Methods for Repairing Frost Damage on Gravel Roads

Asko Pöyhönen, *Finnish National Road Administration*

In Finland, gravel roads are mainly "unbuilt," meaning that the road structure is thin or the structural courses have mixed with subgrade material. Because of this kind of structure and Finland's geographical location (freezing index), Finnish gravel roads suffer from considerable frost damage every spring. The objective of this project has been to determine technically feasible and economical methods for repairing different types of frost damage. The project can be divided into four parts, of which three—the test pit studies, industrial waste material analyses, and studies of 15 different types of test structures—have already been completed. Currently, a follow-up of the test structures is being performed. Test structures were erected in 1991–1992. The length of each structure was 50 m (55 yd). Test structure studies can be divided into stabilization, intensification of drainage, thermal insulation materials, and geogrids and strengthening fabrics. In the stabilization of structural courses, efforts were made to use industrial waste materials. For the follow-up on the functioning of different structural solutions, the structures were equipped with electrical measuring instruments with which it is possible to measure the temperature and moisture distribution in the subgrade and pavement of the road, vertical movements of the road surface, and the deformation behavior of the strengthening fabric. The effect of stabilization on the improvement of the bearing capacity of the road has been significant. The effect of stabilization in balancing the differences in frost heaving has been the same or slightly better than that of reinforcements. However, experience gained from drainage structures is not very promising.

The Finnish National Road Administration (FinnRA) is responsible for the maintenance and care of 77 890 km (48,380 mi) of public roads. Of this almost 39 percent are gravel roads. In 1993 FinnRA spent about 250 million markkaa (FIM) ($45 million U.S.) on the maintenance and repair of gravel roads (winter maintenance not included). Although a large number of all public roads are gravel, about 95 percent of the traffic on public roads occurs on paved roads. However, the share of maintenance costs for gravel roads is almost 20 percent.

Finnish gravel roads are mainly "unbuilt," meaning that the road structure is very thin or the structural courses have mixed with subgrade material. Because of this kind of structure and Finland's geographical location (freezing index), the gravel road network suffers from significant frost damage every spring. If the frost damage period is prolonged, weight limits are imposed during the thawing period. The usual weight limit is 8 tons (8.9 metric tons). Frost-damaged roads cause extra expense to both the road owner and the road users.

In 1990, a project for determining technically feasible economical methods for repairing different types of frost damage on gravel roads was initiated (*1*). The project can be divided into four parts, of which three—the test pit studies, material analyses (industrial waste materials), and studies of 15 different types of test structures—have already been completed. Currently a follow-up of the test structures on the roads rehabilitated with new materials or repairing methods is being performed.

TEST PIT STUDIES

More than 50 test pits were dug to ascertain the main reasons for the different types of frost damage on gravel roads. One of the observations made is that the structural layers (if there are any) have mixed with subgrade materials. As a result of this change, the bearing capacity of the road has lowered. On several occasions, this mixed road structure has turned into frost-susceptible material. Other factors that have contributed to road damage include the thickness variation of structural courses in the cross direction of the road, the groundwater table or rock reaching close to the road surface, settlement of subgrade materials, inadequate drainage, and too steep inner slopes of side ditches (Figure 1). In addition to traditional field investigations, ground-penetrating radar was also used. The bearing capacity of the road was found to be only 20 to 30 MN/m^2 at its lowest. When designing the test structures, the target bearing capacity was set at 70 to 80 MN/m^2.

INDUSTRIAL WASTE MATERIALS AND MATERIAL ANALYSES

Waste Materials Selected

One of the objectives of the project was to use industrial waste materials (by-products) in repairs. If a feasible and economical use could be found for a waste material in the road structure, it not only would reduce waste but would also save natural gravel resources. The following waste materials were chosen for the study: biotite, dehydrated gypsum, blast-furnace slag, power station ash, and materials with the brand names Finnstabi and Lohjamix.

The average annual amount of gypsum produced during the processing of phosphoric acid is 1.4 million tons (1.5×10^6 metric tons) and that of biotite developed during the preparation of apatite is about 5 million tons (5.5×10^6 metric tons). The annual amount of blast-furnace slag produced during the manufacture of pig iron is about 450,000 tons (0.5×10^6 metric tons). Blast-furnace slag resembles sand in its grain size distribution but the specific surface area of blast-furnace slag is much greater. Fly ash is produced in various localities and has useful properties that include lightness and high thermal insulation capacity. Finnstabi is produced during titanium dioxide manufacture in connection with water neutralization. During the production process, substances that improve Finnstabi's stabilization characteristics are added to it. Lohjamix is a product that contains sulphuric gypsum recovered during the flue gas filtration mainly at coal-fired power stations.

Material Studies

One of the disadvantages of the waste materials is the lack of detailed knowledge about their properties. This is why material analyses of the waste materials selected for the study were considered essential. The properties analyzed in the laboratory included the type and quantity of the binding material needed with the waste material, freezing-thawing behavior, strength, solubility, thermal conductivity, frost susceptibility, and dynamic load-carrying capacity. A summary of material analyses is given in Table 1.

TEST STRUCTURES

Test sections were constructed in 1991–1992. The length of each test section is 50 m (55 yd), and they are

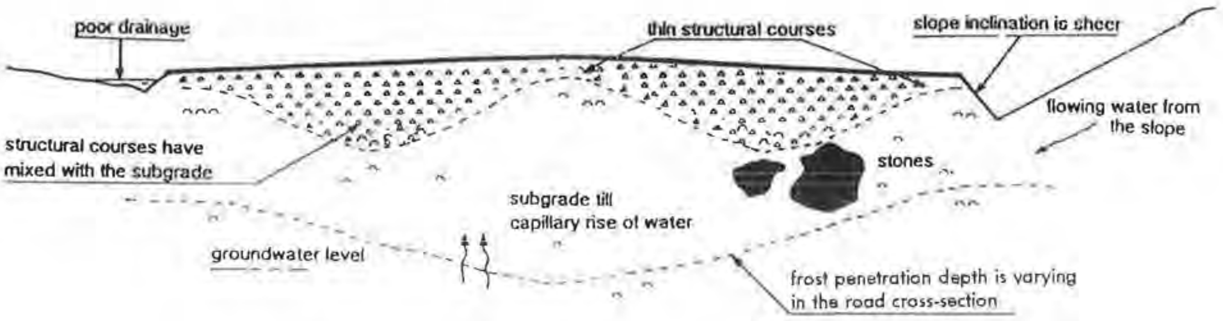

FIGURE 1 Some factors that can contribute to frost damage.

TABLE 1 Some Results of Waste Material Analyses

Material	Property				
	Strength, 30 days MPa	Strength, 90 days MPa	Dynamic modulus of deformation	Thermal conductivity W/mK	Permeability × 10^{-9} m/s
Crushed material + Finnstabi + CaO 8:1 16%	12	14	5,3	1,0	8,4
Crushed material+ blast-furnace slag 30% +CaO 0,6%	1,2	2,1	-	0,8	270
Crushed material+ Lohjamix 18%	5,3	10	0,55	1,0	1,8
Crushed material+ gypsum + cement 1:1 10%	13,5	17,5	-	0,7	-
Power station ash + blast-furnace cement 4%	5,2	11	-	-	<400

located in five maintenance areas. There are 15 different types of test sections. Each test section has a control section. No improvement or repair measures have been implemented in the control section. Consequently, we can estimate how well our test structures have improved the situation on the road.

Intensification of Drainage

By enhancing the drainage of structural courses of the road, it is possible to directly affect the bearing capacity and frost-heaving behavior of the road. As the water content of structural courses decreases, frost action is reduced and the bearing capacity of the road increases. For improving the drainage at damaged sites, underdrains and horizontally or vertically mounted hydraway drains were employed.

A hydraway drain (Enkadrain P32) was placed in the vertical position on both verges of the road (Figure 2). Excavation work had to be performed with a narrow shovel to keep the quantity of excavated and filled ground as small as possible. The trench was filled with sand, and the water collected by the hydraway drain was carried away from the structure through the drainpipe in the lower part of the drain.

In one test structure (Figure 3) a V-shaped hydraway drain (Filtram 1B1) was laid under the road structure so that, in the center of the road, it was at a depth of about 80 cm (2.6 ft) and on the edges, at a depth of about 40 cm (1.3 ft) from the road surface. In the cross section, the angle of gradient of the hydraway drain is 1:10. After the hydraway drain had been placed, the old materials of the structural courses were reused on the drain. The hydraway drain not only dries structural layers of the road, it also reduces the capillary rise of water into the road structure.

Reinforcing Fabrics and Geogrids

The purpose of reinforcements is to transfer the tensile stresses acting on the structural courses to the reinforcements to improve the strength properties of the road structure. So far, reinforcements have not been used on gravel roads partly because of their high price and partly because their advantages have not been realized.

Theoretically, the use of reinforcements leads to thinner structural courses than the use of filtration geotextile alone (Figure 4). Both geogrids (Fortrac 35/20-20) and strengthening fabrics (Televev 150/150) were used in the structural layers. Nearly all test structures in which reinforcements were used were situated in weak soil areas. Where possible, old structural layer material was used in the test structures. In one test structure, the edges of the road were strengthened with "bags" made of strengthening fabrics (Figure 5).

Stabilization

In the stabilization of structural courses, efforts were made to use industrial waste materials. Industrial waste materials often have properties that are needed in earthworks. Waste materials strengthen either by themselves or with an aggregate, in addition to which some waste materials have a high thermal resistance. Stabilization mainly brings the same benefits as reinforcements. A stabilized layer forms a flat sheetlike structure. It not only improves the bearing capacity of the road but also evens out irregular frost heaving and prevents layers from mixing with subgrade material. The purpose of stabilization is to find structures with as high a deformation resistance as possible. When this technique is applied, materials of the old road structure can be used efficiently. It was necessary to use binders with almost every waste material. The binding materials used with the waste materials and the binder contents are shown in Table 1. The objective was to make the stabilized layer, through its strength value, not as rigid as possible but as flexible as possible. The thickness of the stabilized layer was 15 cm (6 in.).

Thermal Insulation Materials

The research includes two solutions for thermal insulation. Compared with average costs, expanded clay is

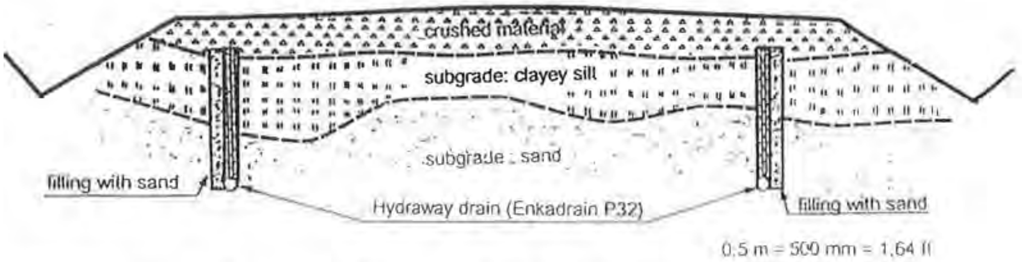

FIGURE 2 Vertically mounted hydraway drain (Enkadrain P32).

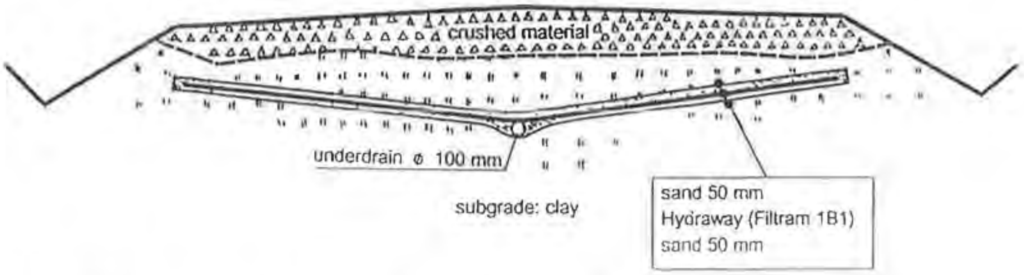

FIGURE 3 Horizontally mounted hydraway drain (Filtram 1B1).

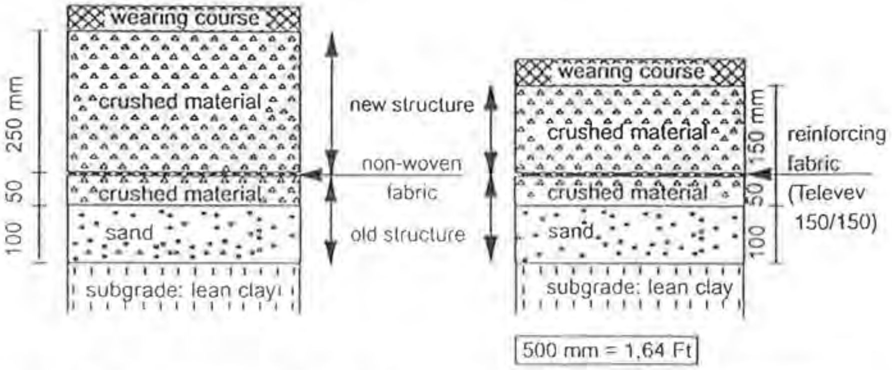

FIGURE 4 Comparison of use of filtration geotextile and reinforcing fabric.

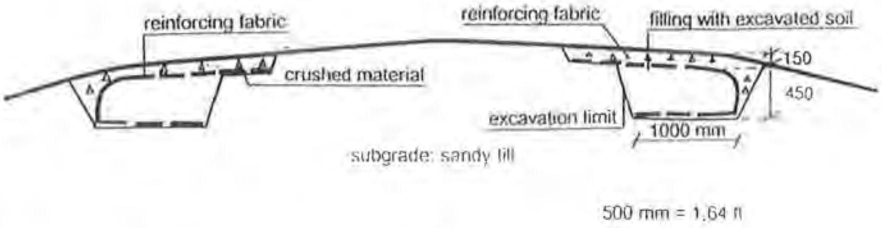

FIGURE 5 Edges of road supported by strengthening fabrics.

a considerably expensive solution. On the other hand, in weak soil areas expanded clay has not only a thermal insulation capacity but also a lightening effect on the structure. An insulation layer made of power station ash is a significantly cheaper alternative. The thickness of both layers was 20 cm (7.9 in.).

REALIZATION OF TEST STRUCTURES

Of the constructed structures, those where the new structure lies directly on the old structure were clearly easiest and quickest to construct. The addition of a new layer of crushed stones and the possible use of reinforcements (usually, a filtration geotextile) are the traditional methods for repair because they are feasible and simple to use.

The use of industrial waste materials, even in separate layers, may be an alternative worth attention if waste materials are located close to the place where they can be used. Stabilization with waste materials will obviously be a viable alternative for improving the bearing capacity of the road. The present problem is mainly to find suitable working methods (spreading and mixing). Furthermore, long transportation distances of the waste materials used as binders may be an obstacle to their use. The advantage of stabilization is that the old road structure can be used. Solutions related to the enhancement of drainage are usually more difficult to realize. When enhancement of drainage is planned, it should be ascertained that the water collected by drainage structures can be carried away from the road area at moderate costs.

FOLLOW-UP AND FUNCTIONALITY OF TEST STRUCTURES

Follow-Up

To follow up on the functioning of different structural solutions, the test structures were equipped with electrical measuring instruments. These electrical instruments measure the temperature and moisture distribution in the subgrade and pavement of the road, vertical movements (frost heaving) of the road surface, and, in one test structure, the deformation behavior of the geogrid. Instrumentation was conducted as shown in Figure 6. The control sections were also instrumented.

Once a year, the groundwater and surface water of the structures in which industrial waste materials have been used are tested for heavy metals. The strength development of the stabilized layers is followed using test specimens taken from the structures. Their strengths are determined in the laboratory. The bearing capacity of the test structures and the control sections are measured each spring.

Functionality

Since the experimental structures were erected only in 1991–1992, no definite conclusions can be drawn about their performance. Since the economy of a structure depends on its lifespan, no conclusions can be drawn about economy at this stage. Frost heaves in the control sections have been as much as 40 cm (15 in.) at their highest and the frost depths about 2 m (6.5 ft).

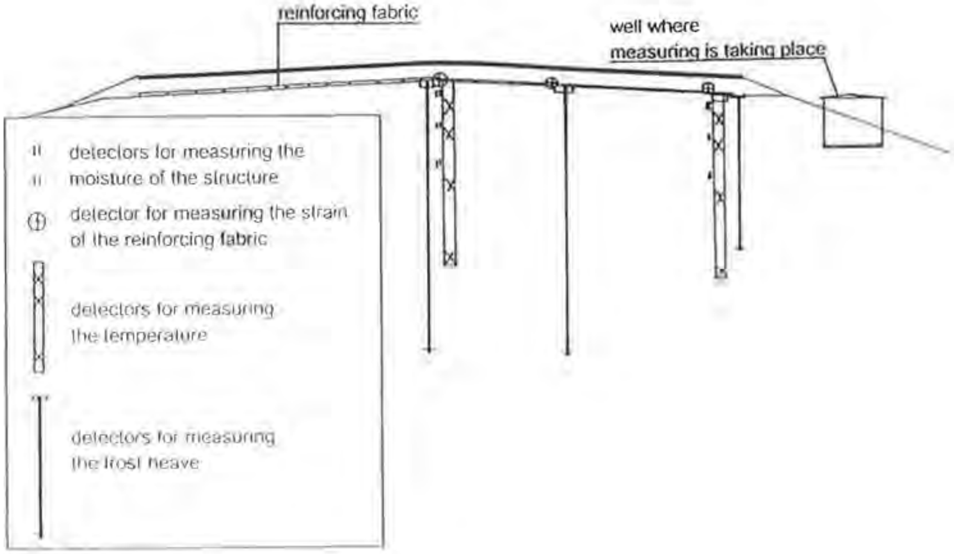

FIGURE 6 Instrumentation of test structures.

Knowledge gained from drainage structures is not promising. The construction of these structures is more expensive and difficult than on average. Their function has been unreliable and the results achieved from improving the bearing capacity and balancing the movements caused by frost have been worse than in other test structures on average.

By using geogrids or strengthening fabrics, it is possible to reduce the thickness of the crushed stone layer needed in reparation construction and, consequently, to save on material and transportation costs. According to the strain measurements, reinforcements have been functioning as expected (i.e., they have strengthened the road structure). Reinforcements have significantly balanced the uneven frost heaving [i.e., the differences in frost heaving have dropped to half of what they used to be within 5 m (5.5 yd)].

The effect of stabilization on the improvement of the bearing capacity of the road has been significant. At its best, the bearing capacity has improved by 50 percent as a result of stabilization. The effect of stabilization in reducing the differences in frost heaving has been at the same level or slightly better compared with that of reinforcements.

Extremely good results were achieved from the use of power station ash. When properly compacted, ash forms a flat sheetlike structure that improves the bearing capacity of the road and serves as a thermal insulation material. After construction, frost heaves have reduced to half of the previous level and the bearing capacity of the road has more than doubled. The expanded clay structure has behaved as expected with the exception of the settlement that has occurred.

REFERENCE

1. *Methods for Repairing Frost Damages on Gravel Roads.* FinnRA Reports 27/1991, 32/1992, 50/1992, and 52/1992 (in Finnish). Finnish National Road Administration, Helsinki.