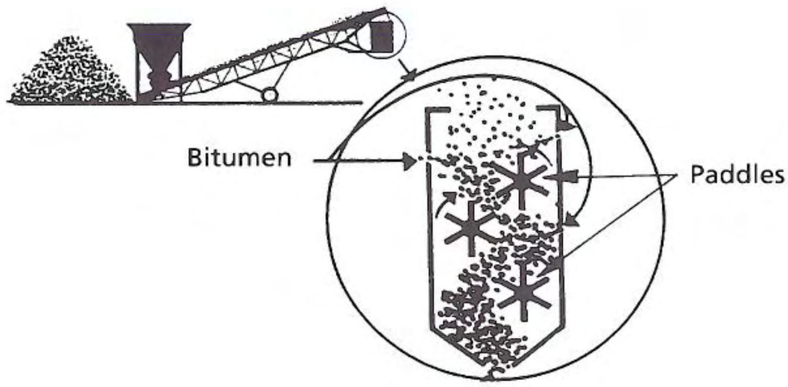


Figure 3.5 Vertical Mixer

3.4.5 Pugmill

A pugmill is a highly mobile plant used for the mixing of cold materials. The plant may be equipped with 2-3 supply bins and conveyor belt for separate addition of coarse and fine fractions to the mixer (split material flow). The mixer can be equipped with spraying bars for separate addition of binder to coarse and fine fractions. Some plants also have two binder addition lines for the addition of two binder types.

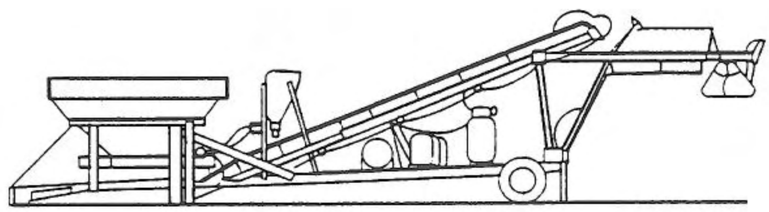


Figure 3.6 Cold Mixing Plant with Continuous Pugmill

3.5 Mix paver

Mix pavers are used for production and laying of cold materials in-situ. A mix paver may also be placed on ramps and used as an ordinary cold mixing plant. Mix pavers are equipped with supply bins for aggregate and binder tanks. Foamed bitumen or bitumen emulsion may be used. In 1996 there were two mix pavers in Norway.

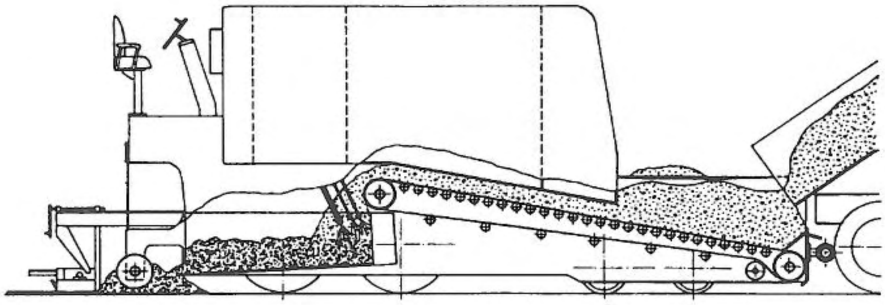


Figure 3.7 Example of a Mix Paver (Midland Mixpaver)

3.6 Production of Recycled Asphalt

3.6.1 General

Recycling of existing bituminous road surfacings can be carried out on the road, in a plant or by using a mix paver. The recycling may be cold, semi-hot or hot.

Milled Materials and Asphalt Flakes

Recycled asphalt is acquired by plane milling of existing bituminous layers or by the crushing of asphalt flakes.

With plane milling, formation of lumps can be a problem. Experiences show that the amount of lumps is reduced by adjusting the teeth distance on the milling drum and the rotation velocity.

Milled asphalt materials often have high fines content. With cold recycling of milled materials, it is therefore in many cases necessary to adjust the grading curve. This can for example be done by the addition of precoated crushed stone, which may improve the material stability and workability of the material during laying.

Crushing of asphalt flakes takes place in mobile or stationary crushing and granulation plants. Traditional crushers for aggregates are unsuitable.

3.6.2 Cold Plant Recycling

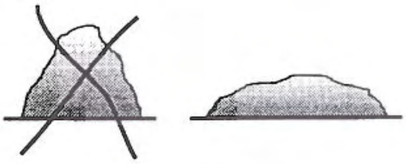


Figure 3.8 Intermediate Storage of Milled Materials

Intermediate Storage

Lump formation can be a problem with intermediate storage of milled materials. Milled materials should preferably be applied directly. Any intermediate storage should therefore be of limited duration. Large stock piles and traffic on the material increase the risk of lump formation and should therefore be avoided. Protection from sun and rain also reduces the lump formation problem.

Sorting Out Lumps

Asphalt flakes must go through a crushing process before use. It may also be necessary to crush milled material which has been stored for longer periods of time (several weeks). Both milled materials and crushed asphalt flakes will normally contain some lumps which should be removed by screening the material.

Maximum Particle Size

The maximum particle size after screening should not exceed 16-20 mm for recycled materials applied as a wearing course. For base course materials, a maximum particle size of up to 32 mm is used. In addition, the maximum particle size should not be greater than half or one-third of the layer thickness of the base course or wearing course, respectively.

Production Equipment

For cold production of recycled asphalt at plants, ordinary production equipment for cold stabilized materials such as free fall mixers, vertical mixers, pugmills ("oil gravel plant mixer") and mix pavers may be used.

Fractioning

Splitting the recycled asphalt into a minimum of two fractions, such as 0-8 mm, and 8-16 mm is recommended in order to improve of the homogeneity and composition of the material for production, see /3/.

Total Fluid Content

The total fluid content (binder and water) during production is important both in terms of the distribution of the binder, mixing (workability) and compaction of the mix, see Chapter 4.6.3 and 4.6.4.

Laying

For laying of recycled asphalt, a paver with a high compacting effort screed is recommended. For recycled asphalt, the lift thickness during laying should not exceed 8-10 cm. If the total layer thickness is greater, the material should be laid in two lifts.

Rolling

The major problems associated with the use of cold recycled asphalt in Norway have been unevenness and premature rutting. This can often be related to the roller type, lift thickness during laying or too low a temperature during rolling. The combination of heavy pneumatic roller and steel roller with high static linear load and large drum diameter is recommended. The best results are achieved when laying and rolling are carried out under high ambient temperatures (warm weather).

3.6.3 Cold in-situ Recycling

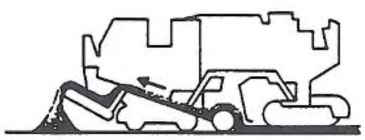


Figure 3.9 Example of Equipment for Cold In-situ Recycling

Cold in-situ recycling is used for production of both base course and wearing course mixes. The equipment for in-situ recycling varies from being made up of several individual units, to large single unit machines. This includes everything from mix pavers to large machines with:

- pre-heating of road surface
- milling
- crushing of aggregates
- screening
- addition of virgin aggregates
- addition of binder
- laying

3.6.4 Semi-hot Recycling with Steam

There are also plant mixers based on the use of steam. The main objective with steam is to improve workability and dissolve any remaining lumps by careful heating. The temperature of the material during laying is approximately 60-70ºC. Equipment of this type is being tested in Norway. The results so far are promising.

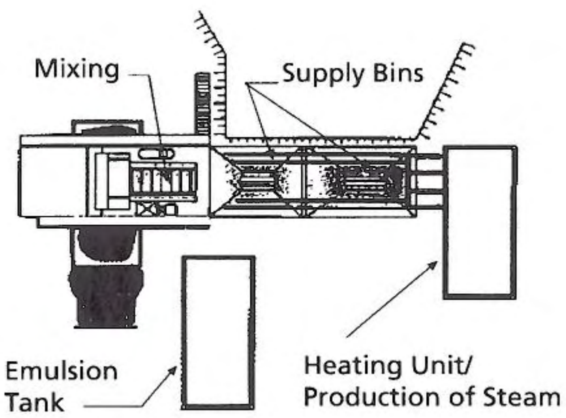


Figure 3.10 Steam Treatment

4 Mix Design

4.1 General

Objective
The term «mix design» is used to reflect the entire process of selecting a mix composition. In Standard no. 018 there are requirements pertaining to the following properties:

- structural coefficient
- binder coverage (gravel emulsion (Eg) and emulsion treated macadam(Ep)).

Durability, adhesion and fatigue properties should also be assessed.

Phases
The mix design can be divided into the following phases, see Figure 4.1:

1) Sampling of aggregates (Chapter 4.3)
2) Evaluation of aggregates (Chapter 4.3)
3) Selection of binder (Chapter 4.4)
4) Selection of emulsion composition (Chapter 4.5)
5) Test preparation (Chapter 4.6)
6) Curing (Chapter 4.7)
7) Testing (Chapter 4.8)

Standard and Expanded Mix Design
The mix design can be carried out by two alternative methods:

- standard mix design
- expanded mix design

Standard mix design is concerned with variation in binder content, whereas with expanded mix design the moisture content is also taken into account, see Chapter 4.6 "Specimen Preparation". Expanded mix design is particularly suitable for materials rich in fines. The procedures for curing and testing of samples are the same for the two methods, see Chapter 4.7 and 4.8. In most cases it is sufficient to use the standard method.

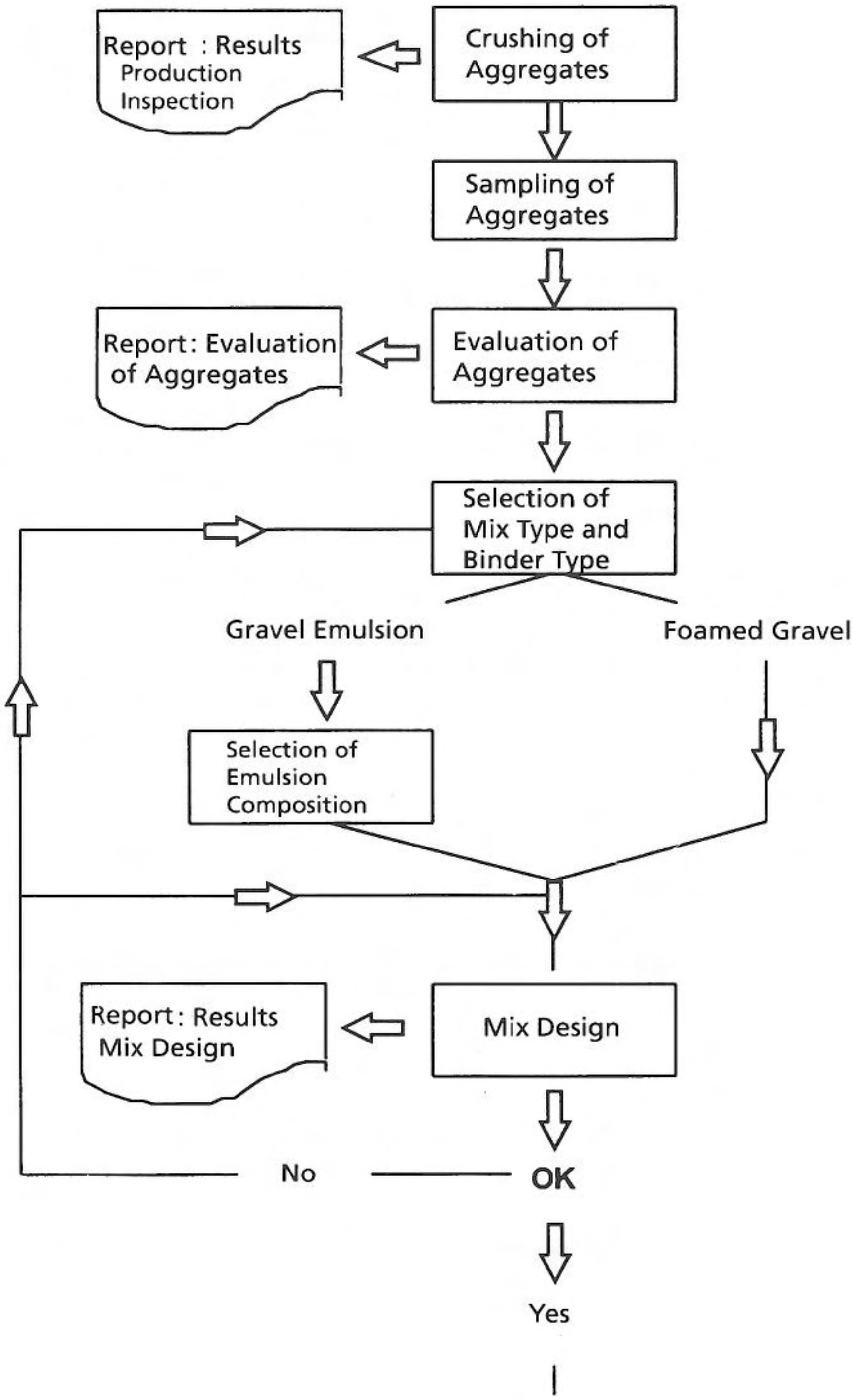


Figure 4.1 Mix Design with Cold Mixes

4.2 Time Schedule

The mix design takes a minimum of nine days using the standard or expanded mix design procedure. In addition it may also be necessary to carry out relatively time consuming supplementary investigations, both in the field and in the laboratory. As previously mentioned, cold stabilized materials should be laid in the spring or summer, see Chapter 3.2 "Terms for Use of Cold Bitumen Stabilized Materials". The planning should therefore commence well before the job itself is to be carried out.

Good planning of cold production also facilitates better utilization of available resources (aggregate materials), optimizes production and improves the quality of the mix itself, see Chapter 4.3.1 "Crushing of Aggregates".

4.3 Aggregate Materials

4.3.1 Crushing of Aggregates

General

The various phases during crushing and processing of aggregates are illustrated in Figure 4.2. Measures related to crushing of aggregates are not directly part of mix design, but are included because this gives an opportunity to optimize crushing with regard to the production of the cold mix. The quality of the cold mix can therefore be improved.

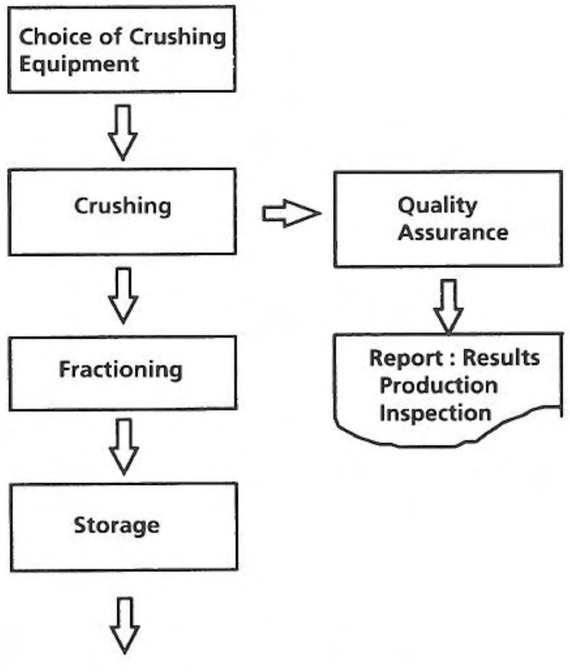


Figure 4.2 Crushing of Aggregates

Reactivity (Eg/Ep)
Reactivity is used to quantify the surface charge of the particles (aggregates). The aggregates are most reactive immediately after crushing. The reactivity then decreases and stabilizes to a level which is almost constant.

The reactivity is important for the assessment of emulsion. A newly crushed material may require a different emulsion composition than aggregates which have been crushed a long time ago. To ensure the most stable reactivity possible for aggregates, one should wait at least two to three weeks after crushing before producing Eg or Ep, so that the reactivity gets down to a stable level. It has not been proven that the reactivity is of a corresponding importance for the production of Sg.

Dust Coating
Dust coating on coarse aggregates can be a problem during production of gravel emulsion, see Chapter 4.3.3 "Assessment of Aggregates Suitability". Any dust coating on aggregates can be removed by washing. Experience shows that problems with dust coating increase when unsorted materials are left in the stockpile for a period of time. The simplest and most effective measure for reducing the problem with coating is therefore to split the aggregate materials immediately after crushing (such as in 0-8 and 8-11 mm).

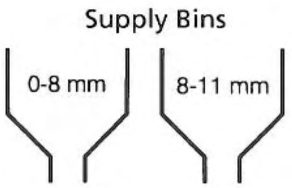


Figure 4.3 Example of Fractioning

4.3.2 Material Sampling

General
In a stockpile, separation can easily take place and the moisture content will often be different on the surface, as compared to a position near the center of the stockpile. Sampling of aggregates for mix design must be carried out in such a way that specimens are representative. This is important so that :

- aggregates (grading, moisture content, mineralogy, etc.) used in the mix design and in production are as much alike as possible
- the mix design will contribute to reveal potential problems during production.
- realistic results are obtained.

Use of Mechanical Equipment
It is absolutely necessary to use mechanical equipment (tractor etc.) in order to obtain representative samples. Therefore, aggregate sampling should be carried out as described in Manual no. 015, "Field Tests" under:

- 15.241 "Digging and Excavation"
- 15.254 "Sampling of Unbound Materials".

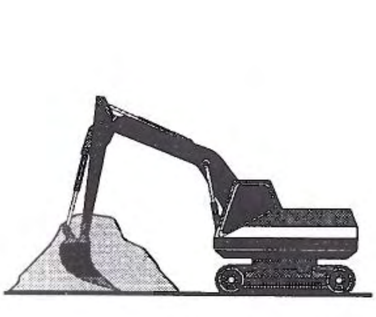


Figure 4.4 Sampling of Aggregates

Sampling, packing and transportation of material samples must be done so the natural moisture content of the aggregate is preserved to the greatest extent possible.

Quantities
A minimum of 200 kg stone materials which is used as follows:

- assessment of aggregates suitability (Chapter 4.3.3): approximately 50 kg.
- selection of emulsion composition (Chapter 4.5): approximately 50 kg.
- mix design (Chapter 4.6-4.8): approximately 100 kg.

4.3.3 Assessment of Aggregates
In the following some of the most significant properties of aggregates are briefly commented.

Gradation
Recommended envelope curves for Sg and Eg are shown in Figure 4.5 through 4.8.

For Bg and Ep, no recommended envelope curves are specified. However, Ep has to comply with the following requirements:

- the maximum nominal stone size is 2/5 of the layer thickness.
- the ratio of the maximum to the minimum particle size for crushed stone fractions should not exceed 3.
- to increase the stability, 10-35% crushed rock < 4 mm should be added.
- the filler content should not to exceed 5%.

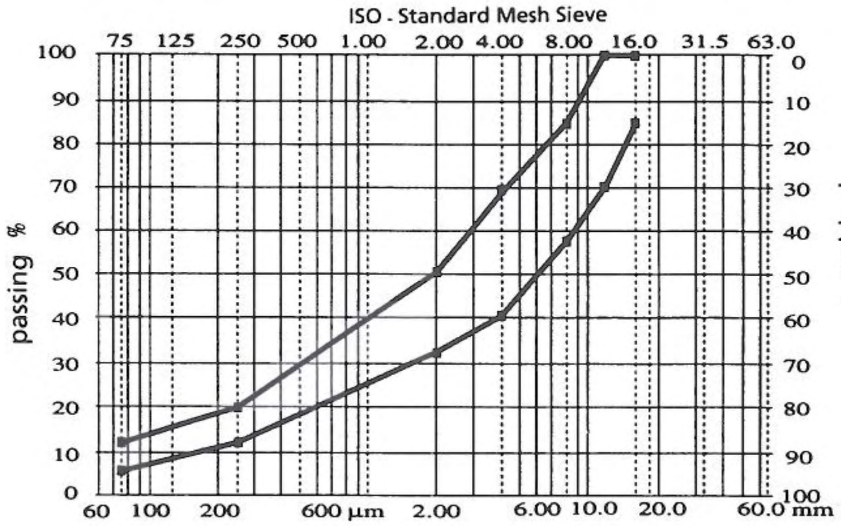


Figure 4.5 Recommended Envelope Curves for Foamed Gravel (Sg)

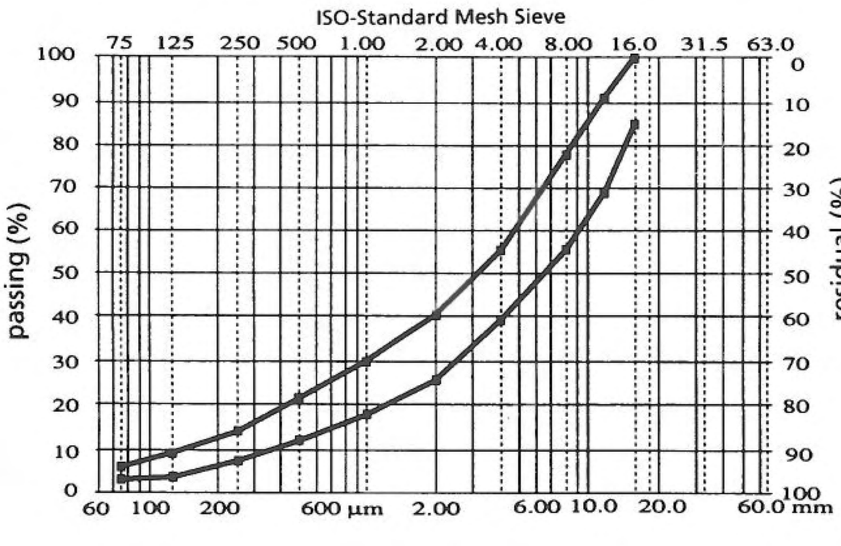


Figure 4.6 Recommended Envelope Curves for Gravel Emulsion (Eg 16)

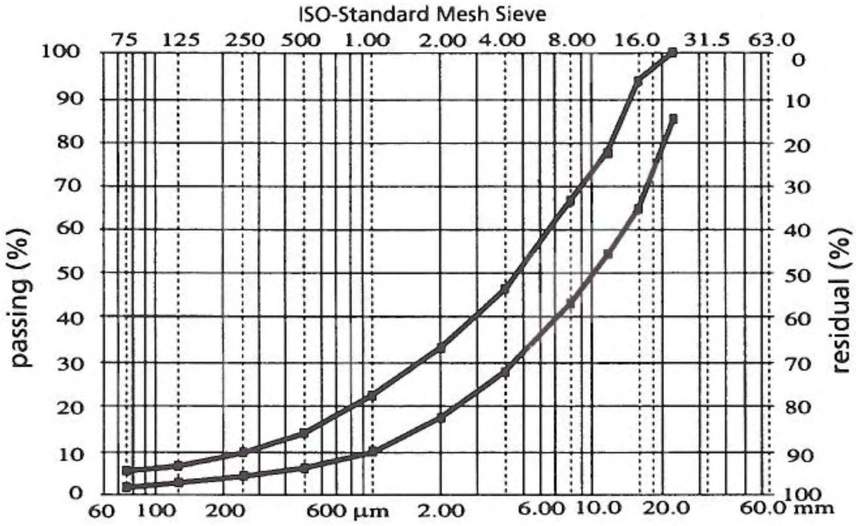


Figure 4.7 Recommended Envelope Curves for Gravel Emulsion (Eg22)

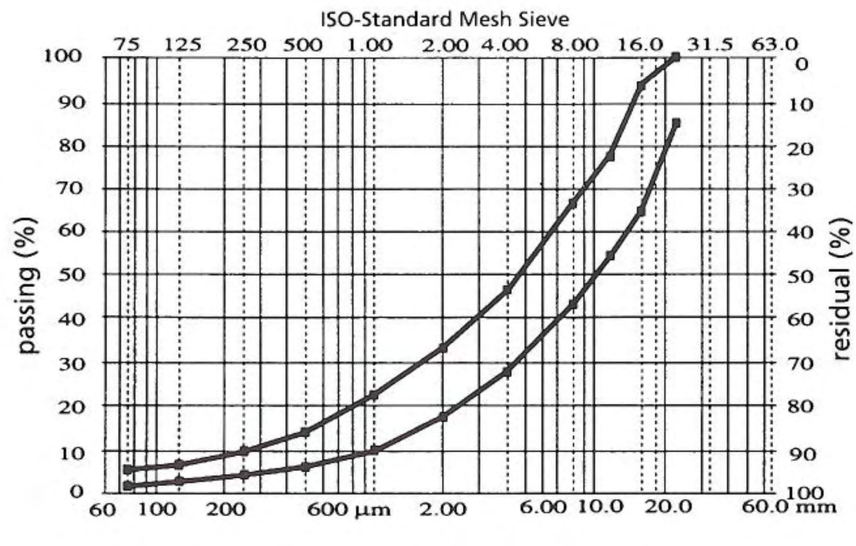


Figure 4.8 Recommended Envelope Curves for Gravel Emulsion (Eg32)

Fines Content

Materials which are stabilized by foamed bitumen (Sb and also Bg) are normally produced using aggregate materials with a fines content (<75µm) between 5-15%. One has, however, had good experiences with fines content (<75µm) between 2-20%. In addition, the amount less than 2 mm should comprise a minimum of 30%. When comparing costs of stabilizing different aggregate materials, it should be taken into account that the required binder content increases with the fines content.

Mixes based on bitumen emulsion (Eg and also Bg) are usually produced using aggregate materials with a fines content (<75µm) between 1-7%. The amount less than 2 mm should also comprise a maximum of 20%.

The fines content is of significance both for the selection of binder type and penetration grade, see further details in Chapter 4.4. Variation in the fines content is one of the most common causes of problems with production of gravel emulsion.

Maximum Stone Size and Amount of Coarse Aggregate

The maximum stone size and amount of coarse aggregate are important with regard to mix compaction and abrasion on equipment used for production and laying. For plant mixing, it is easy to screen out oversize materials to comply with recommended envelope curves. Problems with large stones are therefore first and foremost connected to in-situ milling and stabilization of existing roads.

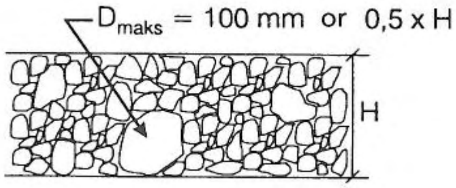


Figure 4.9 Maximum Stone Size for Base Materials

Due to abrasion on the milling equipment, maximum stone size should not exceed 100 mm, and the amount greater than 64 mm should not exceed 20-50%. In addition, the largest stone size should not exceed half the thickness of the bitumen stabilized base course. Addition of virgin materials must be evaluated if the gradation does not comply with recommended envelope curves. Milling without addition of binder followed by removal of large stones may be used. The latter, however, is laborious and costly.

Mineralogy and Humus

Mineralogy is of particular importance in connection with the use of bitumen emulsion. The emulsion must therefore be adapted to the aggregate and the production process, see Chapter 4.5 "Selection of Emulsion Composition".

Humus can result in uneven curing of bitumen emulsions. Aggregates containing humus should therefore preferably be avoided. However if such aggregates are used, the binder content probably has to be increased. This must be taken into consideration when comparing costs connected to the use of different aggregates.

The amount of humus in aggregates will in most cases vary. However, during production one does not usually have the opportunity of varying the binder content according to the humus content. Humus in the aggregate materials will therefore, in practice, often lead to a variable mix quality. Aggregates containing humus should therefore be avoided for all cold mixes.

Mechanical Properties

Requirements for mechanical properties of aggregate materials for Sg, Eg, Bg, and Ep are shown in Table 4.1 and 4.2.

Table 4.1 Mechanical Properties of Aggregate Materials for Sg and Eg

Property	AADT	
	< 1500	1500-5000
Stone Class	1-4	1-3
Flakiness	<1,60	1,50
Ball Mill Value M_v 1)	<19	<19

1) Recommended Values
2) Annual average daily traffic

Table 4.2 Mechanical Properties of Aggregate Materials for Ep

Property	AADT		
	<1500	1500-5000	5000-15000
Stone Class	1-4	1-3	1-3
Flakiness	<1,60	<1,55	<1,55
Portion crushed>4 mm (%)	>85	>85	>85
LA-Value 1)	<30	<30	<30
Ball Mill Value M_v 1)	<19	<19	<19

1) Recommended Values
2) Annual average daily traffic
LA=Los Angeles

Dust Coating

When assessing aggregate suitability for bitumen stabilized base courses, particularly attention should be paid to dust coating on the stones. Dust coating can affect the curing of bitumen emulsion and result in poor adhesion, both for bitumen emulsion and foamed bitumen. This will often be revealed in the mix design when specimens are cured with freeze/thaw cycles, see Chapter 4.6-4.8. For further details on how the problems with dust coating can be reduced, see Chapter 4.3.1, "Crushing of Aggregates".

Amount of Crushed Aggregates
The amount of crushed aggregate is important for among other things, the workability of the mix during laying and the stability of the mix, particularly in the initial phase subsequent to laying. An increased amount of crushed aggregate generally yields better stability and an increased structural coefficient, but can at the same time lead to poorer workability.

Relevant Laboratory Tests
The following laboratory tests can be appropriate when assessing the suitability of aggregates :

- visual assessment (storage, separation, humus, moisture content, coating, etc.)
- determination of amount of crushed/uncrushed surfaces
- determination of particle gradation with wet and dry sieving
- assessment of dust coating
- petrography analysis (visual method)
- amount of weak particles (visual judgment)
- assessment of adhesion (boiling test)
- mechanical properties.

4.3.4 Treatment of Aggregate Samples

General
Mix design in the laboratory should be carried out using the same moisture content in the aggregate materials, as during production. Different moisture content during plant production from that of the design mix reduces the value of the mix design.

In the mix design process, there are two alternatives regarding treatment of aggregate:

- addition of water (without previous drying), followed by splitting of the materials
- drying and splitting followed by recombination and addition of water

Splitting Without Drying
Experience indicates that the properties of aggregates which have been dried, with the subsequent addition of water, may be different from undried materials with the same moisture content. Material samples should therefore be wrapped as soon as possible after sampling to ensure that the natural moisture of the aggregate materials is preserved. Specimen preparation in the laboratory should be carried out by splitting the material in a moist state, in other words without previous drying.

It can, however, be necessary to add more water beyond the natural moisture content for aggregate materials in order to achieve the same moisture content as in the mixing plant. This must be done as described in the following paragraph.

Drying and Sieving
As an alternative to the method described in the previous paragraph, aggregates may be dried and screened. The aggregates are then recombined to the prescribed gradation. Water is then carefully added along the edge of the mixing vat (not directly onto the aggregate), so that any fines on the surface of the stones are not washed away. One then stirs carefully by hand and lets the aggregate materials remain sealed under plastic for 24 hours before further treatment.

Choice of Method
With drying and sieving one has better control over the gradation than with splitting without previous drying. Drying and moistening can, however, change the properties of the materials.

Selection of method for treatment of aggregates depends upon what the aggregate materials will be used for. Splitting without previous drying is recommended for:

- selection of emulsion composition (Chapter 4.5)
- mix design (Chapter 4.6-4.8) if there is dust coating on the aggregates.

Moreover, the treatment of the aggregates must be assessed in each individual case.

4.4 Selection of Binder

4.4.1 Bitumen Emulsion or Foamed Bitumen

Fines Content
Bitumen Emulsion (BE) usually contains 30-40% water, see Chapter 2, "Mix Types". Bitumen Emulsion in combination with a varying fines content can result in uneven curing and low stability of the mix, particularly in the initial period after laying. In addition, the fines will retain water. This may imply increased curing time for the mix. The main rule is therefore that the bitumen emulsion should not be used, if the fines content in the aggregate material is high. For more detailed specifications of limits see Chapter 4.3.3 "Assessment of Aggregates".

Foamed bitumen contains much less water than bitumen emulsion (see Chapter 2, "Mix Types") and does not give rise to the same problems as bitumen emulsions in materials rich in fines. For more detailed specification of limiting values for fines content, see Chapter 4.3.3 "Assessment of Aggregates".

Moisture Content and Precipitation

The moisture content of aggregate materials and climate can be of great importance for the selection of binder. Should the aggregate materials at the outset have a high moisture content and one does not have the opportunity to reduce this through aeration (see Chapter 3.3), the use of emulsion can lead to too high a moisture content in the mix, both with regard to optimal compaction and potential emulsion flow problems. In such cases foamed bitumen is preferable. This is also the case if the climate is wet with a high risk of precipitation during laying. Precipitation can result in instability in the mix.

Economy

Selection of binder type is also an economic question. Usually the binder costs are reduced substantially through the use of foamed bitumen, as compared to bitumen emulsion.

Mix Design

In cases where, on the basis of available production equipment, aggregates, economy, etc., the type of binder is not immediately apparent, mix design should be carried out both with foamed bitumen and bitumen emulsion. The mix design will show if the mix satisfies structural coefficient requirements and other requirements. However, experiences show that in most cases there will not be large differences in the structural coefficient between foamed gravel and gravel emulsion.

4.4.2 Bitumen

General

Selection of bitumen (grade) for cold mixes is described in Chapter 2. In this chapter the following factors related to selection of binder grade will be discussed:

- structural coefficient
- risk of uneven frost heave and uneven settlements
- climatic factors
- production methods
- aggregates
- stability
- workability
- pavement structure
- traffic
- cold mix storage.

Table 4.3 provides an overview of the different factors and how they affect selection of bitumen (grade). This will be commented in detail in the following paragraphs.

In most cases, the penetration grade B370 (at 25°C) will work well. In some cases a softer or harder bitumen is recommended.

Table 4.3 Selection of Binder

Factor		Binder (grade) 2)		
		Soft	Medium	Rigid
Structural coefficient	High	[shaded]	[shaded]	
	Low		[shaded]	[shaded]
Uneven frost heaves/ Settlements	Large		[shaded]	[shaded]
	None			
Climate	Cold		[shaded]	[shaded]
	Warm	[shaded]		
Hauling Distance 1)	Short			
	Long		[shaded]	[shaded]
Stability of Aggregates	Low	[shaded]	[shaded]	
	High			
Fines Content 1)	High			[shaded]
	Low			
Bearing Capacity	Poor		[shaded]	[shaded]
	Good			
Overburden	Little	[shaded]		
	Large			
AADT	High	[shaded]		
	Low			[shaded]
Temporary Storage of Mix 1)	Long Time		[shaded]	[shaded]
	Short/ None			

1) Pertains only to bitumen emulsion
2) Shaded area: the combination should be avoided
AADT (Annual Average Daily Traffic)

Structural Coefficient
Structural coefficient requirements (See Chapter 4.8) are of importance for the selection of bitumen grade. It is recommended, moreover, that one uses as soft a bitumen as possible, within the structural coefficient requirements. This will result in a mix with good workability during laying and high flexibility during the service life of the pavement.

Climate
In the Norwegian design system, the reference temperature for the structural coefficient for bituminous materials is 25°C, and the layer thickness is calculated based on the structural capacity at this temperature. The structural design system does not, therefore, directly take the climate into consideration. To compensate for this, the ambient temperature of the area in question should be considered when selecting bitumen grade.

For colder areas one should, generally speaking, choose softer binder than for warmer areas. Table 4.4 can be used as an aid in the selection of bitumen grade for Eg, Sg and Bg. It can also be helpful to take into consideration temperature changes throughout the year and particularly the temperature during critical periods, such as in the spring when the bearing capacity is low.

Figure 4.10 shows the relationship between E-modulus and temperature. The reference is E-modulus at 25° C. The figure is included to illustrate the significance of temperature for the E-modulus. The results are based on indirect tests of core samples of Sg. The E-modulus at 5° C is for example approximately five times greater than at 25° C.

Table 4.4 Guidelines for Selection of Bitumen Grade for Sg, Eg and Bg

Annual Average Temperature (°C)	Bitumen Grade
< 3	MB6000- 12000
3-6	B370, MB6000-12000
>6	B180-B370, MB12000

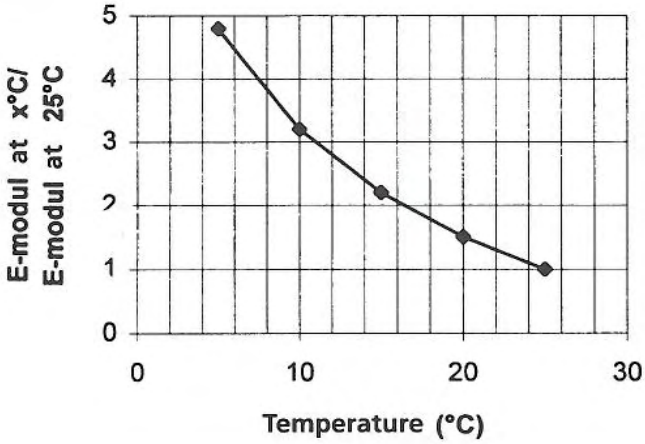


Figure 4.10 The Relationship between E-Modulus and Temperature

Production Method and Hauling Distance

With use of bitumen emulsion, the production method and hauling distance can be of importance for the choice of bitumen grade. Long hauls can result in curing of binder and stiffening of the mix underway. In such cases, one should choose a soft bitumen out of consideration for the workability of the mix during laying.

In-situ production (deep stabilization or use of mix pavers) or short hauls make it feasible to use a somewhat harder binder. For foamed bitumen, the production method and hauling distance are of little importance for the choice of binder grade.

Amount of Fines

For gravel emulsion, the amount of fines will be of great significance for the selection of binder grade because this influences the curing properties of the bitumen emulsion. A high level of fines normally requires softer binder than does a low level, see Chapter 4.3.3. For foamed gravel the fines content is not of such great importance with regard to the choice of binder grade.

The Pavement Structure

When selecting binder grade, one should pay particular attention to the following three factors related to the pavement structure:

- structural capacity of layers below the bitumen stabilized layer
- structural capacity of layers on top of the bitumen stabilized layer
- uneven frost heaves and settlements.

Structural Capacity of Underlying Layers

If the bearing capacity of the underlying layers is low, stiff binders should not be used as this can lead to fatigue cracking.

Overburden

Structural capacity for layers above the bitumen stabilized layer can be of significance for the selection of binder grade. This is particularly the case when the structural capacity of the binder course and the wearing course is low, as for example with the use of surface treatments. In such cases, one should avoid soft binder in the base course, see Chapter 3.1.

Uneven Frost Heaves and Settlements

The risk of cracking caused by uneven frost heaves or settlements should also be considered when selecting binder grade. If there is a risk of uneven frost heaves or settlements, one should use a soft binder.

Traffic

With regard to traffic, the main rule is that stiff binders are preferred on high volume roads, while soft binders are used with moderate and low traffic volumes.

Temporary Storage

Temporary storage of cold mixes should, generally speaking, be avoided. In some cases there will for various reasons still be a need to store the mix for longer periods before use. For temporary storage of gravel emulsion, MB3000 or softer binders should normally be used. For foamed gravel (Sg) temporary storage is feasible, even with penetration grades. For temporary storage it is important that the mix is covered as quickly as possible after production to reduce evaporation and thus retain the moisture in the mix and thereby its workability.

4.5 Selection of Emulsion Composition

Selection of emulsion composition pertains only to gravel emulsion and is carried out after the aggregates have been assessed and found suitable. Selection of emulsion composition includes the following stages:

- Selection of emulsifier
- Selection of emulsion type (amount of binder and water); BE60, BE65, or BE70
- Selection of curing rate, R, M or S.

Emulsion composition and type of emulsifier are selected based on viscosity, homogeneity and storage stability of the binder, binder coverage, adhesion and workability of the mix.

4.6 Specimen Preparation

4.6.1 General

Specimen preparation should include the following phases, see Figure 4.11:

- Selection of moisture content (Chapter 4.6.3)
- Selection of binder content (Chapter 4.6.4)
- Laboratory mixing (Chapter 4.6.5)
- Preparation of test specimens (Chapter 4.6.6)

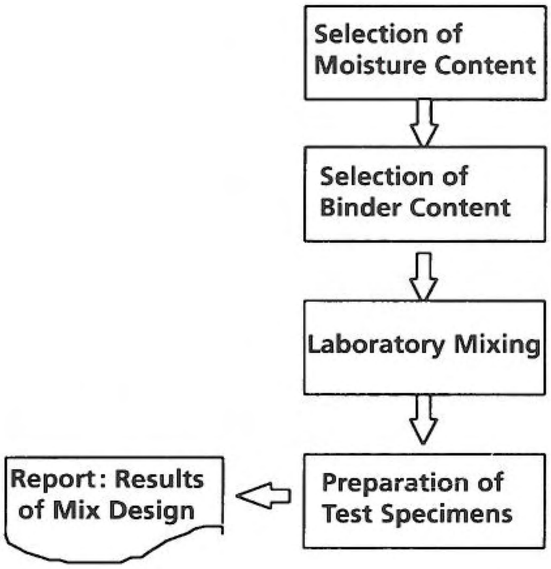


Figure 4.11 Specimen Preparations

For standard mix design, specimens are prepared with varying binder content, while for an expanded mix design, the moisture content also varies, see Chapter 4.1 and 4.6.3. The procedures for curing and testing of specimens are the same for the two methods, see Chapter 4.7 and 4.8.

4.6.2 Equipment

Mix design is carried out by preparing cylinder shaped test specimens to the same size as the Marshall specimens. For this, static compaction or a gyratory compactor can be used. The molds must be perforated so that water can come out. This is of particular importance when making specimens of gravel emulsion.

4.6.3 Moisture Content

General

The moisture content of foamed gravel and gravel emulsion is very important in order to achieve:

- good binder coverage
- good compaction of the mix
- high values for the structural coefficient of the mix

Trial Mixing

Trial mixing should be carried out in the laboratory at different moisture levels. For such tests, the following factors are evaluated for loose, uncompacted materials:

- workability
- binder coverage
- curing

As a rule of thumb one can say that the total moisture content (w) after mixing should be in the area of:

w_{opt} to $w_{opt} - 0.5 \cdot$ binder content (residual)

where: w_{opt} = optimal moisture content (OMC) for non-stabilized materials as determined by Modified AASHTO.

In the following we will look at an example for the determination of moisture content.

Example

Laboratory testing shows an OMC of 7.0% for the combined aggregates. A binder content of 3.0% residual has been selected on the basis of the fines content. The binder is BE 60S (contains 60% bitumen and 40% water). Recommended moisture content in aggregate material before mixing is:

Amount of emulsion:	3/0.6 = 5.0%
Water in emulsion:	5·0.4 = 2.0%
Recommended total moisture content in the mix after mixing:	5.5% - 7.0%
Recommended moisture content in aggregates before mixing:	3.5% - 5.0%

Standard Mix Design

With standard mix design, the binder content is varied and the moisture content is kept at a fixed level.

Expanded Mix Design

With expanded mix design, both the binder content and the moisture content are varied. The moisture content in the specimens is increased successively by 1-2% for each level. The moisture content to start with must be assessed in each individual case, based on among other factors, the fines content of the aggregates.

4.6.4 Binder Content

General
The binder content is determined on the basis of requirements related to:

- structural coefficient (all mix types)
- binder coverage (Eg and Ep), see Chapter 4.8
- minimum requirement for binder content

For further details on the determination of structural coefficient see Chapter 4.8.

Binder Coverage
For Eg and Ep, the requirement for binder coverage is 70 and 50%, respectively. For Sg and Bg there are no requirements on binder coverage.

Minimum Requirements for Binder Content
For base courses with foamed and gravel emulsion (Sg, Eg and Bg) the minimum binder content is 3% (residual). The binder content for foamed gravel and gravel emulsion should to a large extent depend upon the total surface area of aggregates. The greatest contribution comes from the fines.

The binder content for Eg, Sg and Bg should therefore depend upon the fines content (percent). The binder content (P_a) should not be less than:

$$P_a = 0.14 \cdot p_{75} + 2.6$$

where

P_a = binder content (residual)in weight percent (min. 3.0%)
p_{75} = percentage of aggregate material less than 75μm

Figure 4.12 gives the requirements for binder content for different fines content (% material 75μm).

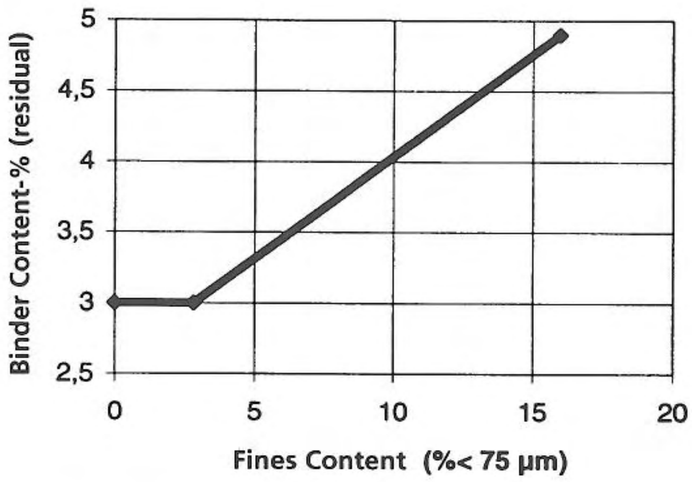


Figure 4.12 Binder content as a function of fines content

Mixing in Old Asphalt

With in-situ milling, it will in some cases be appropriate to mill existing asphalt layers and unbound base course materials in one operation, see Chapter 6.5.2 "In-situ Milling and Stabilization or Plane Milling of Old Asphalt Pavements".

In such cases the mix design should be carried out without mixing in old asphalt and no allowance is made for reduction in binder content. When existing bituminous layers make up approximately 60-80% or more of the mix, the mix design procedure for recycled asphalt (Gja) should be used, see Chapter 4.9.

Number of Test Specimens

Both with standard and expanded mix design, a minimum of three series of test specimens should be made with different binder contents. The lowest binder content is as shown in Figure 4.12. In addition, two test series are made with binder contents of + 0.5% and + 1.0% relative to the minimum binder content given in Figure 4.12.

The number of specimens for each test series should be a minimum of:

- 5 with "Splitting without Drying", see Chapter 4.3.4
- 3 with "Drying and Sieving" see Chapter 4.3.4

4.6.5 Laboratory Mixing

Stones larger than 22.4 mm should be screened out before preparing test specimens, and the percentage of the material larger than 22.4 mm by weight is recorded.

The ideal specimen thickness for indirect tension tests is 50-60 mm with permitted variation between 40 and 75 mm. Sufficient amounts of aggregates are weighed, i.e. 1100-1200 grams. If the shear stress during compacting (applies to gyratory compactors), is used for interpretation of workability, compactability, stability, etc., samples of approximately 1900 g are recommended. This gives a test specimen thickness of approximately 100 mm, which necessitates sawing before determination of indirect tensile strength.

Mixing can be done by hand or in a laboratory mixer. In the latter case, the size (weight) of the batch must be adapted to the size of the mixer. The mixing time is usually 1-2 minutes, dependent upon the fines content and batch size.

4.6.6 Compaction

Both for static and the gyratory compaction, 100 mm diameter is recommended.

Static Compaction

The following procedure should be used with static compaction:

- static load of maximum 8 tons
- the load is increased gradually from 0 to 8 tons within two minutes
- the maximum load of 8 tons is maintained for two minutes
- the specimen is unloaded and demolded

Gyratory Compaction

With gyratory compaction, the CEN procedure which is used for hot mixes, is also recommended for cold mixes:

- 1° angle
- 600 kPa static load (on specimen surface)
- 30 rotations per minute

The following compacting procedure is recommended:

- first a test series with a minimum of three test specimens are compacted using a total of 200 rotations.
- subsequently a new test series is compacted, with a minimum of three test specimens, to 96% of the density of the previous test series (200 rotations)

The latter test series is used to determine the structural coefficient based on static indirect tensile tests.

4.7 Curing

4.7.1 Equipment

A modified freezer may be used for testing of frost resistance, see Chapter 4.7.2. The freezer should be automated and the capacity should be 15-20 specimens in the same batch. The duration of each freeze/thaw cycle is six hours and the total number of cycles is eight.

4.7.2 Procedure

Temporary Storage

The test specimens should be cured immediately after preparation. For practical reasons, however, there may be a need for temporary storage before curing. In such a case, the specimens are treated as shown in Table 4.5. Specimens should in any case not be stored for more than 14 days before curing. During storage the specimens have to be in half plastic pipes.

Table 4.5 Temporary Storage

Time in Temporary Storage	Maximum Temperature	Specimens contained in plastic bags
< 3 hours	Room Temp: 18-22° C	Not necessary
3-12 hours	Room Temp: 18-22°C	Necessary
12 hours-14 days	Refrigator Temp: 2-6°C	Necessary

Curing Procedure

Curing is carried out as follows:

- The specimens are stored in an oven for 7 days at 40° C (dry stor age). An oven with airing is to be used and the air channel must be open during curing. In the event of lack of time, one can with the approval of the Client alternatively cure the specimens for three days at 60° C.
- The volume of the specimens is determined by measuring the height at three places along the periphery and the diameter in two places.
- The specimens are weighed dry.
- The specimens are then exposed to eight freeze/thaw cycles: four cycles per day for two days.
- Each cycle is to be made up of five hours freezing and one hour thawing in water.
- Freezing takes place without water in the vat.
- With freezing, a temperature of -5° to -10° C shall be reached in the middle of the specimen.
- With thawing, cold tap water is to be used.

The freeze/thaw process starts by first freezing the specimens for five hours followed by one hour of thawing in water. The freeze/ thaw process is finished after exactly two days. After the freeze/ thaw process, the samples are immediately placed in a water bath for tempering at 25°C. Should temporary storage of the specimens before curing and testing be necessary for practical reasons, this is carried out as shown in Table 4.5.

4.8 Testing

Equipment
The indirect tensile test apparatus is used for testing of the specimens.

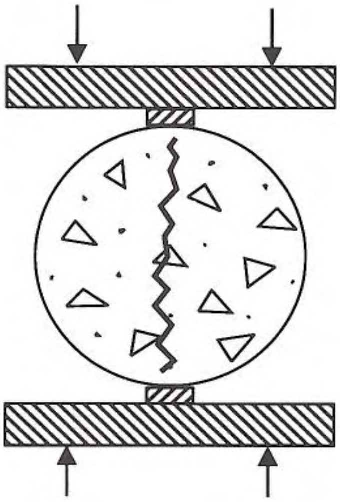


Figure 4.13 Indirect Tensile Test Apparatus

Procedure
The specimens are tempered (wet) in a water bath at 25º C for 30-40 minutes before testing. After this follows mounting in the loading frame. It may be necessary to turn the specimen in order to ensure good contact between the loading strips and the specimen surface.

The deformation rate is constant (2 inch/minute) during the test.The test must be finished within three minutes after tempering has been completed and mounting of the specimen into the loading frame has commenced. During the indirect tensile test, the maximum strength is measured. After testing, the specimens are dried in order to determine the moisture content and the dry density (all pieces have to be collected).

Calculations
Indirect tensile strength is calculated according to the following equation:

$S_t = (636.62 \cdot P_{max})/(t \cdot D)$

where

S_t = indirect tensile strength (kPa)
P_{max} = maximum load at break (N)
t = specimen height (mm)
D = specimen diameter (mm)

The structural coefficient is calculated as follows:

$a = 0.38 \cdot (S_t)^{1/3}$

When laboratory tests have not been carried out, standard values for the structural coefficient shown in Table 4.6 may be used.For determination of structural coefficients in the laboratory, the maximum value is limited to 0.75 units above the standard value in Table 4.6.

Table 4.6 Structural Coefficient

Type Mix	Binder Type	Structural Coefficient 1)
Eg/Sg	All	2,0 1,75 1,5
Bg	All	1,75 1,5 1,25
Ep	B MB>6000 MB<6000	1,75 1,5 1,25
Gja	-	1,5 3)

1) The reference material is subbuse gravel which has a structural coeffisient of 1.0 Underlined values give the standard value, i.e. the standard value to be used when the mix composition is not established.
2) Experiences show that this value is probably too low for current production methods and equipment.

Assessment of Results
When selecting mix composition, minimum binder content and structural coefficient requirements must be met. In addition, thickness and stiffness of other layers in the road structure (see Chapter 3.1) and climatic conditions should also be considered (see Chapter 4.4.2). If several mix compositions meet the requirements, preference should be given to high binder content rather than high structural coefficients.

Reporting
The following results are to be reported:
- grading (including % > 22.4 mm) and moisture content for aggregate materials.
- dry density, moisture content, indirect tensile strength and structural coefficient for each of the specimens.
- average dry density and structural coefficient for each test series (3-5 specimens).

The average structural coefficient is calculated on the basis of mean structural coefficient for each individual test specimen.

4.9 Recycled Asphalt

For cold recycling, the gradation for the milled material should be used as a basis for mix design. In addition, the properties of recovered bitumen are also of interest.

The mix design procedure for cold recycled asphalt equals the one used for Sg, Eg and Bg, see Chapter 4.7.

In addition to static indirect tensile tests, the following laboratory tests may be relevant:

- dynamic indirect tensile tests
- dynamic creep tests
- gyratory compaction
- determination of cohesion build-up
- binder content
- penetration, viscosity/softening point for recovered bitumen
- voids content
- durability

Rutting is often a problem with cold recycled materials. Correct rolling (see Chapter 3.6.2 "Cold Plant Recycling") and proper mix design can reduce such problems.

5 Construction of New Roads

5.1 General

When using cold base course materials for construction of new roads, it is common to use plant mixed materials. Unbound materials may also be transported and stabilized in-situ in mix pavers, see the description of available production equipment in Chapter 3.

Applications

In connection with new construction, cold bitumen stabilized mixes may be applied for:

- upper and/or lower base course
- keying material
- leveling material
- temporary surfacing during the construction stage
- on insulation panels (tunnels).

5.2 Base Course

Layer Thickness

The thickness of the base course is determined through the structural design system, see Chapter 51 in Manual no. 018. In addition, the thickness of the base course should be minimum $2 \cdot d_{max}$ (maximum aggregate size).

H_{max} - 12 cm for Laying and Milling in one Layer.

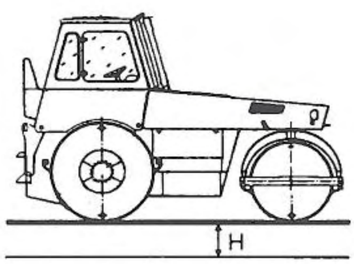


Figure 5.1 Rolling

Laying and Compaction

Laying and compacting in several lifts is necessary for a base course thickness greater than approximately 12 cm. See Chapter 7.4 "Compaction".

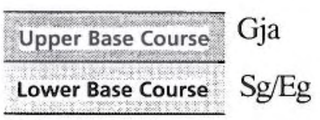


Figure 5.2 Use of different Material Types in Upper and Lower Base Course

Upper and Lower Base Course

Normally, the same type of cold mixes is used in the upper and lower base course. However, it may also be relevant to use different types of materials in these layers for technical or economic reasons. This is particularly true for roads with heavy traffic. In such cases the material quality in the upper base course will normally be better than in the lower base course. The reason for this is that there are more stringent requirements the higher up in the road structure the cold mix is being placed.

For example it can be relevant to combine a lower base course of non-stabilized materials with an upper base course type Sg or Eg. Or one can combine a lower base course of Sg or Eg with an upper base course of Gja or Asphalt Concrete (Ag). See Chapter 51 in Standard no. 018 for selection of material types as a function of AADT (annual average daily traffic).

5.3 Keying

Bitumen stabilized materials can be used for keying of non-stabilized materials (base course and subbase course), as an alternative to unbound materials, see Figure 5.3.

Base courses of unbound materials in combination with bitumen stabilized mix as keying can also be a good alternative to a base course of penetrated macadam (Pp).

Advantages
Bitumen stabilized materials have a range of advantages over unbound keying materials:

- the materials are normally more pliable under laying
- the keyed layer (subbase or base course) is not so easily contaminated (fines brought in on e.g. truck tires and/or produced by construction traffic)
- the keyed layer can be used as a temporary surfacing and is easily cleaned by sweeping or washing before applying tack coat and laying of pavement.

Binder Content
The binder content in the keying mix is usually minimum 2-3% (residual).

Fractions
The most used fractions for unbound base materials are 16-32, 22-63 or 22-80 mm. To key the fractions size 22-63 mm or 22-80 mm, it can be appropriate to use bitumen stabilized materials with a maximum aggregate size of 16 or 22 mm.

Asphalt Recycling
It has become more common to use recycled asphalt with the addition of bitumen as leveling and/or keying material of the subbase course. However, for technical and economic reasons, recycled asphalt should preferably be used higher up in the pavement structure, i.e. in the upper base course, see Chapter 2.6 "Recycled Asphalt".

Example

Figure 5.3 shows an example of the use of bitumen stabilized keying material. The base course consists of aggregates with a grading of 22-63 mm. The stone layer is keyed with a foamed gravel (Sg), produced from aggregates of fractions 0-22 mm. The keying material of 7-8 cm thickness is laid with a road grader and then rolled. The described solution is a good alternative to the use of penetrated macadam (Pp) in the base course.

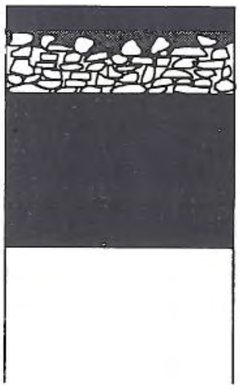


Figure 5.3 Bitumen Stabilized Keying

5.4 Leveling

Cold bitumen stabilized materials are well suited as a leveling material:

- to correct rutting, settlements and unevenness in the wearing course in connection with repaving
- on the base course or subbase course
- to adjust cross slope or roughness (evenness).

The leveling material is used to reduce unevenness of the top layer to be repaved. The use of a leveling course will reduce the thickness of the asphalt overlay which normally is more expensive than the leveling mix.

Fractions

The leveling mix can, for example, be produced by stabilization of 0-11, 0-16 or 0-22 mm. It is not usual to split the aggregate materials into several fractions with the production of cold bitumen stabilized materials for leveling.

Binder Grade

Leveling material is normally relatively inexpensive and can be stored for several years (1-2) if a soft binder is used (MB3000 or softer), see Chapter 4.4.

Material Consumption
Generally, one should use as little leveling material as possible. Material consumption must be adjusted according to the grading of materials to be finished, maximum stone size for the leveling material as well as requirements for evenness of the layer.

Adhesion/Tearing Up
For leveling of a bituminous layer a tack coat must first be applied. For leveling of thin layers, such as surface treatments, one can alternatively tear up or rip the layer of asphalt or it can be milled.

Laying
The leveling course is normally laid with a road grader or an asphalt mix paver. After laying, the cross slope and evenness in the longitudinal direction is adjusted with a road grader. Subsequently, the material is compacted.

Example
An example of use of cold mix for leveling is shown in Figure 5.4. Before rehabilitation there were deep ruts. Therefore the road was leveled before laying of the base course. For practical and economic reasons, the same cold mix was used both in the leveling and the base course.

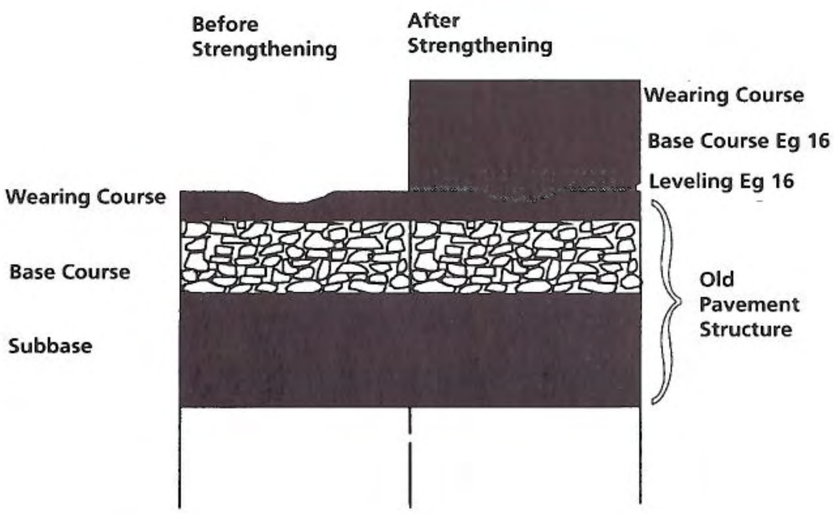


Figure 5.4 Bitumen Stabilized Leveling Material

5.5 Temporary Surfacing

Bitumen stabilized materials used in base course or as keying and leveling, can be suitable as temporary surfacings during the construction stage. Any damage, such as rutting, potholes and raveling must be repaired before laying the next layer.

Cleaning the Road Surface

When using bitumen stabilized materials as temporary surfacing, one can quite simply clean the surface by sweeping and/or hosing before laying the next layer.

Example

An example of use of bitumen stabilized materials for temporary surfacing during the construction stage is shown in Figure 5.5. The subbase course consists of crushed rock, 22-63 mm which is produced by a screening of 22-63 mm fractions from unsorted materials 0-63 mm. A leveling course of foamed gravel (binder content 2.5%) is laid on top of the subbase course. The leveling course functions as a temporary surfacing during the construction stage.

The base course of Sg has a total thickness of 14 cm and is therefore laid in two lifts. The foamed gravel is produced from a 0-22 mm fraction and is to function as a temporary surfacing for about one year. The surface is therefore sealed with BE50R to withstand traffic-loading. Before laying of the wearing course, the surface is leveled with Sg based on fraction 0-11 mm.

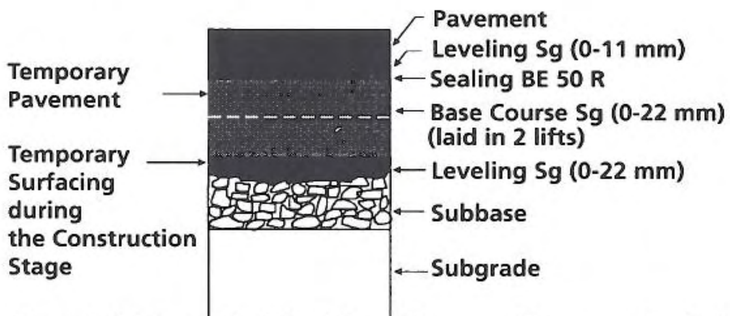


Figure 5.5 Bitumen Stabilized Base Course as Temporary Surfacing

5.6 Insulation Panels

Insulation panels high in the pavement structure are first and foremost used in connection with tunnels. A hot mix or cement stabilized gravel (Cg) is often used as a base course on insulation panels. However, use of cold bitumen stabilized mixes is a good alternative to the above mentioned materials.

When laying hot mix on insulation panels, a leveling course must first be laid to protect the insulation panels from the heat. Cold bitumen stabilized materials can, however, be laid directly onto the insulation panels. Compared to cement stabilized gravel (Cg), cold mixes are more flexible and have better self-healing properties.

Example

Figure 5.6 shows an example of use of a cold mix on insulation panels. The example is taken from a tunnel in the county of Sogn og Fjordane (insulation panels in open terrain should lie a minimum of 30 cm below the surface).

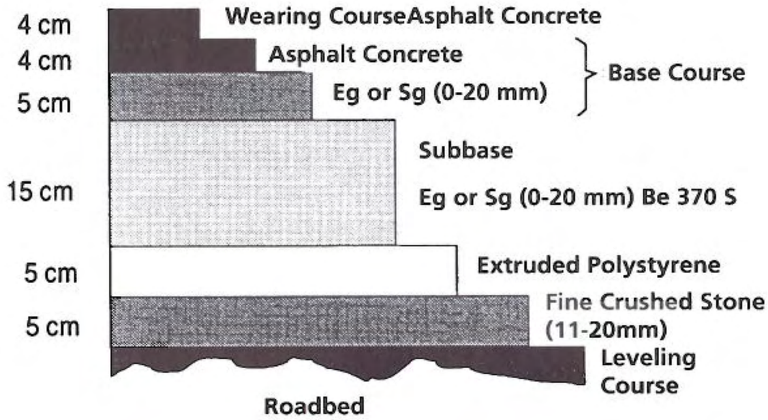


Figure 5.6 Example of use of Cold Materials on Insulation Panels

6 Rehabilitation

6.1 Basic Data

6.1.1 General

For rehabilitation and maintenance of an existing road, one must acquire a range of basic data, such as:

- layer thicknesses and types of materials
- traffic data
- road alignment
- drainage situation
- rutting and evenness development
- bearing capacity
- traffic load allowance
- pavement condition
- pavement service life

This information is necessary to determine the rehabilitation method and strengthening measures. For further details on structural design of strengthening see Standard no. 018.

6.1.2 Materials and Layer Thickness

General

It is important to know the materials and thickness of the layers in the existing pavement structure, in that this provides a basis for determining the strengthening needs. The thickness and grading of the existing gravel base course is of particular importance for milling. Data on variations in layer thicknesses both lengthwise and crosswise must therefore be provided.

To assess whether milling stabilization is suited for rehabilitation, one must have information on the amount of stone larger than 64 mm and the maximum stone size for the materials in the existing road structure. This is important for:

- wear on the milling equipment
- the capacity of the milling machine
- thickness of the bitumen stabilized layer
- the compactability of the mix
- surface evenness
- costs

Limiting values for the parameters mentioned above are specified in Chapter 4.3.3, "Assessment of Aggregates".

Equipment

The layer thickness can be determined for example by DCP (Dynamic Cone Penetrometer) measurements, drilling or excavation. Ground Penetrating Radar (GPR) will in the long run be a useful aid for determination of layer thickness but some development remains before this equipment can be used effectively for this purpose. For determination of maximum stone size and number of large stones, drilling or excavation is recommended.

Measurement Procedure

The sampling interval or frequency of measurements should be assessed based on the condition of the pavement and knowledge about the pavement structure.Excavation every 250 meters is recommended as a standard, but it can be advantageous to increase the frequency to for example one every 100 meters if the pavement structure is not uniform.

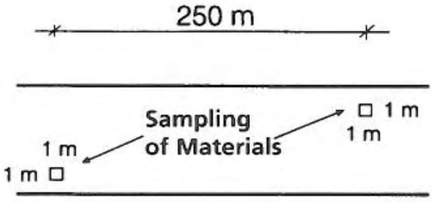


Figure 6.1
Sampling of Materials

Holes for determination of number of large stones should measure 1.0·1.0 meters and be dug to 20 cm below the top of the existing base course. On sections with large local variations in materials and layer thicknesses, one can alternatively also carry out drilling with a tractor equipped with a 10 to 15 cm drill. The advantage of this method as opposed to excavation, is that one can increase the sampling frequency (number of sample holes per km). The method is also cheaper. Such holes provide information on layer thicknesses and depth to large stones. It is also possible to take small material samples to determine gradation, but one must keep in mind that drilling may produce fines. Drilling can be used to determine if a section is suitable for stabilization by milling or not, but is hardly sufficient as the sole method to decide necessary strengthening. In such cases, drilling must be supplemented with excavation.

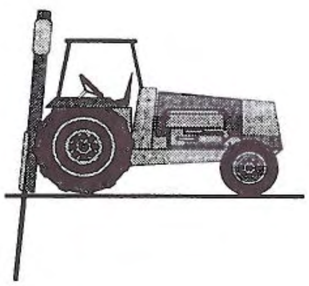


Figure 6.2 Tractor with drill

6.1.3 Supplementary Investigations

In addition to the tests mentioned above, it may be necessary to carry out supplementary measurements such as damage surveys, video documentation, photographs, etc. Useful information can be acquired from persons familiar with local conditions, such as supervisors responsible for road maintenance of the road sections in question.

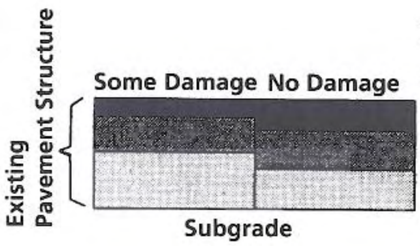


Figure 6.3 Division into Homogeneous Sections

6.2 Homogeneous Sections

Basic data mentioned above are used to calculate necessary strengthening including layer thicknesses. The section in question is then divided into homogeneous subsections. This can for example be based on:

- rate of deterioration, pavement condition and pavement age
- estimated strengthening need
- existing materials
- thickness of the new bitumen stabilized base course
- bitumen type (viscosity)
- binder content of the bitumen stabilized base course
- thickness and type of materials in other layers of the road structure

For division into homogeneous sections, one most also take into consideration the variations in material types, layer thicknesses, material properties, drainage and that the construction is to be run in a rational and practical way. Frequent changes in layer thicknesses and material types can lead to increased construction costs.For further details on basic data and structural design of strengthening, see Standard no. 018.

6.3 Selection of Rehabilitation Measures

Factors of Significance

Selection of type and extent of rehabilitation depends upon a number of factors. The most important are (see also Chapter 1.2 "Costs"):

- strengthening needs
- costs
- expected pavement service life
- available production equipment
- size of job
- the road's future function

In addition to costs, such factors as material availability in the area and hauling distances are decisive for selection of rehabilitation measures.

With the milling equipment that exists today, it is difficult to recycle bituminous layers with steel reinforcement. Use of steel reinforcement must therefore be evaluated in particular. Milling of asphalt layers with geogrids or geotextiles can also cause problems, but not to the same extent as those with steel reinforcement.

Principles for the Selection of Measures
For selection of measures one should try to minimize the total costs over the service life of the road, see Chapter 1. One must also consider whether the measures in question are to be carried out in one or more phases.

Rehabilitation with the use of plant mixed materials or by in-situ milling is described in Chapters 6.4 and 6.5 respectively. It can also prove expedient to combine a milling stabilized material in the lower base course with plant mixed materials in the upper base course.

6.4 Plant Mixed Materials

Suitability
Production of cold bitumen stabilized base course materials in plants or with mix pavers can be a good solution if:

- a nearby quarry with suitable materials for stabilization
- the distance to the closest hot mix plant is long
- the existing road structure does not contain sufficient amounts of suitable materials for milling (in-situ)
- an increase in total thickness of the pavement is acceptable (this often leads to increased road width).

In the following we will look at two examples where plant mixed materials are used.

Example 1
The pavement structure in this example has developed severe rutting.On top there is an Otta seal (comparable to a chip seal but a continous graded gravel is used in stead of chippings). The base course consists of natural gravel with a high content of fines (12% <75 μm), and a high moisture content, see Figure 6.4. It has been concluded that in-situ milling should be avoided. This is due to:

- high fines content (uneconomical because of a high binder consumption)
- it is difficult to reduce the moisture content by drainage measures (high ground water level).

A relevant solution is therefore to tear up or rip the existing surface to prevent pore pressure buildup and then lay a well drained layer of crushed stone on top of the surface.

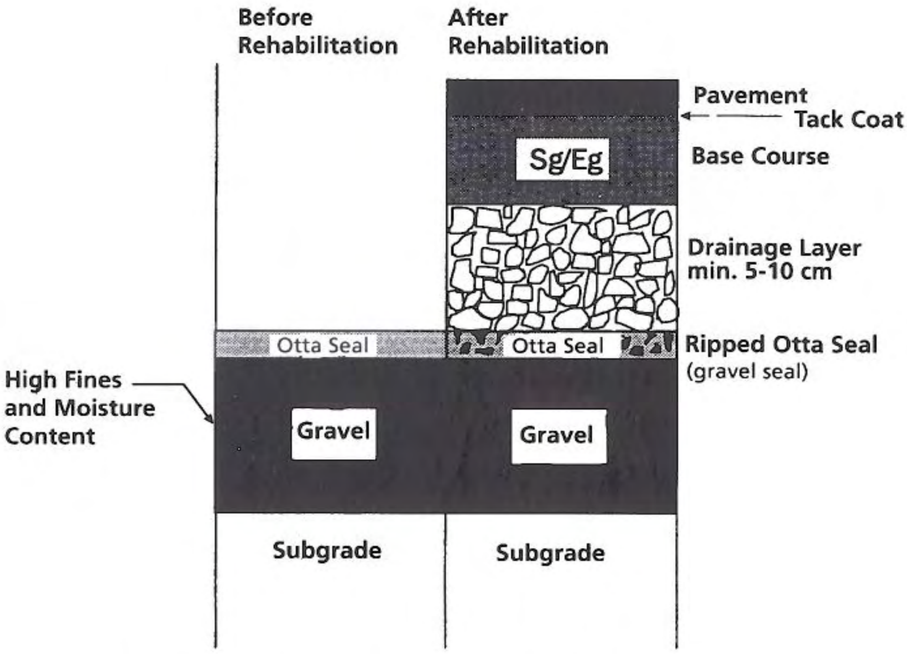


Figure 6.4 Strengthening with Cold Plant Mixed Material

A plant mixed bitumen stabilized base course, type Sg or Eg and a surfacing is laid on top. This will ensure good drainage of the new base course and thus a strength development (curing) as foreseen. The thickness of the drainage layer should be minimum 5-10 cm.

Example 2

In this example the pavement structure has a gravel base course with large stones, see Figure 6.5. The base course is therefore not suitable for in-situ milling. The existing surface drainage is good. Nearby there is a quarry suitable for the production of bitumen stabilized material of the type Sg/Eg. This means a short hauling distance. One has therefore chosen to lay a new base course on the existing pavement structure.

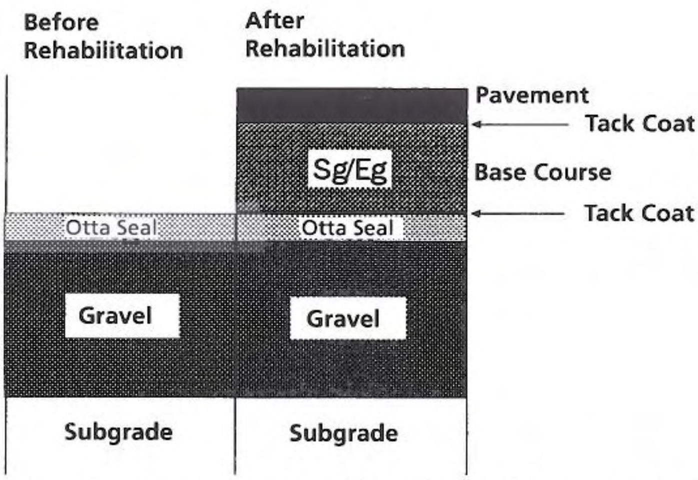


Figure 6.5 Use of Cold Plant Mixed Materials for Rehabilitation

6.5 In-situ Milling

6.5.1 General

Suitability
Repaving is the most common type of rehabilitation. Repaving implies an increased total pavement thickness and often leads to an increased road width. Stabilization by in-situ milling is therefore particularly suited in cases where:

- widening of the existing road should be avoided because of environmental consideration (farm land) or because of extra costs in connection with land acquisition, other connecting roads along the section or adjustment of technical installations such as guardrails.
- one has a shortage of suitable materials for the plant production
- the existing road has a moisture or frost susceptible gravel base course.

If the thickness of the existing unbound layer is insufficient, one must consider adding gravel materials before milling, or choose other measures.

Gravel Base Course
Some years ago, natural gravel was frequently used as base course on low volume roads in Norway. This has resulted in short pavement service lives which can often be related to the gravel base course being moisture susceptible. In-situ milling stabilization is particularly well suited in such cases.

Stabilization by milling of moisture susceptible gravel base course can provide a good basis for the binder and wearing course. This may yield a long pavement service life and low maintenance costs. In addition, the technique allows for good exploitation of resources, in that existing materials are used.

Large Stone
Milling of the existing gravel base course can, however, be a problem if there is a high content of large stones, see Chapter 6.1.2. The limiting values for the amount of large stones and maximum stone size is specified in Chapter 4.3.3. "Assessment of Aggregates". If the existing gravel base course contains too much coarse stone on short sections, it may prove expedient to add new materials before milling, see Chapter 6.5.3 "Addition of Virgin Base Course Materials".

6.5.2 In-situ Milling and Stabilization or Plane Milling of Old Asphalt Pavements

General

In connection with in-situ milling stabilization one must consider whether the existing bitumenous and unbound layers will be milled and stabilized in one or several operations.

The following points are of importance for this question:
- pavement thickness
- asphalt type
- hardness (millability) of the asphalt
- condition of asphalt layer (alligator cracking, cracks and deformations)
- cross slope and evenness of the road
- other application possibilities for recycled asphalt

Milling in One Operation

Milling of the existing bituminous layers together with unbound base course materials in a single operation is recommended when:
- the total thickness of bituminous layers is small (3-5 cm)
- the bituminous layers are thin as with surface treatments
- the bituminous layers are cracked or uneven because of rutting, large deformations, frost heave, etc.

Factors of importance for milling in one or two operations are further described in Chapter 6.5.4.

Plane Milling of Asphalt

It is common to plane mill existing bituminous layers and recycle the materials separately if these layers are thick and relatively even. Emulsion (normally 1-2% residual) can be added to the recycled materials which may be used for keying, base course, temporary surfacing and a binder or wearing course on low volume roads, see Chapter 2 "Mix Types" and Chapter 5 "Construction of New Roads".

Thickness of Old Asphalt Layers

In-situ milling and stabilization of hot mixes with thicknesses greater than 3-5 cm has often proven to result in low milling capacity (progress), see Chapter 3.3 "Stabilization by in-situ Milling". This is related to milling machines used for in-situ stabilization not being adapted to such use. In such cases it can be relevant to tear up the old asphalt layers by plane milling and subsequently stabilize the milled materials and gravel base course in one operation. However, in many cases it is more cost-effective to plane mill the old asphalt layers and apply the recycled asphalt in for example the upper base course. This depends both on the milling equipment and the market price for in-situ milling.

Example

Figure 6.6 shows an example where one has chosen to plane mill the existing bitumous layers and apply the recycled materials (Gja) as an upper base course. The subgrade consists of sand and gravel. The base course materials are made up of crushed gravel (Gk) of 15 cm thickness. The surfacing is asphalt concrete which is 7-8 cm thick. The surfacing is somewhat cracked, but relatively even. This, along with the type of asphalt mix, make the pavement interesting for recycling. The drainage system on the existing road works well.

A relevant rehabilitation measure can therefore be first to plane mill the existing bituminous layers and subsequently stabilize parts of the existing base course. Approximately 6 cm of the existing bituminous layers is removed by plane milling so not to come into contact with the existing base course materials during the first milling operation.

The existing base course materials (Gk) are then stabilized to a depth of approximately 10 cm with the addition of 3.3% binder (residual) in the form of foamed bitumen or bitumen emulsion in accordance with the results from the mix design.

Emulsion (1-2% residual) is added to the recycled asphalt. The material is to be used as an upper base course. For economic reasons, laying of the wearing course is postponed. This means that the upper base course is used as a temporary surfacing or binder course for 2 years. If necessary the surface is sealed before the road is opened to traffic.

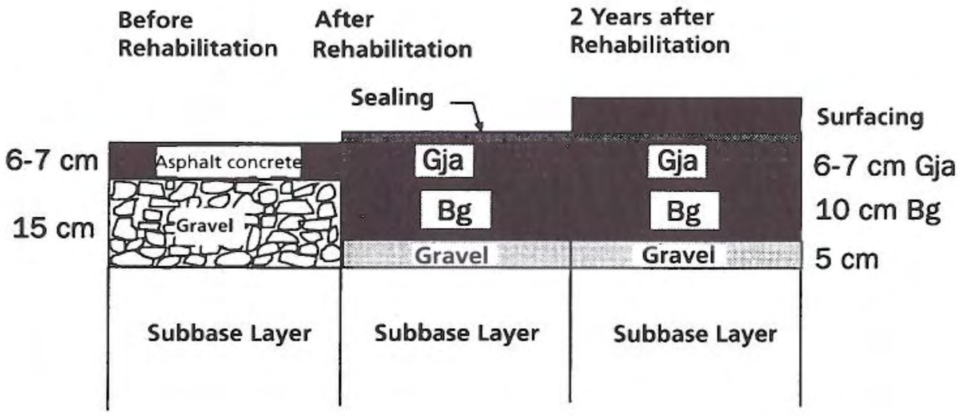


Figure 6.6 Example of Plane Milling

6.5.3 Addition of Virgin Base Course Materials

When to add virgin materials?

Addition of virgin base course materials can be relevant:

- if the structural design shows that materials have to be added in order to attain the specified bearing capacity

- to adjust the grading of the gravel materials in the existing road structure to reduce the moisture susceptibility or to increase the stability of the material.
- to establish the right profile (lengthwise or crosswise)
- to improve drainage of the pavement structure
- if the layer thickness above coarse aggregates is too small in relation to the prescribed milled depth.

Fines Content

For milling and stabilization of existing base course it can be relevant to add virgin materials, depending upon the gradation of the base course. This applies whether the existing gravel base course contains too much fines, is too coarse or uniformly graded, see Chapter 4.3.3 «Assessment of Aggregates».

Old gravel base courses often have too much fines and also sand. With milling stabilization it can therefore be expedient to improve the gradation by adding crushed stone, in that this will increase the stability of the material.

Amount of Coarse Material and Maximum Stone Size

The amount of coarse stone and the maximum stone size set limits on the milling technique, see Chapter 4.3.3 "Assessment of Aggregates". It will therefore be relevant to add virgin aggregate materials in cases where many and large stones are encountered high up in an existing pavement structure and where the thickness of layers with suitable materials is insufficient.

The maximum stone size for base course materials shall not exceed half of the layer thickness, see Standard no. 018. The requirement is set taking into consideration the structural capacity of the layer. It can therefore be necessary to provide additional aggregate to satisfy the requirements.

Longitudinal and Cross Profile

In-situ milling and stabilization does not lead to any significant changes in longitudinal or cross profile of the road. It is therefore necessary to establish the correct longitudinal and/or cross profile before milling. This can be done by laying virgin materials out on the existing pavement structure. Next, the layers should be leveled by a grader to comply with longitudinal or cross profile requirements. The materials should then be milled without addition of binder and finally stabilized in a second milling operation, see Chapter 6.5.4.

Drainage

Good drainage is important for the curing of the bitumen stabilized base course. The need for a separate drainage layer under the bitumen stabilized layer must be assessed on the basis of characteristics of the bitumen stabilized layer (material type, binder content and drainage properties), climate and drainage conditions for the pavement structure.

Addition of virgin materials may be necessary if:

- the groundwater level is high
- the drainage capacity of the existing layer in the pavement structure is too low.

In such cases, a drainage layer of at least 5-10 cm is recommended beneath the bitumen stabilized layer.

Example

Figure 6.7 shows an example where virgin materials have been added before milling and stabilization. Structural evaluation of the pavement has shown that the thickness of the existing gravel base course (Gk) is too small. Moreover, the cross section and longitudinal profile of the existing road is poor. One has therefore chosen to place a new base course of crushed gravel (Gk) on top of the existing pavement structure. The thickness of this layer depends among other things on the bearing capacity of the road and the strengthening required.

The virgin materials which were added are leveled with a grader to establish the correct cross section and longitudinal profile. The materials are then milled and stabilized together with the existing surfacing (Otta Seal) in one milling operation. In-situ milling and stabilization should be carried out to a depth of 3-5 cm below the existing surfacing to ensure that none of the old surfacing remain and because the materials here often have high fines content.

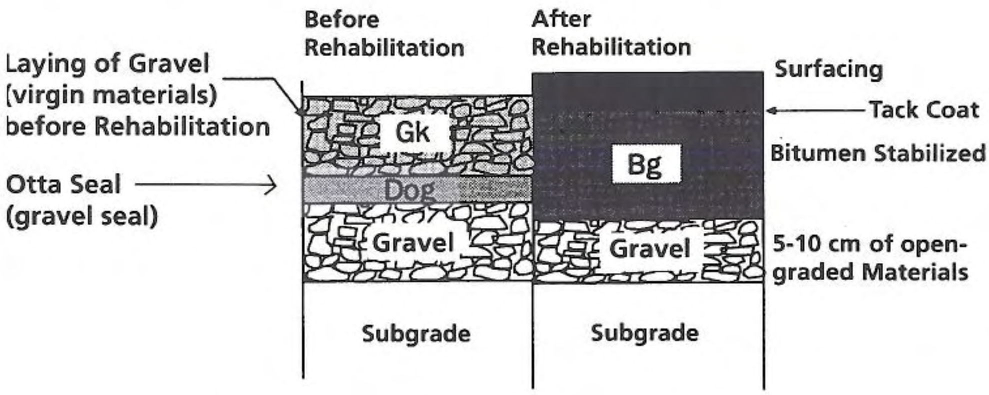


Figure 6.7 Rehabilitation with Addition of Virgin Base Course Materials

6.5.4 Milling in One or Two Operations

Milling in Two Operations

When milling in two operations, the material is normally milled without binder addition in the first milling operation. After this, the correct cross section and longitudinal profile is established with a grader. Finally, the materials are stabilized and milled once more, with addition of binder. The method is used to:

- establish the correct cross section and longitudinal profile
- to adjust the moisture content in aggregates
- to obtain an even thickness of the stabilized layer
- to homogenize the material.

Order of Work Operations

The order of the work operations is as follows:

- addition of virgin materials and milling without addition of binder
- possible addition of water
- grading to establish correct cross section and longitudinal profile
- rolling
- milling and stabilization

Stabilized materials laid with a paver must not be "moved" afterwards with a grader, as this will result in an uneven thickness of the stabilized layer.

Cross Section and Longitudinal Profile

Milling contributes only to a small extent to even out the road cross section or longitudinal profile, see Chapter 6.5.3, "Addition of Virgin Base Course Materials". If the existing road is seriously deteriorated and has an unacceptable cross section or longitudinal profile, one can correct this by the method described in this chapter.

In cases where there is a large need for correction of cross section or longitudinal profile, milling in two operations has clear advantages:

- the layer thickness becomes more even
- homogeneity is improved
- correct cross slope can be established
- the moisture content in the materials can be adjusted (before binder addition).

Moisture Content in Aggregate Materials
The moisture content in the aggregate materials is important to obtain a good binder coverage and a high density during rolling. By milling in two operations, it is easier to add water to bring the moisture content of the material to the right level. However, milling during rainy weather should be avoided because of the risk of too much water in the aggregate materials.

The Thickness of the Stabilized Layer
Milling in two operations gives better control of the thickness of the bitumen stabilized layer. The first milling is done to a depth somewhat greater than the thickness of the stabilized layer (minimum 5 cm deeper). Subsequently, the material is milled and stabilized to the specified depth.

Homogeneity
Milling in two operations normally yields more homogeneous material, compared to milling in one operation.

Unforeseen Factors
Milling in two operations makes it possible to compensate for unforeseen factors which are difficult to ascertain by the standard sampling and excavation procedures. Examples of unforeseen factors may include little or varying thickness of existing gravel base course or unsuitable gradation of the materials.

Economy
Milling and stabilization in one operation is of course cheaper than milling in two operations. The quality of the cold mix (Bg) will, however, often be much better with milling in two operations. This can lead to lower maintenance costs and longer surface service life of the pavement.

Example
Figure 6.8 shows an example where the existing road has a poor cross slope and longitudinal profile. In order to meet requirements, milling in two operations was chosen.

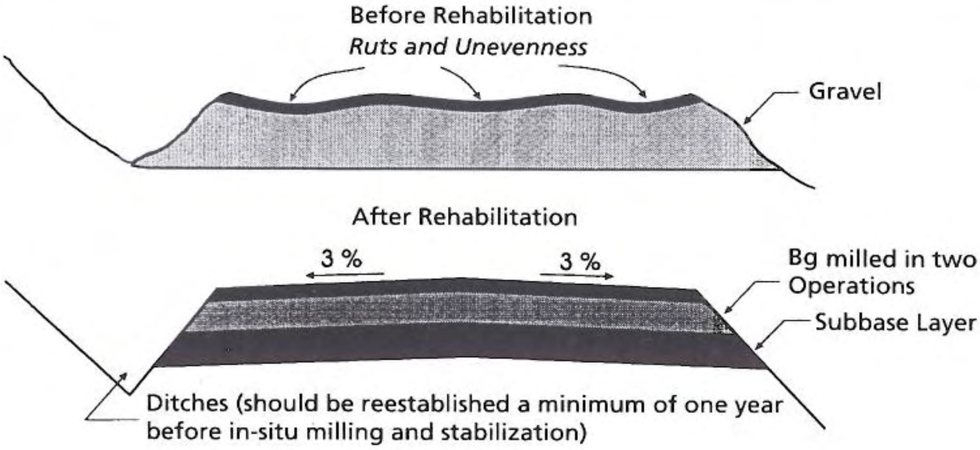


Figure 6.8 Example of Milling in two Operations

Preliminary tests which are carried out indicate that the thickness of the existing gravel base course varies greatly. By milling in two operations, virgin materials may be added between the two milling operations. The need for addition of virgin materials is evaluated during or after the first milling operation.

6.5.5 Practical Execution

In which cases is milling and stabilization to be used?
In-situ milling and stabilization often proves to be appropriate in the following cases:

- low traffic volumes
- if the pavement structure or the surfacing is strongly deteriorated.
- narrow roads
- the drainage is poor
- moisture susceptible gravel base course materials.

Unstable and moisture susceptible base course materials often results in premature rutting, high roughness and short pavement service life.

Drainage
Good drainage of the pavement structure is as previously mentioned important in order to obtain good results with the use of cold bitumen stabilized base course mixes. Upgrading of the drainage system should therefore always be carried out as the first measure in connection with rehabilitation. Because of possible settlements, this should be done at least one year before other measures. In this way one can assess whether improvement of the drainage alone is sufficient or if other measures are called for.

Widening
Many candidate roads for in-situ milling and stabilization are narrow. In general, wide shoulders and good lateral support towards the edges

of the road are desirable. It will therefore be frequently necessary to carry out local widening in connection with rehabilitation. It is, however, difficult to obtain good compaction of such embankment materials. Any widening should therefore be carried out at least one year before other measures, out of consideration for settlements and post-compaction.

Bearing Capacity Across the Road

The bearing capacity is often greater in the middle of the road, compared to on the shoulders, because of reduced lateral support towards the edges. Milling should therefore be done as far out towards the edges of the road as possible to ensure a good bearing capacity across the entire cross section. Such a practice also has other advantages:

- variable settlements caused by different materials in the cross section are eliminated.
- any problems due to different frost penetration and frost heaves in different materials on the road shoulder are eliminated.

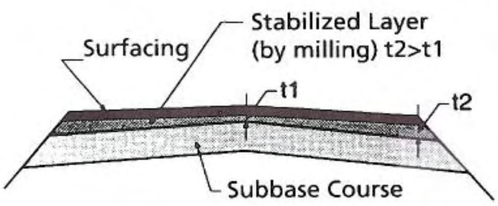


Figure 6.9 In-situ Milling and Stabilization

It may also be relevant to mill and stabilize so that the thickness of the bitumen stabilized layer is greater towards the road shoulders compared to the middle of the road.This is due to reduced bearing capacity towards the shoulders.

To reduce possible edge damage one should consider placing the edge striping further in to discourage driving too close to the edge. This can, however, result in increased rutting due to the channelization effect.

Temporary Surfacing

The bitumen stabilized base course can often function as a temporary surfacing, see Chapter 5.5 "Temporary Surfacing". For how long time depends on traffic, climate, weather conditions during laying and the mix composition. In such cases one should, however, seal or lay a temporary surfacing (slurry or surface treatment) on the base course. Another alternative is to lay the base course in two layers and use a better quality mix (e.g. increased binder content) in the upper layer.

Timing

It is a big advantage to carry out the stabilization early in summer so that the mix is exposed to warm weather and traffic at the early stage of curing, see Chapter 3.2 "Terms for Use of Cold Bitumen Stabilized Materials".

Evenness and Cross Profile

It is important to satisfy the requirements for longitudinal evenness and cross section, as well as cross slope. The correct shape of the

,,,0road crosswise or in the longitudinal direction must be established before in-situ milling and stabilization. This can be done as described in Chapter 6.5.3 "Addition of Virgin Base Course Materials" or Chapter 6.5.4 "Milling in One or Two Operations". The method is selected on the basis of the thickness of the existing gravel base course. It is, therefore, important to investigate the thickness variations both in the cross section and the longitudinal direction of the road. Combinations of the two methods can also be used.

7 Quality Assurance

7.1 General

Inspection Types
The quality of cold bitumen stabilized base course is to be assured by:

- inspection by the contractor during start up and regular operational inspections
- inspections by the Client in the form of visual checks, random tests and post-inspections.

This chapter covers inspection by the contractor. For further details on regular operational inspection, see Standard no. 018.

The inspections described in the following are to be understood as recommendations. Local factors may require more or less frequent inspections than described here.

Start Up Inspection
Start up inspection should be carried out for at least the two first days.

Start up inspection covers geometry, evenness, compaction and binder content, while regular operational inspection also includes material properties and structural coefficient.

Test results are evaluated consecutively during the start up inspection. If results show large deviance from specifications, the production should be adjusted. It is recommended that at least three samples are analyzed before adjustments are made. After the final adjustment the average of the last five individual tests in the start up inspection must satisfy the requirements.

If the mix does not comply with the given specifications, but nonetheless seems to be satisfactory, the Client can decide that the mix recipe should not be adjusted and start up inspections terminated.

7.2 Material Properties

Table 7.1 shows the testing frequency for aggregates and binders for cold bitumen stabilized base course mixes. For Bg there are, however, no requirements for the aggregates.

Table 7.1 Material Properties and Inspection Type

Inspection of	Mix Type	Inspection Type	Number of Samples
Mechanical properties of aggregate	Sg, Eg Ep	Operation	1 per $5000m^3$
Flakiness	Sg, Eg, Ep	Operation	1 per $5000m^3$
Binder	Sg, Eg, Bg, Ep	Operation	Min. 1 per delivery and month

7.3 Geometry and Evenness

Inspection of geometry and evenness includes:

- layer thickness
- height
- width
- evenness of the cross section
- evenness in the longitudinal direction

Inspection frequency for geometry and evenness is shown in table 7.2 in terms of the number of tests per 500 meter two lane road, while Tables 7.3 to 7.5 give the respective tolerances..

Table 7.2 Inspection Frequency for Geometry and Evenness per 500 meter Two-lane Road

Type Inspection	Type of Road		
	H 1)	S 1)	A 1)
Start up	10	10	4
Operational	5	5	2

H - Main Roads
S - Minor Roads
A - Local Roads

Table 7.3 Tolerance (mm) for Geometric Requirements and Evenness, Main Roads (H)

Inspection of	Single Value	Average
Height: -max 1) -min.	+30 -30	+7 -7
Width: -max. -min.	+200 -100	+200 0
Evenness in cross section max. 2)	20	+10
Evenness in longitudinal direction, max. 2)	15	+10

1) Minimum number of points in the cross section: 3
2) Measured with 3 m straight edge or other approved equipment.

Table 7.4 Tolerances (mm) for Geometric Requirements and Evenness, Minor Roads (S)

Inspection of	Single Value	Average
Height: -max. 1) -min.	+35 -35	+10 -10
Width: -max. -min.	+200 -100	+200 0
Evenness in cross section max. 2)	+20	+10
Evenness in longitudinal direction, max. 2)	+20	+10

1) Minimum number of points in the cross section: 3
2) Measured with 3 m straight edge or other approved equipment.

Table 7.5 Tolerances (mm) for Geometric Requirements and Evenness, Local Roads (A) and Pedestrian/Bicycle Roads

Inspection of	Single Value	Average
Height: -max. 1) -min.	+40 -40	+15 -15
Width: -max. -min.	+200 -100	+200 0
Evenness in cross section max. 2)	+20	+15
Evenness in longitudinal direction, max. 2)	+20	+15

1) Minimum number of points in the cross section: 3
2) Measured with 3 m straight edge or other approved equipment.

7.4 Compaction

Cold bitumen stabilized materials should be compacted immediately after laying. The compacting requirement is given in the form of method specifications. This means that there are requirements for:

- total fluid content (binder and water) in the mix
- type of roller
- maximum layer thickness in one lift.

In addition, rolling tests must be carried out (trial sections) for determination of the optimum number of passes. The method which is described in the Appendix , is used for Eg, Sg, Bg and Gja.

7.5 Binder Content

The binder content is determined by measuring the binder consumption and by taking samples of the mix from the plant or the road at the construction site.

7.5.1 Binder Consumption

Inspection frequency and tolerances for binder consumption are given in Table 7.6. The consumption is measured during a shift by reading off the volume of binder at start up and after the shift (max. 24 hours) is finished. This method can be used both with plant production and with in-situ milling. The read off (volume) is then related to the amount of stabilized dry materials for calculation of binder content. Allowable deviance from the specification is 0.2% by weight.

Table 7.6 Inspection Frequency and Binder Consumption Tolerances, (Consumption per Shift)

Mix Type	Inspection Type	Tolerance, percent binder content byweight
Eg, Sg, Bg, Ep	1 test per shift	-0,2

7.5.2 Binder Content

The binder content is to be determined by taking samples at the plant or from the stabilized base course on the road. If existing bituminous layers are mixed in during in-situ stabilization, the binder content should be adjusted according to the contribution from these layers. This can be done on the basis of the binder content in the "old asphalt" and the amount of recycled asphalt compared to the total mix. The inspection frequency and tolerances are given in Table 7.7 and 7.8 respectively. The binder content is to be determined by the extraction test.

During in-situ milling (production of Bg) one must make sure that all binder nozzles are open. It should also be checked that the nozzles provide approximately the same amount of binder. This should be done at start up and at regular intervals during production.

Table 7.7 Inspection Frequency for Binder Content, Eg, Sg, Bg and Ep

Inspection Type	Inspection Frequency
Standard Start Up1)	- min. 10 samples over the 2 first days of production 2) - min. 1 sample per 300 tons 2)
Simplified Start Up 1)	- min. 2 samples per 800 tons 2) or - 2 samples per 2,500m.road (in mix paver width) 2)
Operational	- min. 1 material samples per 800 tons or - 1 box sample per 2,500 m road (in one paving width)

1) Start up inspection shall last for a minimum of 2 days, see Chapter 7.1

Table 7.8 Tolerances for Binder Content, Eg, Sg, Ep and Bg

Production Method	Tolerance, percent (binder content, by weight)			
	Single Value	Mean with Multiple samples		
		2	5	10
In-situ Milling	±1,0	±0,7	±0,6	±0,5
Plant	±0,6	±0,5	0,4	±0,3

7.6 Structural Coefficient

Before the job starts up, the contractor has to provide information on the structural coefficient of the mix on the basis of test results from mix design. In most cases the indirect tensile test is used to determine structural coefficient.

In addition, samples must be taken during production, see Table 7.9 and 7.10. The structural coefficient has to be determined for every 5000 tons. It is calculated as the average of three parallel samples. The average structural coefficient for the samples should be as specified, and none of the samples should have a structural coefficient lower than the specified limit in Table 7.10.

Table 7.9 Inspection Frequency for Structural Coefficient, Eg, Sg, Bg and Ep

Location	Inspection Type	Per Quantity Unit	Min.numbers of Samples
			H, S, A
Production Site	Operational	5000 tons	3

Table 7.10 Tolerances for Structural Coefficient

Material Type	Allowed Deviance on Structural Coefficient	
	Single Value	Average of 3 Samples
Bg	-0,30	-0,0
Sg, Eg, Ep	-0,15	-0,0

APPENDIX

Compaction Control

A-1. Introduction

This Appendix describes compaction control of cold bituminous materials used in base and wearing courses.

Compaction control involves laying of test sections. The number of such sections are determined by the size and type of project (see Chapter A-4). The optimum number of passes and compaction requirements are ascertained by undertaking rolling tests for each individual homogeneous section.

To ensure adequate compaction, roller type and maximum lift thickness must be specified.

A-2. Equipment

Nuclear gauges are used for compaction control. Calibration data for nuclear gauges is frequently gauge specific. Therefore the same nuclear gauges should be used on the test sections as with regular operational inspection.

A-3. Division into Homogeneous Sections

Prior to rolling the road should be divided into homogeneous sections. This should be done based on factors that may affect compaction and the density of the bitumen stabilized layers. Compactability is primarily affected by the following:

- thickness of the bituminous layer
- binder content and grading curve

Other factors may have an impact on the density such as the stiffness of underlying layers.

Should any of these factors change, a new homogeneous section must be established and additional rolling tests undertaken.

A-4. Control Categories

The following rolling tests are relevant for compaction control of cold mixes:

- test section A: rolling test to ascertain optimum number of passes
- test section B: rolling test to establish compaction requirements

Which rolling tests to be undertaken depends on project category. The following categories have been defined:

- patching, repairs and minor jobs
- in-situ milling
- plant production

Table A-1. Category and Scope of Controls

Category	Scope of Controls
Patching, repairs and minor jobs	Rolling tests not required
In-situ Milling	Rolling test A shall be undertaken
Plant Production	Rolling test A and B shall be undertaken

With patching, repairs and minor jobs rolling tests are not necessary. In such cases the number of passes may be based on past experience or Table A-2.

Table A-2. Number of Passes with Patching, Repairs and Minor Jobs

Layer Thickness	Number of Passes
<5 cm	6
>5 cm	10

With in-situ milling only test section A is necessary to find the optimum number of passes, see Table A-1. Later, during regular production, the optimum number of roller passes determined from test section A should be used. When using plant mixed materials the following two test sections are required:

- test section A to ascertain the optimum number of passes
- test section B to establish compaction requirements

This is elaborated on in Chapters A-6 and A-7.

A-5. Locating and Laying of Test Sections

Test sections should be located such that they are representative of the corresponding homogeneous section as a whole.

No roller turns should be made on test section A and B. To allow for roller turns between the test sections, the spacing should be at least 20 m, see Figure A-1.

Rolling should be undertaken with no more than 10 cm sideways overlap. To avoid measurements being taken in overlapped areas, these surfaces should be marked immediately after rolling with spray paint.

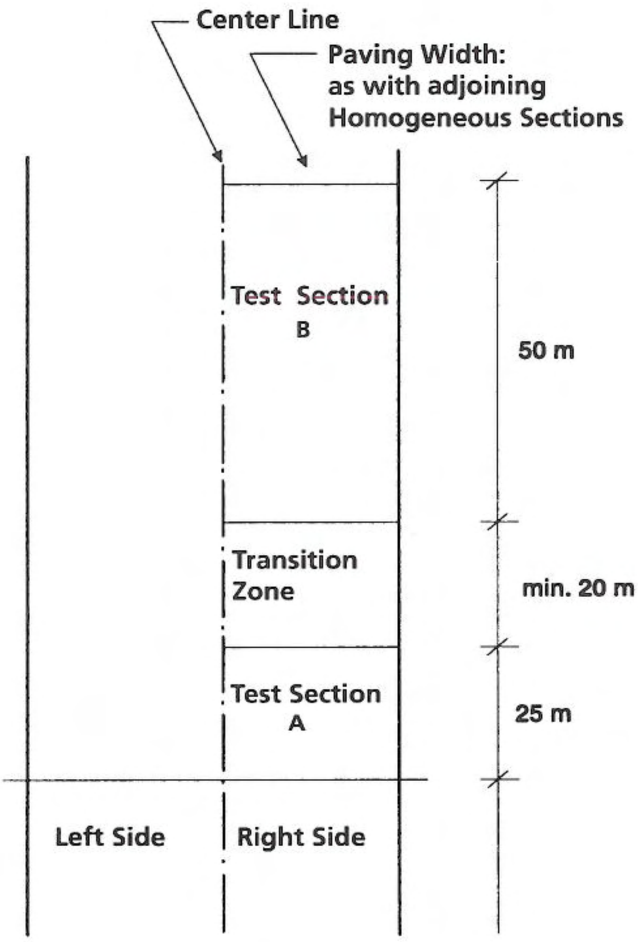


Figure A-1. Test Section A (optimum number of roller passes) and Test Section B (compaction requirements)

A-6. Optimum number of Passes (Test Section A)

Test section A is used to determine the optimum number of roller passes.Test section A shall be 25 m long, see Figure A-1. Measurements shall be taken after the second, fourth, sixth etc. roller pass. The optimum number of roller passes N_{opt} is normally determined as the number required to reach maximum density. In some cases there will be no clear maximum value. N_{opt} is then attained as when the density increases less than 1% compared to the previous reading. To make a best estimate of the maximum value, rolling should continue until $N_{opt} + 4$.

In addition to density readings, a visual inspection of the cold mix must be done during rolling. As a general rule the optimum is reached when water appears on the surface or when surface cracks are formed.

The density should be measured at three points for each test section. The measuring points shall be distributed evenly over the length and width of the test section and located where the road surface is as even as possible. Areas with sideways overlapping must be avoided, see Chapter A-4.

A-7. Compaction Requirements and Tolerances (Test Section B)

Test section B is used to determine compactive requirements and tolerances as related to desity. Test section B shall be 50 m long, see Figure A-1. The test section shall be rolled immediately after laying. Rolling shall be undertaken continuously using the optimum number of passes as determined from test section A (Chapter A-6). After rolling of the test sections has been completed, density measurements shall be undertaken.

Density measurements shall be made at six points distributed evenly over the length and width of the test section and placed where the road surface is as even as possible. Areas with sideways overlap shall be avoided, see Chapter A-4.

Surface leveling with filler material before taking readings is not necessary. An average value is estimated based on these readings. Results from test section B form basis for estimating the compaction requirements and tolerances shown in Table A-3.

Table A-3. Compaction Tolerances

Design Criteria 1)	Average Value 1)	Single Value 1)
93 %	94 %	91 %

1) Percent of average reading from test section B.

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