Pavements and Maintenance of Pavements for Low-Volume Roads in Finland

Mats Reihe, *Finnish National Road Administration*
Laura Apilo, *Technical Research Centre of Finland*

Oil gravel has been the most commonly used pavement material for low-volume roads in Finland. There are 22 000 km of oil gravel pavements. The binder in oil gravel contains volatile hydrocarbons. From 1 km of oil gravel, about 1000 kg of solvents evaporate over the life of the pavement. Environmental concerns have become increasingly important, and Finland is under contract to reduce the amount of evaporated solvents by 30 percent in this decade. This has created a need for a new soft asphalt mixture, emulsion gravel, with no solvents. Research methods used for mix design of emulsion gravel were studied. The investigation program on emulsified asphalt mixtures included construction of test roads and a large variety of laboratory tests, mainly to find out what material properties might have an influence on pavement behavior. A design method suitable for soft emulsified mixtures was developed. Aggregate and particularly aggregate and binder adhesion properties were studied closely. Stability of different types of mixtures was also determined with the indirect tensile test. For soft mixtures, a bitumen with a viscosity of 1000 to 3000 mm^2/sec at 60°C was emulsified. These types of binders seemed to give the emulsified mixture properties similar to oil gravel. These emulsion gravel mixes could be stockpiled, and the pavement could be scarified at the surface years after paving. Harder emulsified binders were used and recycled mixtures were made. The construction of emulsion gravel roads has increased rapidly. Recently, the maintenance methods suitable for oil gravel roads, especially new remixer machines, have been developed in Finland. There are two different remixer methods that are very economical. The stabilization of old oil gravel roads has increased rapidly. For stabilization, foam-bitumen and emulsions are used. The stabilization is economical and natural materials are saved. Maintenance methods used for oil gravel are suitable also for other soft pavements, for example, emulsion gravel.

Finland is a vast country with low population density—15 inhabitants/km^2, on average. Hence, the low-volume roads account for a very high percentage of Finland's total road network. There are 77 000 km of public roads 60 000 km of which are low-volume roads with average daily traffic (ADT) < 1,000 vehicles per day. To ensure the needed access for industry and inhabitants, a proper road network is important, even in areas where ADT is less than 1,000 vehicles. The requirements for low-volume roads in Finland dictate that construction and maintenance be economical. Also, the limitations and requirements of construction under cold region conditions, as well as other environmental aspects of low-volume roads, should be taken into account in road design.

The Finnish low-volume roads are classified according to pavement as shown in Table 1. The most common low-volume road pavement is oil gravel, which has

TABLE 1 Type and Percentage of Finnish Low-Volume Roads

Pavement	Length (km)	%
Oil gravel	22,000	37
Asphalt concrete	5,300	9
Surface dressing	3,500	6
Emulsion gravel	200	0,00
Gravel	29,000	48
Total	60,000	100

been in use for 35 years. Annually 1000 to 2000 km of new pavement are constructed. Asphalt concrete is the oldest type of pavement in Finland and has been used for more than 50 years. Currently, asphalt concrete is used for high-traffic roads. Surface dressings have been done for 20 years, but very little is done on an annual basis. Emulsion gravel is a new type of pavement that is suitable for low-volume roads. It has been used in Finland for the last two years, and the amount of emulsion gravel used is increasing.

Selection of the type of pavement in Finland is based on ADT as shown in Table 2.

Production and Construction of Pavements

Oil Gravel

Oil gravel is an exclusively Scandinavian soft pavement specialty not used elsewhere. The aggregate used in oil gravel is continuously graded crushed material with low filler content (Figure 1). There is less fine aggregate compared with hot-mix asphalt. Less bitumen is required to coat the aggregate satisfactorily. Road oil is used as a binder and the binder content is usually 3.5 percent. In road oil, there is about 8 percent of volatile solvents, which decrease binder viscosity by mixing and evaporate gradually from oil gravel pavement.

Oil gravel has many advantages. In the oil gravel mixing process, the binder is added into cold one-grade aggregate, which reduces the mixing costs compared with hot mixing. The cold mixture is transported by trucks and laid with a paver and compacted with rollers. To produce oil gravel in low temperatures, the binder of oil gravel, road oil, must contain volatile solvents to decrease its viscosity. Oil gravel maintains its flexibility for years. Therefore, it can be used on roads with lower bearing capacity. The pavement is adequately flexible to resist the displacement of road base caused by frost and traffic loading. It is also possible to scarify the surface throughout its life, which reduces the maintenance costs. The softness of the mixture also makes it possible to store the pavement mixture in stockpiles. It can be used cold in patching. Especially in northern Finland, keeping the mixture in stock is important because it extends the operating time of mixing plants by as much as one month.

TABLE 2 Criteria for Pavement Selection in Finland

ADT (vehicles / day)	Pavement type
under 300	Surface dressing
under 1,000	Emulsion gravel or oil gravel
under 2,000	Soft asphalt concrete
under 5,000	Asphalt concrete
over 5,000	Split mastic asphalt

Emulsion Gravel

Low-viscosity binder is essential in the cold mixing process. Instead of heating or blending with petroleum solvents, binder viscosity can be decreased by emulsifying bitumen in water to form bitumen emulsion. In bitumen emulsions, there are no solvents that would pollute the environment. They are not flammable and cause no health risk.

The aim of research on emulsified mixtures was to develop a pavement material that has all the advantages of oil gravel but none of its disadvantages. Environmental factors were especially considered. As a result of research done during 1992 through 1994, two emulsified asphalt mixtures different in their properties were developed. One of the mixtures is like oil gravel; the other is stiffer and more suitable for minor roads with high traffic.

Emulsified asphalt pavement is produced at oil gravel plants, where mixing is done in a batch or continuous mixer (Figures 2 and 3). In Finland, both methods are used. It is possible to connect an aggregate heater to the mixing plant. The aggregate is either divided into two fractions, 0 to 6 mm and 6 to 16 mm, or only a 0 to 16 mm fraction. Divided aggregate improves the quality of mixture to the continuous process. The grading curve is similar to that of oil gravel. The mixture is best when the water content is 2 to 3 percent. Slow setting emulsions are used. The breaking of emulsion must begin while it is in the mixer and should continue during transport and laying. The mixing temperature in cold mixing should be higher than 5°C and in warm mixing 40 to 50°C. The temperature of the binder should be 60 to 85°C. The water content of the aggregate must be at least 2 percent to ensure a homogenous mixture. The maximum allowed amount of water is 6 percent. The residual binder content in emulsion gravel is usually 3.2 to 3.6 percent.

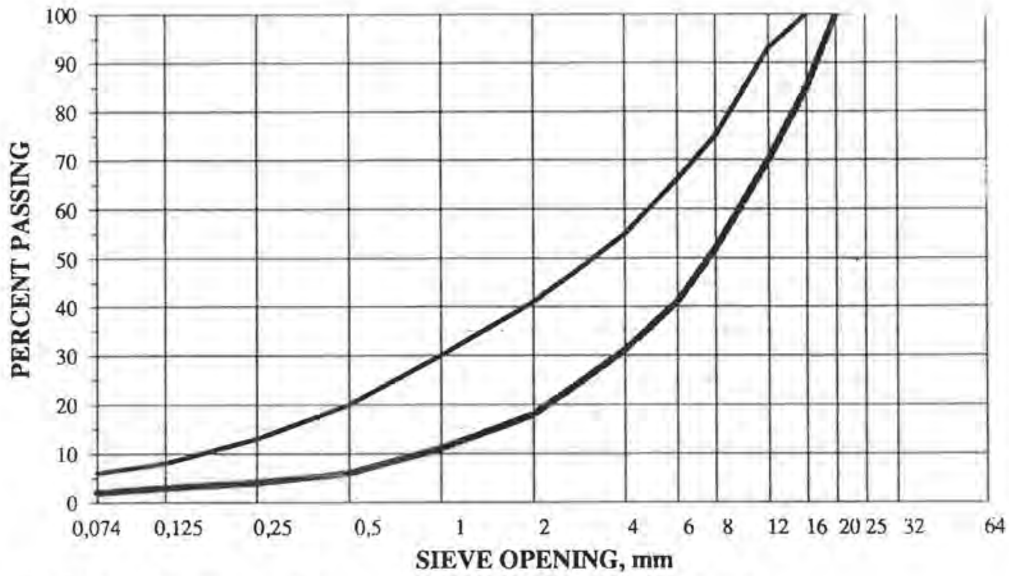

FIGURE 1 Grading envelope of soft mixes used on low-volume roads.

The binder is typically emulsified at the mixing plant just before use to save transport costs and to make the binder most suitable for the existing conditions. Therefore, a mobile asphalt emulsion manufacturing plant is needed. During emulsification, the emulsifier and hydrochloric acid are added. With the amount and type of emulsifier used and the pH-value, emulsion breaking rate can be influenced. The viscosity of emulsion at 25°C is 35 to 170 mm^2/sec. The distillation residue is minimum 60 weight-percent. The viscosity of the bitumen in the emulsion in the thin-film oven test is maximum 6,000 weight-percent in soft emulsion gravel, and maximum 12,000 weight-percent in hard emulsion gravel.

Emulsified mixes made with bitumen with a viscosity at 60°C of 1000 to 3000 mm^2/sec before emulsifying

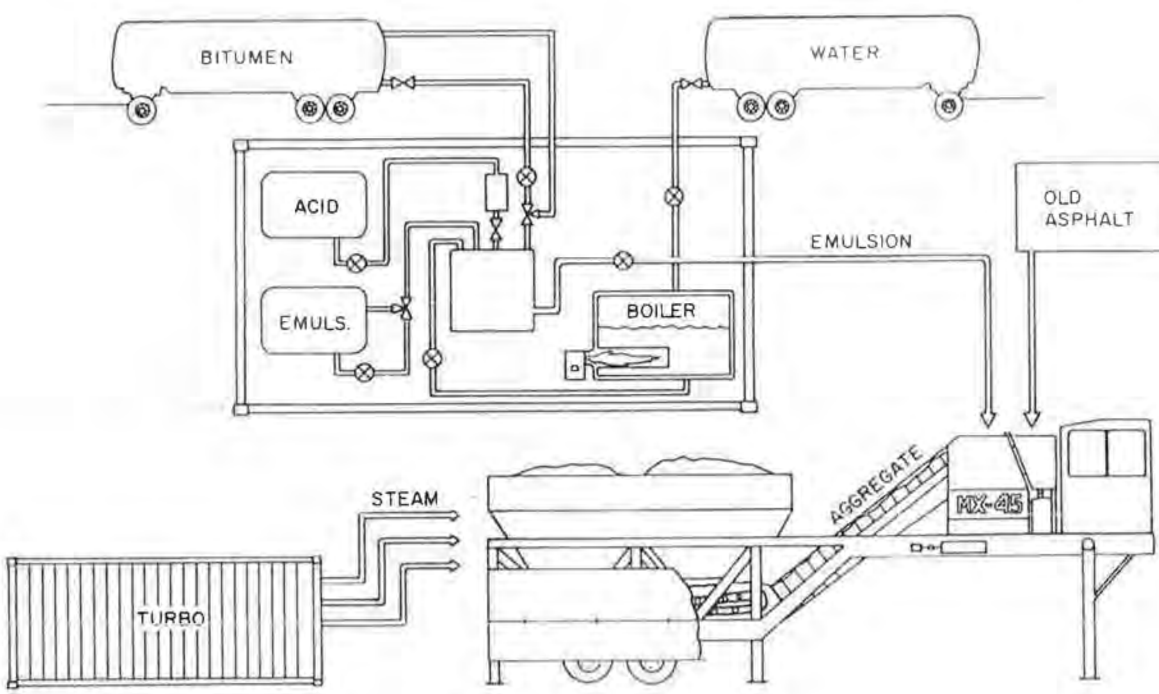

FIGURE 2 Production of emulsion gravel in batch plant.

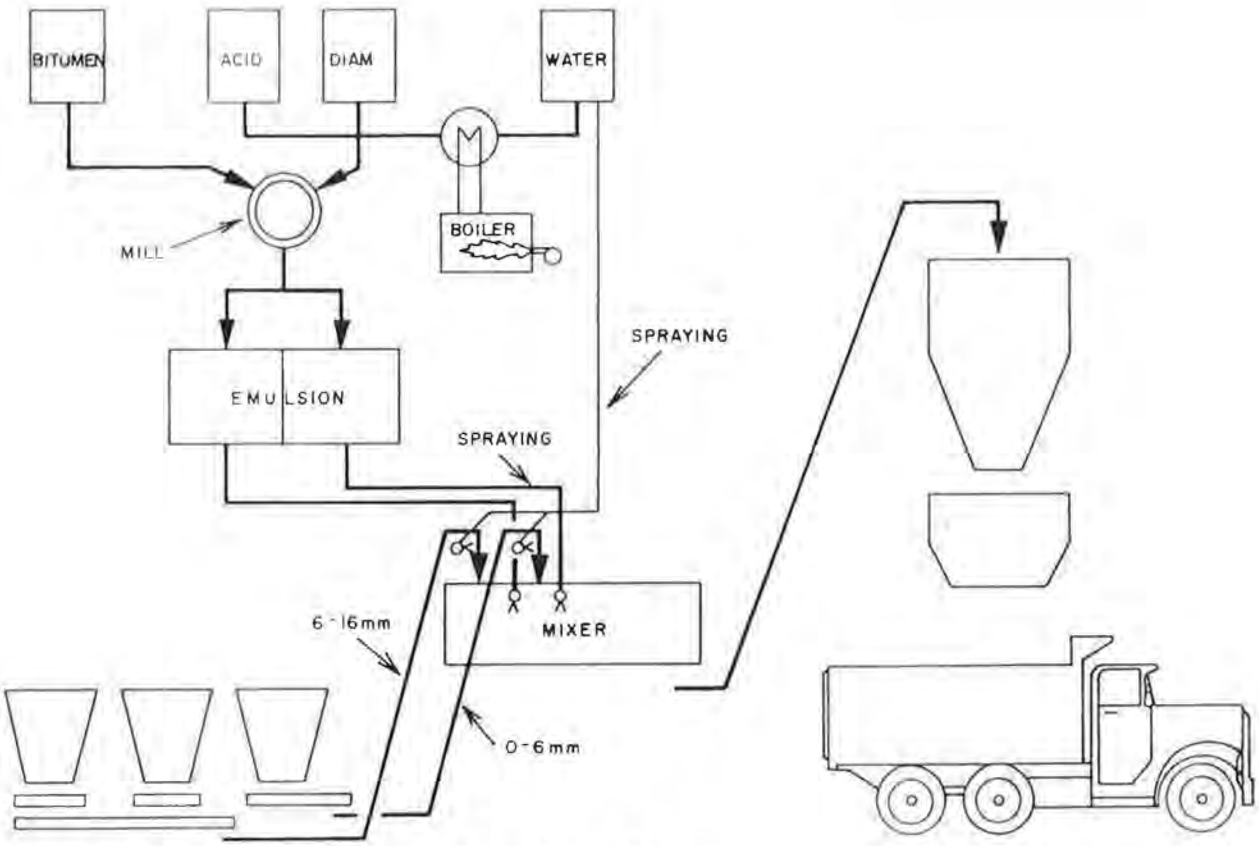

FIGURE 3 Production of emulsion gravel in continuous plant.

are soft mixes. They are suitable for roads where ADT is less than 1,500 vehicles per day. They can be scarified at the surface, stored in stockpiles, and laid on bases, where the lack of bearing capacity causes displacements. Emulsified binder can be added into cold and damp aggregate. Because petroleum solvents are not required in the process, pavement mixture does not cause any hydrocarbon emissions. These factors save the environment and lower the costs compared to use of road oil because no heating is required and a lower binder content is adequate.

The workability of emulsion mixtures becomes worse with increasing stiffness of the emulsified bitumen residue. Breaking of the emulsion has to begin under the mixing process. If breaking is delayed, the emulsion runs off because of its low viscosity and the aggregate remains uncoated. Need for early breaking makes mixing and handling difficult with stiffer binders. Warming of aggregate is necessary when the viscosity of bitumen increases up to 6000 mm^2/sec. A mixing temperature of 40 to 50°C is adequately high for proper coating of aggregate and produces a homogenous mixture. At this temperature, pavements can also be recycled. Compared to hot mixing, there is a significant savings of energy. In addition to energy savings, there is also an environmental advantage. When aggregate is not heated to dryness, there is no need for dust control.

Research was done in the laboratory and the field. In this research, the relationships between different materials, suitability of oil gravel laboratory testing methods on emulsion mixtures, and the influence of field conditions on the mixture properties were investigated. In addition to the laboratory testing, construction of the test roads was a significant part of the research. It allowed verification of results of laboratory tests.

Many variables determine the functional properties of the mixture and the pavement. Mixing temperature and viscosity of binder are very important. The effect of these two variables is presented in Figure 4. Warming the aggregate makes it possible to use stiffer binders. Stiff pavements satisfactorily resist traffic loadings, but they lack workability. The appropriate viscosity for the binder and the mixing temperature should be selected case by case.

Other Pavements for Low-Volume Roads

Asphalt concrete with penetration bitumen and limestone filler can be used, but soft asphalt concrete is more

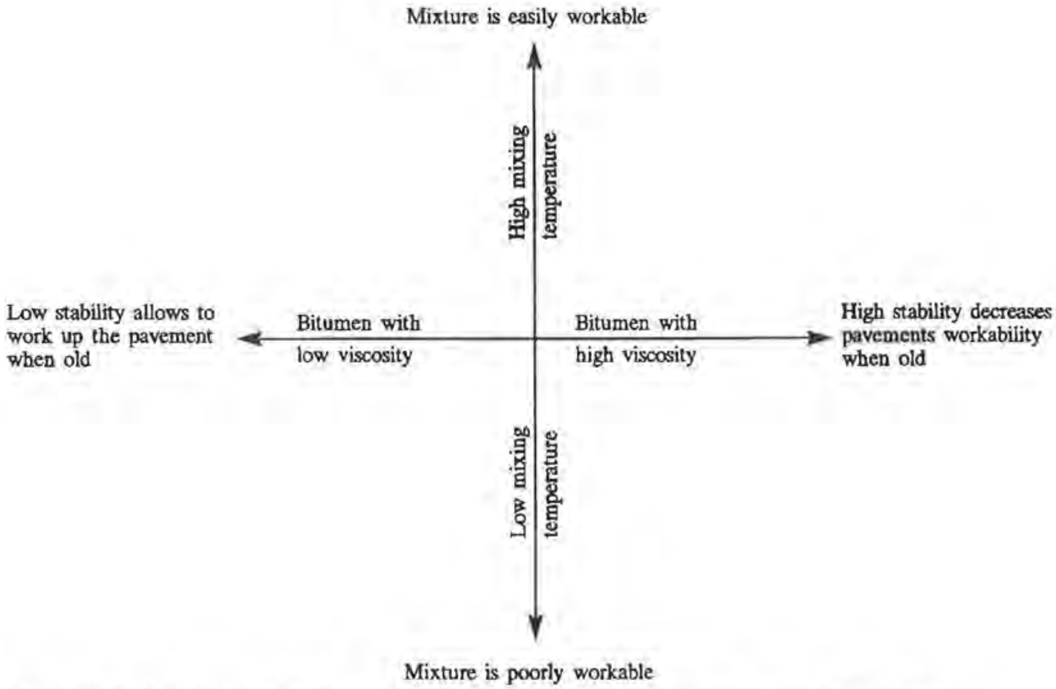

FIGURE 4 Effect of binder viscosity and mixing temperature on mixture and pavement properties.

suitable for low-volume roads. Soft asphalt concrete is produced of soft bitumen without limestone filler.

For roads with very low traffic volume, surface treatments are an alternative to paving.

Design Methods for Emulsion Gravel

The design of soft pavement mixtures was based on volume and compaction properties of the mixture (Table 3). Laboratory design procedures should be as realistic as possible, and they should reflect the field conditions. In proportioning based on volume measurements, the aim is to simultaneously balance the binder content, the voids in mineral aggregate (VMA), the voids filled with binder (VFB), and the void content of the mixture. The binder should be adequate to give the mixture proper stability. Too much binder causes bleeding and increases the cost. In proportioning, the samples with different bitumen content are made. Different grading curves can be tested. Volume and compaction properties are measured and calculated from the samples. This laboratory design procedure is relatively rapid and provides the desired information in a short time.

Selecting optimum binder content is a compromise between different pavement properties. A good mix is achieved, in most cases, with binder content causing VFB of 36 to 38 percent when binder viscosity is under 3000 mm^2/sec. With increasing viscosity, the risk of bleeding is reduced and it is possible to use more binder, resulting in VFB of 45 percent for soft asphalt concrete. The residual binder content of emulsified mixtures is

TABLE 3 Proportioning of Different Mixtures on Basis of Volume and Compaction Properties of Mixture

Property	Soft asphalt concrete	Oil gravel	Emulsion gravel 1,500 mm^2/s	Emulsion gravel 3,000 mm^2/s
Voids filled with binder	40-50%	37-43%	32-38%	37-43%
(optimum)	(45%)	(40%)	(35%)	(40%)
Void content	7-11%	10-14%	10-14%	10-14%
Void in mineral aggregate	18-22%	18-23%	18-23%	18-23%

reached immediately after mixing and does not change with time as it does in pavement mixtures containing volatile solvents.

Compared with paving mixtures with cutback bitumen, the design of emulsified mixtures is more complex. Emulsion mixes contain mineral aggregate, bitumen, and water. There is water in cold aggregate. When the emulsion is broken, the water in the emulsion is set free. Usually this high water content of freshly placed pavement does not cause any problems. It is a problem when void content is too low compared with free water. The stability reduces dramatically, and water and bitumen are pumped to the pavement surface under traffic loading. The critical water content of aggregate should be determined in design. The water content of a fresh pavement can be reduced by shortening the emulsion breaking time.

The most difficult problem in mixture design turns out to be the reliable predetermination of the pavement's water sensitivity. Poor water sensitivity of emulsion pavement causes ravelling. This results in early damage and reduces the pavement's service life. Additives are used to ensure proper bonding between bitumen and binder. Additives, which usually are amines, can be used as an antistripping agent before emulsifying since it is done with binder with solvents. They can also be added as emulsifier. To investigate the optimum content of additives, a reliable testing method with good correlation to field performance is needed.

Water sensitivity was investigated with different laboratory methods. Many water sensitivity tests that are typically used on soft pavement mixtures lack precision because they rely on visual investigation. They often do not simulate the conditions in the field because only a narrow aggregate fraction is used.

The most suitable and reliable method for predicting water sensitivity and providing the optimum antistripping additive content is the tensile test, where the strengths of cured and soaked samples are tested. Water sensitivity is calculated as the ratio of the indirect tensile strengths at 5°C of wet and dry conditioned specimens. The ratio determined has good correlation with the results of test roads. Correlating the tensile strength ratio values with aggregate properties such as specific surface area and water adsorption ability revealed distinct trends.

Durability Properties of Pavements for Low-Volume Roads

The most important factors that influence pavement durability are adhesion between aggregate and binder and stability development shortly after paving. When volatile solvents are used to soften the binder, it takes several years for the pavement to reach its final stability. Emulsified mixes reach their final strength in a short time, which makes them less sensitive to early damage. The difference in stability growth when using emulsions or binders containing volatile solvents is presented in Figure 5.

Many of the desirable properties of soft emulsified mixes are closely related to the stability of pavement. This made it interesting to evaluate the stability shortly after paving and the ultimate stability of different pavements. Table 4 presents the results for pavements with different binders. Binder viscosity is the most important variable to determine strength.

Stability was measured with indirect tensile tests on samples of different ages. The test method provides information about stability development of emulsion mixtures. Knowing the stability development and early damage caused by traffic to pavements, predictions can be made of flexibility and ability to be scarified and stored in stockpiles. The durability of test roads is still unknown, and their service life is difficult to predict. Variations of traffic and different seasons will be monitored for a few years.

Economy of Pavement

The economy of pavement depends on construction, maintenance, vehicle operating costs, and service life. The average 1993 construction costs in Finland are shown in Table 5. The maintenance costs of soft pavements caused by patching or sealing cracks are generally insignificant compared with construction costs. The service life is important. Pavements on low-volume roads usually have a service life of more than 10 years; surface dressing has only about 5 years. The annual costs of surface dressing are high.

Maintenance of Pavements and Selection of Maintenance Method

The maintenance methods for pavements on low-volume roads in Finland are stabilization and paving, milling and paving, remixing, and repaving. The selection of maintenance method depends on the amount and type of deterioration. If the road has significant deterioration caused by the base course, 15 to 20 cm of the road needs to be stabilized. In some cases, crushed aggregate is added before stabilization. Roads are stabilized only where there is significant deterioration. If the deterioration is small, the pavement is milled, shaped with a scraper, and paved. Milled material is used as raw material, which saves environmental and financial resources.

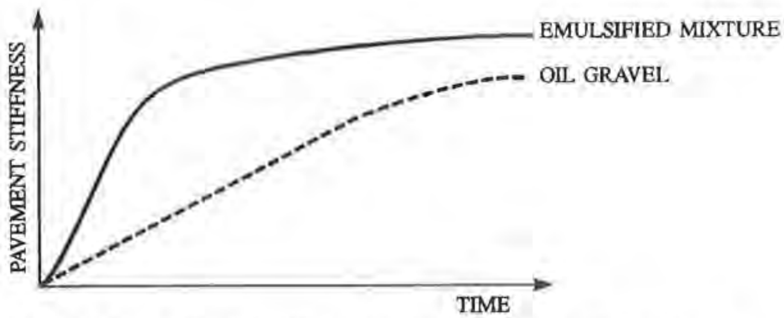

FIGURE 5 Principle of stability increase in pavements containing volatile solvents and emulsified mixtures.

If there is no damage in the base course but significant damage in the pavement, the pavement is remixed. This method is very common and popular in Finland because there are numerous old oil gravel roads. About 40 kg/m^2 of new material is added. The unit price of remixing is about 8 Fmk/m^2. New oil gravel costs about 11 Fmk/m^2; therefore, the remixing is 20 to 30 percent cheaper.

The remixing of oil-gravel pavement is most suitable when the roads have satisfactory shape and bearing capacity and pavement is thicker than 4 cm. The additional material needed depends on the condition of the old pavement and the shape of the road. The use of additional binder is necessary when the binder content of old pavement is definitely less than 3 percent.

There are two remixing methods in Finland: the ELG method and the ROADMIX method (Figure 6). Old oil gravel pavement is preheated up to 40 to 60°C before milling. About 20 kg/m^2 of new material is added, mixed with milled pavement material, and laid and compacted.

TABLE 4 Stability of Fresh and Old Soft Wearing Course Mixtures

	Indirect tensile strength (kPa)	
Binder / Binder content	1 Day	Ultimate
RO / 3.6%	83	290
BE 1000 / 3.6%	68	183
BE 1500 / 3.6%	94	336
BE 3000 / 3.6%	104	423
BE 6000 / 4.0%	149	718
BE 1500 / RC 60 / 3.3%	179	499
BE 6000 / RC 60 / 4.0%	289	736

RO stands for road oil
BE bitumen emulsion
RC amount of recycled material (%)

The ROADMIX method is suitable unless roads have poor structure, rough spots, or low bearing capacity. If the roughness is due to frost heave, there is no cheap maintenance method. However, the bearing capacity can easily be improved with stabilization. Currently, the oil-gravel remixer is able to stabilize and repave the road. Roads can be stabilized with foam bitumen or emulsion.

Conclusions

Approximately 78 percent of Finnish public roads are low-volume roads. Oil gravel is used most often. Road oil, which contains volatile solvents, is used as the oil gravel binder. The environmental risk factor of volatile solvents has attracted attention. To minimize environmental pollution, a new type of pavement for low-volume roads, emulsion gravel, has been developed.

Laboratory and test road results are encouraging. In Finland, 170 km of emulsified asphalt test roads was successfully constructed during 1992 and 1993. Experience on suitability of oil gravel laboratory test methods for soft emulsion mixtures has increased. A design procedure and test method for water sensitivity of emulsified mixtures has been determined. The durability of

TABLE 5 Construction Costs of Pavements in Finland, 1993

Pavement type	Thickness (cm)	Unit price (Fmk/m^2)
Asphalt concrete	4	16
Soft asphalt concrete	4	14
Emulsion gravel	4	14
Oil gravel	4	11
Surface dressing	1-2	6

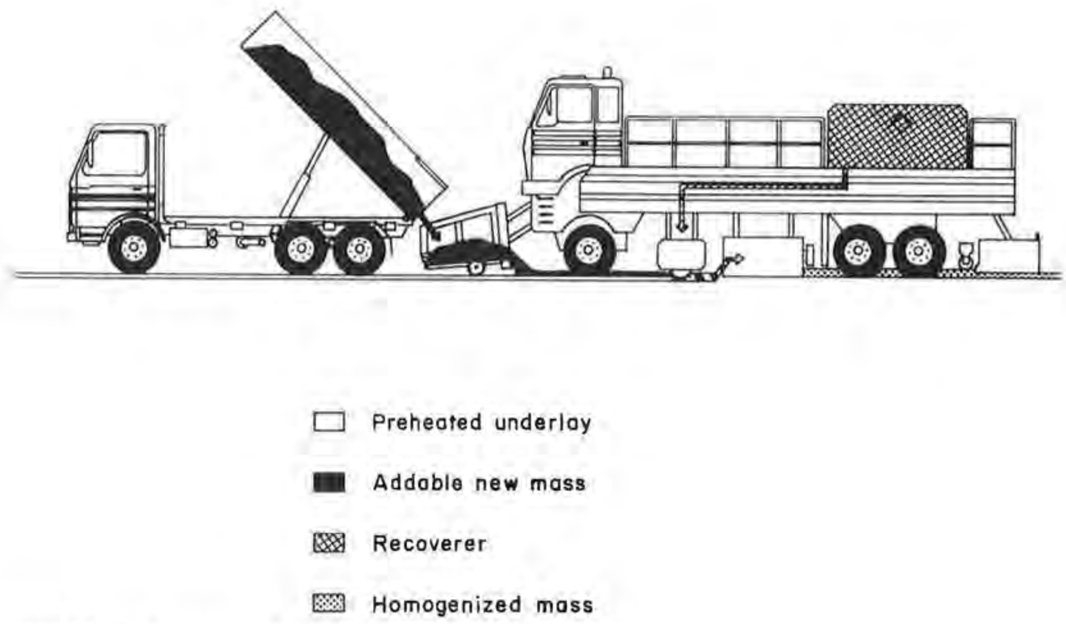

FIGURE 6 Remixing oil gravel (ROADMIX).

pavements is still unknown, but long-term monitoring is planned. However, bitumen emulsion mixtures are an alternative to soft pavements containing petroleum solvents. The use of soft emulsified mixtures in wearing courses and the use of emulsified bitumen in recycling mixtures will increase in Finland.

Maintenance costs on low-volume roads are generally low. The economy of pavement is determined by its construction costs and service life. Roads with inadequate bearing capacity are stabilized. Remixing provides a cost-effective and environmentally friendly method for maintaining low-volume roads.