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MATERIAL TREATMENT

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MATERIAL TREATMENT

REPORT ON TASK 2.2

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PREFACE

This is the final report from the Phase II Task 2_2 of the Roadex II project, a technical transnational cooperation project between the Highland Council, the Western Isles Council, and Forest Enterprise from Scotland; the Northern Region (formerly Troms District) of the Norwegian Public Roads Administration and the Norwegian Road Haulage Association; the Northern Region of the Swedish Road Administration; and from Finland the Regions of Central Finland and Lapland of the Finnish Road Administration, as well as Metsähallitus Region of Eastern Lapland, the Forestry Centre of Lapland (Lapin Metsäkeskus), Stora Enso Metsä, and Metsäliitto, Procurement Area of Northern Finland. The Roadex project is partly financed by the Interreg IIIB Northern Periphery Programme. The lead partner in the project is the Highland Council from Scotland and project consultant is Roadscanners Oy from Finland. The Roadex II project Chairman is Ron Munro from the Highland Council and the project manager is Timo Saarenketo from Roadscanners.

The report summarises the work done in Task 2_2 ‘Material treatment’ of the Roadex II Project concerning technologies that can be used in improving the technical properties of the low volume road materials, especially those of the base course layer. The work has been done in close connection to Task 2_1 ‘Permanent deformation’ the results of which are, however, presented in a separate report.

The experimental work presented in this report was done in the Laboratory of Foundation and Earth Structures at the Tampere University of Technology (TUT) in Finland. In addition to the work done specifically for the Roadex II Project use has also been made of the results from a parallel national research project, which has been going on at TUT since late autumn 2003, and some other smaller scale research initiatives, which had already been completed prior to the Roadex II Project. Most of the experimental laboratory work has been conducted by Research Engineer Nuutti Vuorimies who has been assisted by Research Assistants Timo Raitanen and Mirko Harjula and Laboratory Technician Marko Happo. The project leader of Task 2_2 at TUT has been Professor Pauli Kolisoja who has also written the report jointly with Nuutti Vuorimies.

In addition to acknowledging the above mentioned assisting personal of the Tampere University of Technology the authors specifically want to thank the members of the Steering Committee and the Road Condition Working Team for their encouragement and valuable guidance in this work.

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ABSTRACT

Task 2_2 of the Roadex II Project 'Material treatment' deals with the available methods that can be used in improving the performance of the structural layers, especially the base course layer, of the low volume roads in the Northern Periphery (NP) area. The main emphasis is on the so called non-traditional treatment agents and methods that can potentially provide cost-effective alternatives to the traditional stabilisations performed using hydraulic and bituminous binding agents. Since the main problem, to which the new material treatment methods are being applied, is permanent deformations on low volume roads, the task has been done in close co-operation with Task 2_1 'Permanent deformation'. The final report of Task 2_2 attempts to make a concise summary of the current knowledge concerning the types of non-traditional treatment agents available and to assess their applicability in treating the base course materials of low volume roads in the NP area.

In the beginning of the report a short summary of the typical climatic conditions and the related problems on the low volume road network in the NP areas is given. After that an overview of the currently available stabilisation and treatment methods is made. Special attention is given to the non-traditional treatment agents and the various types of classifications presented for them in the literature. Further, a classification applicable to the materials typically used in the base courses of low volume roads in the NP area is suggested. Based on that classification, the primary influence mechanisms of the various types of non-traditional treatment agents are considered.

The experimental results presented in this report include Tube Suction (TS) tests and repeated load triaxial (RLT) tests with four Finnish, one Norwegian and one Swedish test material. The TS test is used as a simple to perform test method to assess the water suction properties of the various types of base course materials and the effect of different treatment agents on them. The RLT tests have been done according to a special test procedure attempting to simulate the effect of seasonal variations on the mechanical behaviour of the base course materials.

Both the results of TS and RLT tests indicate that even a fairly small amount of bitumen, 2 to 3 % and in some cases only 1 %, can markedly reduce the water suction tendency of a problematic base course aggregate and thus improve its performance under a repeated loading corresponding to the effect of heavy vehicles even during the thawing period of seasonal frost. The results obtained with the non-traditional treatment agents were twofold. Some of the treatment agents did not indicate any positive effect while some of them seemed to have great potential as alternatives to traditional stabilisation methods. Concerning many of the negative results it must be noted, however, that the tests were done even with treatment agents that, according to the information provided by the manufacturers, could only be expected to be effective with materials having a much higher fines content than what is typical for the base course materials in the areas of seasonal frost.

At this stage, the main conclusion concerning the applicability of the non-traditional treatment agents and methods is that at least some of them really have potential to become true alternatives to the traditional stabilisation methods. Based on the experiences thus far, it also seems that the Tube Suction test is a very useful tool in making a preliminary assessment of the applicability of the various types of treatment agents. On the other hand, however, it should be realised that there is still much research work to be done in this area before the non-traditional treatment agents and methods can be utilised in a controlled manner. One vital aspect of this additional research would be the construction and monitoring of full-scale test sites from which it could be possible to obtain reliable information concerning the long term performance of treated structural layer materials in realistic environmental and loading conditions.

KEY WORDS: Roadex, Base Course Material, Moisture Susceptibility, Non-Traditional Stabiliser, Laboratory Test, Bitumen Emulsion, Polymer

1 Introduction

The Northern periphery of Europe includes a large area, but it is quite sparsely populated. Respectively, the traffic volumes are usually fairly low except in the vicinity of some major cities. Many of the roads in the Northern periphery area have not actually been built properly but they have gradually been improved or repaired from old cart-tracks to improve their trafficability to meet the needs of vehicle traffic (Figure 1). Usually the improvements have been done at minimum cost and the materials have been taken from local borrow pits even though they have not always been optimally suitable as road construction materials. Throughout the years the traffic loads have also been increasing on the low volume roads especially because of the transports related to forest and fishing industries and agriculture. Most often the permanent deformations that have developed in the road surface, have been repaired by reshaping the wearing course material on the road surface. Since these kind of repairs have been done time after time the thin structural layers have become mixed together and with the subgrade material as well.

Figure 1. A typical low volume road in the central part of Finland.

Climatic conditions of the Northern Periphery usually necessitate higher quality requirements for the road structures in comparison to the warmer areas of Europe. Concerning the performance of road structures the main problem in the Northern Periphery is the effect of seasonal variation including the freeze-thaw cycles. To prevent or at least to limit the frost damage the thickness of the structural layers of roads must be increased and the materials have to be selected carefully so as to avoid formation of segregation ice lenses and related increase in the water content of the upper part of road structure. However, from an economic point of view it is only feasible to build the most important road connections according to these standards.

In Norway and Scotland, the coastline is long and winds from the Atlantic Ocean carry a lot of moisture, which results in precipitation in mountainous coastal areas. Just like in the case of a seasonal frost thawing period, too much water in the road structures makes them more vulnerable to the permanent deformation even during a limited number of cyclic loads created by the heavy traffic. Because the resources for making proper drainage throughout the entire road network have been economically limited, damage occurs (Figure 2).

Figure 2. A low volume road on the island of Senja in the Northern Norway suffering from permanent deformation problems caused by inadequate drainage and a too thin structure.

One efficient way to avoid the permanent deformation problems created by heavy traffic on low volume roads during the thawing period in the spring has been to set load restrictions. However, as demands for greater logistical efficiency have emerged in many businesses the need to have unlimited access to the roads throughout the entire year has continuously increased. Therefore the need for new cost efficient solutions to maintain the trafficability of the low volume roads year round is becoming more and more evident.

Because the overall thickness of the structural layers in the low-volume roads is usually relatively low, the significance of the base course is emphasised. This is also the reason why this research deals mainly with the base course layers and materials used in low-volume roads. In this report the base course materials considered are assumed to have a fines content less than 20 per cent which is the typical situation at least in the Nordic countries in which higher fines contents are clearly unacceptable due to the effects of seasonal frost. The aim of this report is to make an assessment of the commercially available non-traditional stabilization agents used to reduce the water-susceptibility of the base course materials. The assessment is based on information gathered from a literature survey, information available on the www-pages of the treatment agent producers, results of laboratory tests done in connection with this project and last, but not least, results from a national research project that has been running parallel to this project at the Tampere University of Technology.

2 Treatment techniques for low-volume roads

2.1 Background

Stabilisation of the base course layer using cement or bitumen is a well known method used to improve the bearing capacity of roads (Figure 3). In the conditions typical to the Northern European countries the traditional stabilisation methods have been observed to be fairly effective if the fines content of the materials does not greatly exceed 10 percent. The method is, however, usually too expensive to be used very extensively on the low-volume roads.

Figure 3. Improving the bearing capacity of the base course layer of a low volume road by means of stabilisation.

The inadequate bearing capacity of the low volume roads and permanent deformation of the road structure and the underlying subgrade, which occurs under heavy vehicle loads, is a major problem on the low volume road network of the Northern Periphery area. On the roads having a bituminous wearing course this results in unevenness of the road surface and premature deterioration of the bituminous layer. On gravel roads the unevenness is easier to repair in connection with the regular maintenance operations, but even then, the continuously repeated reshaping of the road surface results in a situation where the structural layers are mixed together along with the subgrade material as well.

In consideration of the above statements any kind of new, cost-effective rehabilitation methods for improving the bearing capacity of the low volume roads would be the most welcome. Besides the traditional stabilisation methods one potential alternative for the future is the use of the non-traditional stabilisation techniques i.e. treatment of the base course layer with additives that aim towards improving the performance of the road structure e.g. by making it less sensitive to the effects of water, which is commonly the main cause of the permanent deformation problems. Some of these new types of treatment agents may even enable the use of locally available lower quality materials and thus a marked reduction in the use of good quality materials and the related transportation costs.

2.2 Traditional stabilisation

The main aim in the use of the traditional stabilizers has been to increase the strength of the treated layers. The most traditional stabilizing agents are pozzolanic materials like cement and lime. The use of cement and lime in stabilization has been studied for a long time and in many countries codes of practice are available. In Finland, for instance, the design codes for cement stabilization present the range of grain size distribution of the base course materials on which cement stabilization can be used. According to the codes, the grain size distribution curve of a material to be stabilized should fall into zone B in Figure 2.2 and the fines content should remain below 9 per cent. Meanwhile, materials that fall into zone A, included in the respective draft of the European standard (prEN 14227-1), are not recommended for cement stabilization in Finland. It must also be noted that cement stabilisation produces a base course with high stiffness but which is, however, fragile. Therefore, the technique is normally not very suitable in improvement of the low volume roads laying on frost-susceptible subgrades.

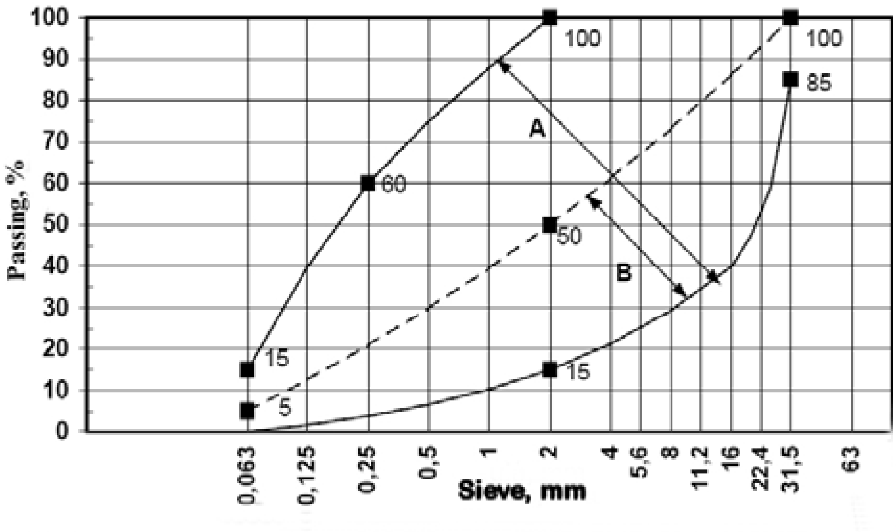

Figure 4. The range of grain size distribution of the materials suitable for cement stabilisation (area B) according to the Finnish design codes (Tiehallinto 2002).

Nowadays bitumen is also frequently used in improving the technical properties of the base course materials. In bitumen stabilization 3 to 4% of the mass, of either foamed or emulsified bitumen, is mixed with the material to be treated. According to the Finnish design codes used here again as an example, emulsified bitumen can be used if the fines content of the material to be treated is 5 to 8 %. Correspondingly, foamed bitumen can be used if the fines content is less than 12 % (Figure 5).

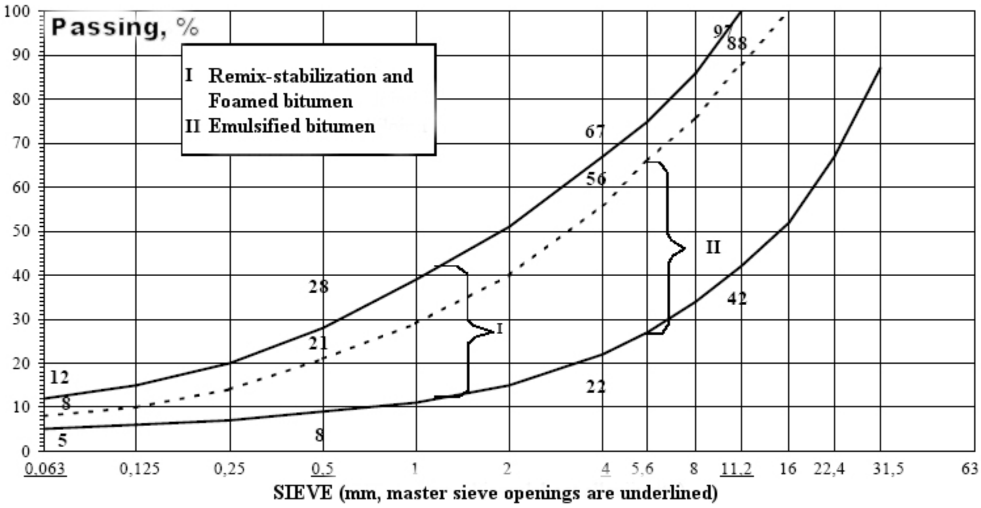

Figure 5. The range of grain size distribution of the materials suitable for bitumen stabilisation according to the Finnish design codes (Tiehallinto 2002).

The stabilization techniques nowadays used in the Northern Periphery areas have been described in more detail on the CD-ROM summarizing the results of the first phase of the Roadex project carried out in 1998 - 2001 (Roadex project 2001).

Compaction of the material has always been a vital element when building structures using earth materials. This also holds true when stabilisation agents are used. One possibility for affecting the properties of the stabilised material is also to change the grain size distribution of the source material either by adding coarse grained fractions, and maybe sometimes even fine grained materials, into it.

The major limitation in the more wide-spread use of the traditional stabilising agents on the low volume roads is the high cost involved. Another limitation may also be, in many cases, the too high fines content of the material to be treated.

2.3 Non-traditional stabilisation agents

2.3.1 General

The use of non-traditional stabilisation techniques has been increasing little by little over the years. Various types of industrial by-products have been tested as dust suppressants or for improving the bearing capacity of the road. The cement and bitumen industries have also developed additional agents to improve the performance of their products. As knowledge of the influence mechanisms of the non-traditional treatment agents has improved, variations in the products available have increased and manufacturing costs have decreased, the amount of producers to market these new types of products has gradually been increasing.

Usually there is evidence that the new types of material treatment products have worked on certain types of aggregates although the duration of the effects is still generally unknown. Quite often there is, however, some kind of knowledge or information gap between the road construction people and manufacturers of the non-traditional stabilization agents that quite often diminishes the confidence that the users have in these products. Because the lifetime of a road is long and the influence of traditional road construction methods is strong, general approval of new non-traditional stabilization agents would require that well-documented, long term trial road sections be constructed and reported. Proper reporting would increase the confidence and knowledge of these products and would help in accumulating knowledge of the limitations and benefits of these products.

A significant amount of development work on non-traditional stabilisation agents has been done in arid and warm climates. The work has concentrated mainly on aggregates with plastic properties, which have quite a high fines content and a specific minimum amount of clay particles. The main aim of many of the products has been to reduce plasticity properties and ease compaction to achieve higher densities, which will increase the bearing capacity of roads and reduce the loss of material.

According to the usage guidelines provided by the manufactures, the treatment techniques used with non-traditional stabilizers are not significantly different than those used with the traditional ones. Some are easier to use and some might be a little more difficult. In liquid form some non-traditional stabilizers are easier to mix and also cleaning of the machines will be easier.

2.3.2 Classification principles of the non-traditional stabilisation agents

Nowadays there are many types of non-traditional stabilisation agents available. For example Scholen (1991) has classified them into five groups: electrolytes, enzymes, mineral resins, clay fillers and acrylic polymers. He has studied the effects of the various types of products especially on fine grained soil materials.

Bolander (1999) assessed the in-situ performance of different types of treatment agents by means of laboratory investigations that he performed with dense-graded aggregates. The test methods were an indirect tensile test and a durability test performed with drying-wetting and freeze-thaw cycles. The test series included variations in the aging period and the amount of additive. His key findings included, among others, that:

- the enzymes and sulphonates were increasing tensile strength marginally in warm and dry climatic conditions, but when the moisture content was increased the gain in tensile strength was lost,
- once hardened the synthetic polymer and tall oil emulsions were improving the tensile strength markedly in warm and dry climate, but when exposed to moisture and freezing in a moist climate they tended to lose the strength,
- the hardening temperature has a marked effect in the strength and durability of tall oil,
- the non-traditional additives can be cost-efficient depending on the goals of the project and the local materials.

Based on his experience Bolander (1999) states that it is clear that thorough preparation, sufficient mixing and curing time all have a marked effect on the efficiency, durability and service life of the structures treated with the non-traditional treatment agents.

According to Jones (2002) the treatment agents for road construction materials used in dust-suppression and stabilisation should be classified in one of the following categories. In dust-suppression the categories are:

- water and wetting agents,
- hygroscopic salts,
- natural polymers (e.g. lignosulphonate, tannin extracts),
- synthetic polymer emulsions (e.g. acrylate, polyvinyl acetate),
- modified waxes,
- petroleum resins and tars,
- bitumens and
- others.

The respective groups in stabilisation are:

- synthetic polymer emulsions (e.g. acrylate, polyvinyl acetate),
- sulphonate oils,
- enzymes and biological agents and
- tars and bitumens.

Until now the classification of treatment agents has not become established. The classifications that are used are much affected by the differences in local practises and if the experiences are primarily based on dust-suppression or on stabilisation of subgrade materials. In this report the non-traditional treatment agents for base course aggregates are classified in the following classes:

1) polymers,
2) enzymes,
3) ionic treatment agents,
4) lignins,
5) resins and
6) other types of stabilisers.

In addition, the group of combined treatment agents could be added including materials clearly consisting of more than one group of material.

2.3.3 Polymers

Polymers are available in many different types and when in the form of emulsion they are, in most cases, usually fairly easy to use. An emulsion normally contains 40 to 50 % of polymer, 1 to 2 % of emulsifying agent while the rest is water. Most of the polymer products intended for stabilisation are vinyl acetates or acrylic copolymers (Newman & Tingle 2004).

Polymers can be developed in very many different forms. Acrylic polymers, for instance, strengthen as they are drying. They develop a chemical adhesion that binds and holds the particles together. However, at least one polymer product has been reported as having enzymatic effects. One of the polymer products potentially applicable in stabilizing coarse grained materials is polymer-coated fly ash which is used in the form of powder and may also contain lime (Vuorimies et al. 2004). It is likely that, in the future, the assortment of available polymers will increase and the areas of application will be more diversified. This would require that a more detailed sub-division of the polymer products be made.

2.3.4 Enzymes

The basic structure of enzymes consists of proteins which in biological systems act as catalysts. If a soil is to be stabilised with enzymes there should be a lot of silt and clay sized particles and organic material. Enzymes that have been added to a soil material remain continuously reactive. The enzymes are very specific in synthesising certain groups of chemical compounds and limiting their action to specific bonds in the compounds with which they react. When the enzymes contained in a treatment agent have been mixed with water and spread into the soil they can act in many different ways. The reaction can include breaking of the clay lattice and combining of cations and other compounds with the aid of organic molecules. Breaking of the lattice decreases the grain size of clay particles and helps them to combine with organic materials. In the case of enzymatic treatment agents a very important issue is compaction, which enables close contact between the soil particles and thus initiation of the cementation process. (Scholen 1995)

Because the use of enzymes requires a lot of fines they are hardly applicable for materials containing less than 20 % of fines. According to several sources the enzymes require a curing period, which can also hinder a more widespread use of the enzymatic treatment agents in the Northern periphery areas when the weather conditions are often rainy and wet.

2.3.5 Ionic treatment agents

The electrolytes contained in ionic treatment agents affect the basic nature of clay minerals. In soil materials with normal moisture content the electrolytes are transported by osmosis. They release the adsorbed water and coagulate as a dense moisture free mass. According to the information provided by the manufacturers ionic treatment agents are only effective if the fines content is at least 35 % and a certain proportion of the fines must be clay minerals. After stabilisation and compaction drying-wetting and freeze-thaw cycles should have no effect on the treated soil material. Treatment with ionic stabiliser should be done when the soil material is at the optimum water content or near full saturation. If the treatment is done by means of scarifying, a very slippery surface will form which requires a friction layer. According to Scholen and Coghlan (1991) treatments can even be done deep below the ground surface through an injection method.

Many of the sulphonated oils belong in the category of ionic products. In many of the ionic treatment agents acids are also included as a reactant.

2.3.6 Lignins

Lignine types of products are often made of by-products from the forest industry. They are generally used as dust suppressants. However, lignosulphonate, for instance, provided good short-term bearing capacity in some test series but the treatment agent was water-soluble (Scholen & Coghlan 1991). On the other hand, in another research project the optimum amount, 5 % of lignosulphonate, proved to give good water-protection properties in silty sand (Santoni et al. 2002). Consequently the lignine products could, in some cases, be used to stabilise, for instance, forest roads for temporary use.

2.3.7 Resins

The resins category contains a wide range of products. Part of the treatment agents are natural products which means that some of the materials are biodegradable and, as such, have a fairly short term effect. On the other hand, the oil resin products from this group may pose low environmental risks if somehow, in connection with the treatment operation, some of the material is released, for instance, into water systems. In terms of the mechanisms of effect, a common feature of the resins group is that they coat and bind the fines. Some of the resins may also form a hydrophobic surface as they coat the fines.

2.3.8 Combined products

The combined products group consists of treatment agents that combine at least two clearly different constituents none of which can be considered more important than the others. An example of a material from this group is the combined treatment agent type F (see Chapter 4), in which the liquid is aimed at affecting deeper materials while the powder compound, consisting of lime and cement, is used to improve the strength properties in only the upper part of the stabilised layer.

2.3.9 Other types of stabilisers

This group contains the products that cannot be classified into any of the above mentioned groups. They are mainly materials used as dust suppressants or materials with very marginal use in reducing the water suction properties of soil materials/aggregates.

3 Test materials

The test results presented in this report include experiences from laboratory scale tests performed with four different crushed rock aggregates from Finland, Lädesglo, Lepoo, Emet and Lillby, one crushed gravel aggregate from Norway, Troms, and one crushed rock material from Sweden, Angesby (Figure 6).

Figure 6. Test material from Angesby, Sweden.

Lädesglo crushed rock aggregate is a porfyric granite from Raippaluoto near to the town of Vaasa while Lepoo is an intermediate vulcanite with thin layers of acid and alkaline vulcanite in between. In terms of strength properties, the Lepoo aggregate is of very good quality and it has been successfully used in wearing courses (Saarenketo et al. Tampere 2000).

Emet crushed rock aggregate is fine-grained, reasonably oriented alkaline vulcanite in which the primary minerals are plagioclase, feldspar and hornblende and amphibole. The Emet crushed rock material also quite often contains pyrites and it has a specific gravity of 3,05 g/cm3. Lillby crushed rock is acidic, medium coarse, mica-rich, fairly weak granite – granoriorite in which the main minerals are quartz, feldspars and black mica. (Vuorimies et al. 2004)

Troms aggregate is taken from a material borrow pit on the island of Senja in the North Western part of Norway. The rock types included are quartz-feldspar-gneiss, granoriorite and amphibolite while the main minerals are quartz, feldspar, black mica and hornblende.

Angesby aggregate was differing from the other previously mentioned test materials in two ways: it was taken from an existing road structure and as a result of bitumen stabilisation performed earlier it already contained some bitumen prior to laboratory testing.

4 Test methods and test results

4.1 Tube Suction tests

4.1.1 Test Method

The Tube Suction (TS) test method, originally suggested by Saarenketo (1995) and Scullion and Saarenketo (1997), is an easy to perform laboratory test method for assessing the water suction properties of various types of aggregates. The test includes compaction of a 180 to 200 mm thick aggregate sample in a plastic tube with an internal diameter of 150 mm. After the specimen has been dried it is put into a plastic tube with a layer of water at the bottom. The absorption of water into the specimen is then monitored by measuring the dielectric value and electrical conductivity at the top of the specimen at frequent intervals (Figure 7). A more detailed description of the test method is given by Saarenketo (2000).

Figure 7. Measurement of the dielectric value and electrical conductivity of the upper part of the Tube Suction test specimen.

4.1.2 Test results with bitumen emulsion

Table 1 presents the dielectric values determined for the Angesby, Lädesglo, Lillby and Emet aggregates in connection with Tube Suction tests. Because the base course material at Angesby was, at some point, stabilised with bitumen, the TS test specimen contained lumps of fines bound together by bitumen. After the TS test, the sample was wet sieved and the results showed that the amount of unbound fines was 3,2 %. In the Angesby base course the bitumen stabilisation had not been successful and the TS test indicated that the unbound bitumen treated Angesby material was very susceptible to moisture and thus also apt to produce frost heave.

Both Lädesglo and Lepoo aggregates have, in earlier studies, been observed as being materials that are very sensitive to moisture. In the laboratory tests, the fines content of Lädesglo aggregate had been about 6 % while in Lepoo aggregate it had been 5,5 %. The effect of bitumen on these materials was investigated by means of TS tests with bitumen contents of 2,2 to 3,6 %. With bitumen treated materials the dielectric values remained low, which, according to the TS tests, indicated that the use of bitumen emulsion would be an efficient solution for reducing their susceptibility to moisture, at least when the bitumen content is 3,0 % (Saarenketo et al. 2000).

With Lillby and Emet crushed rock aggregates a low bitumen amount of 2,0 % was tried, which resulted in a reduction of the dielectric value in both of the materials. In Lillby aggregate, however, the reduction was insufficient. In Emet aggregate the dielectric value was reduced below the limit value of 9, but it still might be sensible to use a slightly higher bitumen content in-situ. Most likely, both of the materials would perform sufficiently well if the guideline of using a bitumen content of 2,2 to 3,6 %, as given in the stabilisation codes of practise set by the Finnish Road Administration (Tiehallinto 2002), were followed.

Table 1. Some TS-test results with bitumen treatment. The results of Lädesglo and Lepoo aggregates are originally presented by Saarenketo et al. (2000). The maximum grain size in the tests was 20 mm.

Aggregate	Dry density, kN/m³	Max dielectric value	Water content after the test, %	Bitumen content, %	Fines content, %
Angesby *)	21,4	34,4	4,9	-	3,2 **)
Lädesglo	20,9	5,2	2,3	2,2	-
	21,5	4,2	1,1	3,0	-
	21,6	4,8	0,6	3,6	-
Lepoo	21,8	4,2	1,0	1,0	-
	21,6	4,5	0,5	2,0	-
	21,2	4,4	0,5	3,0	-
Lillby	22,9	25,8	5,7	0,0	6,5
	22,1	16,4	4,2	2,0	-
Emet	23,2	22,1	4,4	0,0	7,6
	23,5	8,6	2,0	2,0	-

*) Angesby material was stabilized on site with bitumen emulsion. The sample was taken a few years after stabilization.

**) Results of wet sieving which indicated the amount of unbound fines material.

4.1.3 Troms aggregate stabilised with commercially available treatment agents

All of the commercially available treatment agents tested were not meant to be effective in materials having a low fines content. In spite of that, they were tested with the Troms aggregate containing about 11 % of fines so as to discover their effect in the TS test. According to figure 4.2 the polymeric treatment agent C clearly lowered the dielectric value. The other treatment agents had no marked favourable effect on the material. Instead, the ionic treatment agent D even increased the dielectric value in the TS test. The test specimen labelled 'No treatment 2002' was prepared in 2002 following a test procedure in which the test specimen did not have a cover which would have limited evaporation. Meanwhile, the test specimen labelled 'No treatment' was prepared in the same way as all of the treated test specimen i.e. high relative humidity of the air surrounding the TS test specimens was maintained by means of keeping the specimen containers covered. The unit weight of the test specimens varied from 21,7 to 22,2 kN/m³, the test specimen treated with a dry powdered polymer agent remained looser than the ones treated with liquid types of agents.

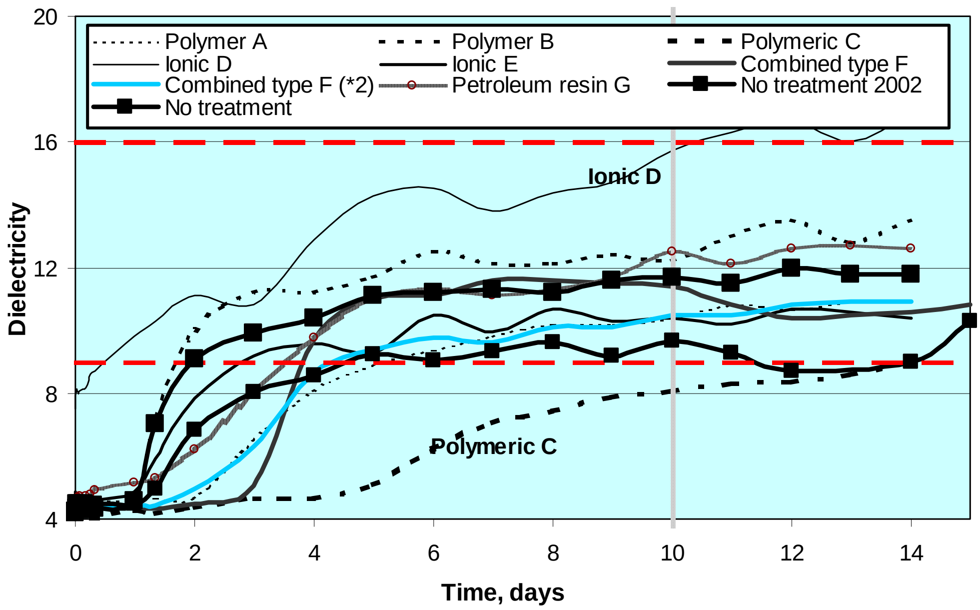

Figure 8. The TS test results obtained with the Troms aggregate. The test specimen 'No treatment 2002' was prepared earlier following a slightly different test procedure than what was used in connection with the other specimens.

4.1.4 TS test results with Lillby aggregate

Figure 9 presents the dielectric values determined in connection with TS tests performed earlier with the Lillby crushed rock aggregate (Vuorimies et al 2004). According to the TS test results only the polymeric treatment agent C lowered the dielectric value enough to maintain it at the acceptance level. With one of the ionic treatment agents no change in the TS test dielectric value was observed. This could, however, be expected because the Lillby aggregate does not contain clay minerals and even its fines content is lower than 7 %. The result obtained with bitumen treated material is the same as that shown in Table 1.

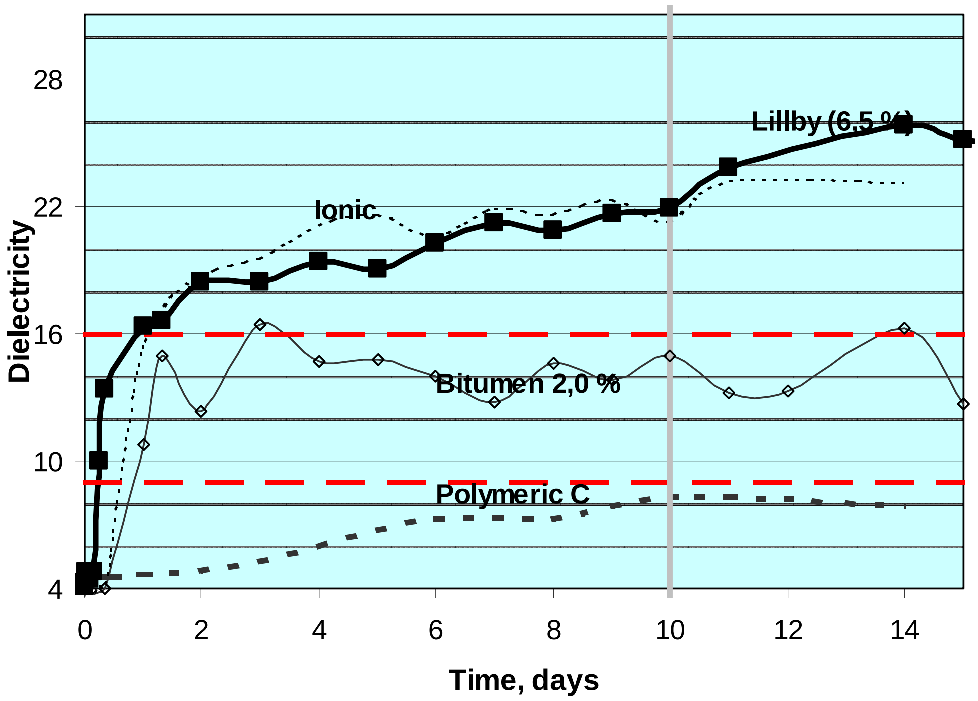

Figure 9. The dielectric values determined in the TS tests performed with Lillby crushed rock aggregate.

4.2 Large scale triaxial tests

4.2.1 Applied test method

The cyclic loading tests, dealt with in this report, were performed using the large scale repeated load triaxial testing facility (Figure 10) developed earlier in the Laboratory of Foundation and Earth Structures at Tampere University of Technology as described by Kolisoja (1997). The diameter of the test specimen was 200 mm and the height was approximately 400 mm. The sample was compacted in four layers using a vibratory compactor.

Figure 10. Large scale repeated load triaxial test facility developed at the Tampere University of Technology.

Testing of the mechanical behaviour of the aggregates was done in several stages. In between the consecutive tests stages the specimens were exposed to treatments that simulated the effects of the seasonal variations that occur in real pavement structures. The test procedure was composed of the following stages:

- The test material was prepared with fixed grading and fines content and compacted in the water content close to w-opt.
- The test specimen was dried in an oven at a temperature of about +45º C for about two weeks.
- Resilient deformation properties of the test specimen were determined.
- The specimen was allowed to absorb water through the bottom of the specimen for one week.
- Resilient deformation properties of the test specimen were determined again.
- The specimen was exposed to a freeze-thaw cycle.
- Resilient deformation properties of the test specimen were determined for a third time.
- The test specimen was exposed to a permanent deformation test of about 100 000 load cycles.
- If permanent deformations in the preceding test stages were not significant the specimen was exposed to a monotonic loading triaxial test.

In determining the resilient deformation properties of the test specimen, the American SHRP protocol P46 (AASHTO 1992) was followed with the exception that preconditioning was not done in connection with the determination that was made after the freeze-thaw cycle.

4.2.2 Resilient deformation test results

Figure 11 indicates the resilient modulus values of Lädesglo and Lepoo crushed rock aggregates determined in connection with triaxial tests simulating the effect of seasonal variations. At first the fines content in both of the aggregates was varied and after that the effect of bitumen content was tested with the materials having an intermediate fines content. In Figure 11, F means the fines content of an untreated test material while B indicates the bitumen content of a treated test material. As can been seen from the figure, the fines content is decreasing the values of resilient modulus determined after the freeze-thaw cycle. In the test specimens treated with bitumen the values of resilient modulus both in moist condition and after the freeze-thaw cycle are clearly higher than in the respective untreated test specimen. In practice this means that the bitumen treatment is preventing the absorption of water into the test specimen and thus also limiting the frost heaves. (Saarenketo et al. 2000).

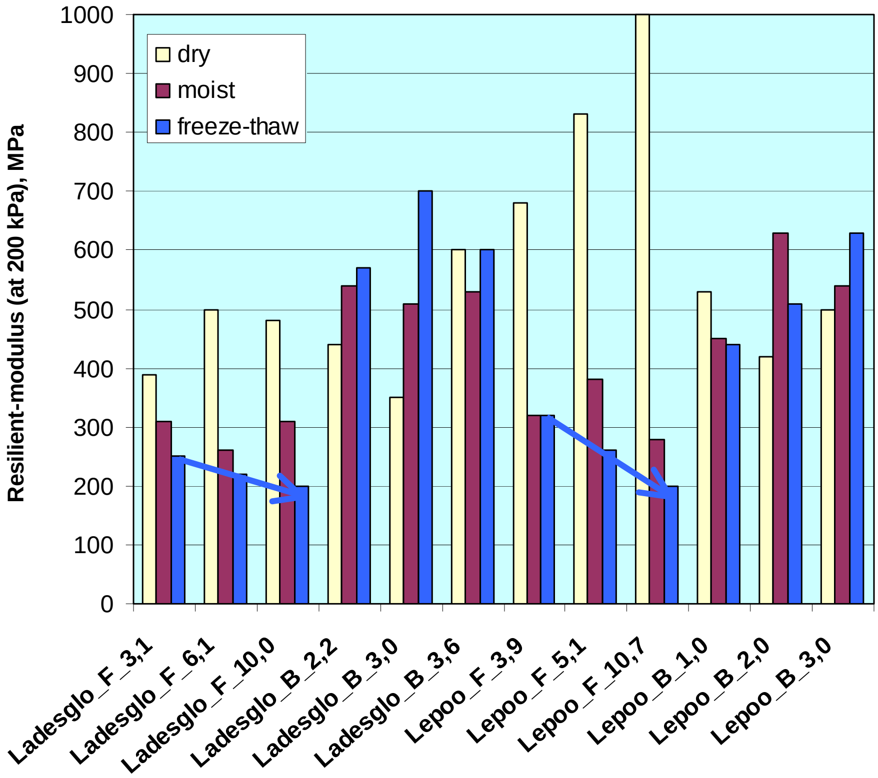

Figure 11. Resilient modulus values of the Lädesglo and Lepoo aggregates tested in dry condition, in moist condition and after a freeze-thaw cycle. The resilient modulus values correspond to the sum of principal stresses 200 kPa. Notation F means the fines content in a non-treated test specimen while B indicates the bitumen content in a treated test specimen. In the bitumen treated test specimen the fines contents were about 5 % for the Lädesglo aggregate and about 6 % for the Lepoo aggregate.

4.2.3 Permanent deformation test results

Figure 12 presents the total amounts of permanent deformation that have accumulated in the same test specimen during the resilient deformation tests performed according to the SHRP loading procedure (AASHTO 1992) after the freeze-thaw cycle and during the subsequent long lasting permanent deformation test series. During the resilient deformation tests large permanent deformations developed especially in the Lepoo and Lädesglo aggregates containing a lot of fines. In the permanent deformation test series, performed after the resilient deformation test, the Lädesglo aggregates practically lost their bearing capacity and the same also happened with the fines-rich Lepoo test specimen. However, in the bitumen treated test specimen hardly any permanent deformations developed during the resilient deformation tests. Noteworthy is also that in the test specimen treated with bitumen emulsion the accumulated permanent deformations during the permanent deformation test increased as the bitumen content increased.

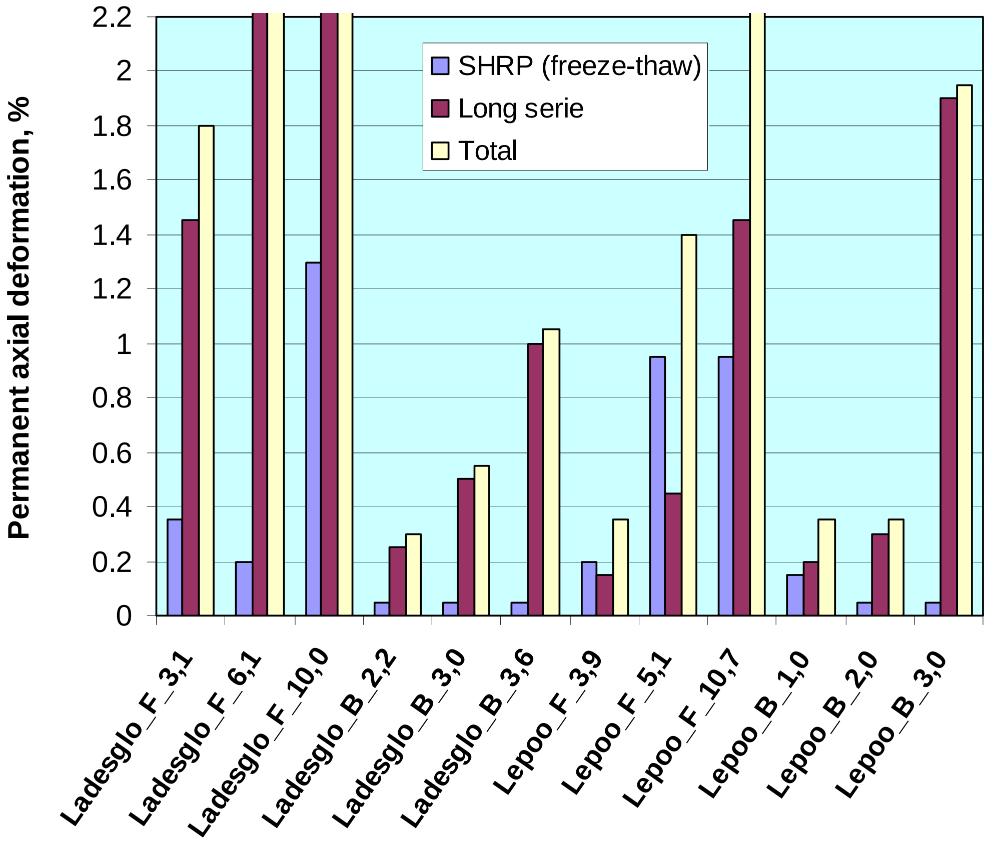

Figure 12. The accumulated permanent deformations of the Lädesglo and Lepoo aggregates during the resilient deformation test performed after the freeze-thaw cycle and during the succeeding test series consisting of 100 000 load cycles in which the deviator stress was 300 kPa and the constant confining pressure was 50 kPa. A permanent deformation value greater than 2 % indicates premature failure of the test specimen. During compaction of the test specimen Lepoo_B_3,0 the bitumen emulsion started to break too early which resulted in clearly lower density of the respective test specimen.

With the Lillby aggregate three cyclic loading triaxial tests simulating the effect of seasonal variations were performed. In the test specimen named 'Lillby 0-20 mm' the maximum grain size was the same as in the Tube Suction tests. However, the test specimen 'Lillby 0-32 mm' was closer to the prevailing grain size distribution in-situ and, as such, it also demonstrated the effect of making the grain size distribution coarser. With the third test specimen the idea was to test the effect of a treatment agent that, according to the results of the Tube Suction tests, proved to be the most promising one in reducing the water suction properties of poorly performing coarse grained aggregates (Lillby 0-20 mm + Polymeric C).

Figure 13 presents the permanent deformations developed in the three triaxial test specimens during the resilient deformation tests. In the test specimen Lillby 0-20 mm the permanent deformation was about 1,2 % while in the more coarse grained test specimen Lillby 0-32 mm it was only half of that. Further, the figure shows that in the treated test specimen there was hardly any permanent deformation during the resilient deformation test.

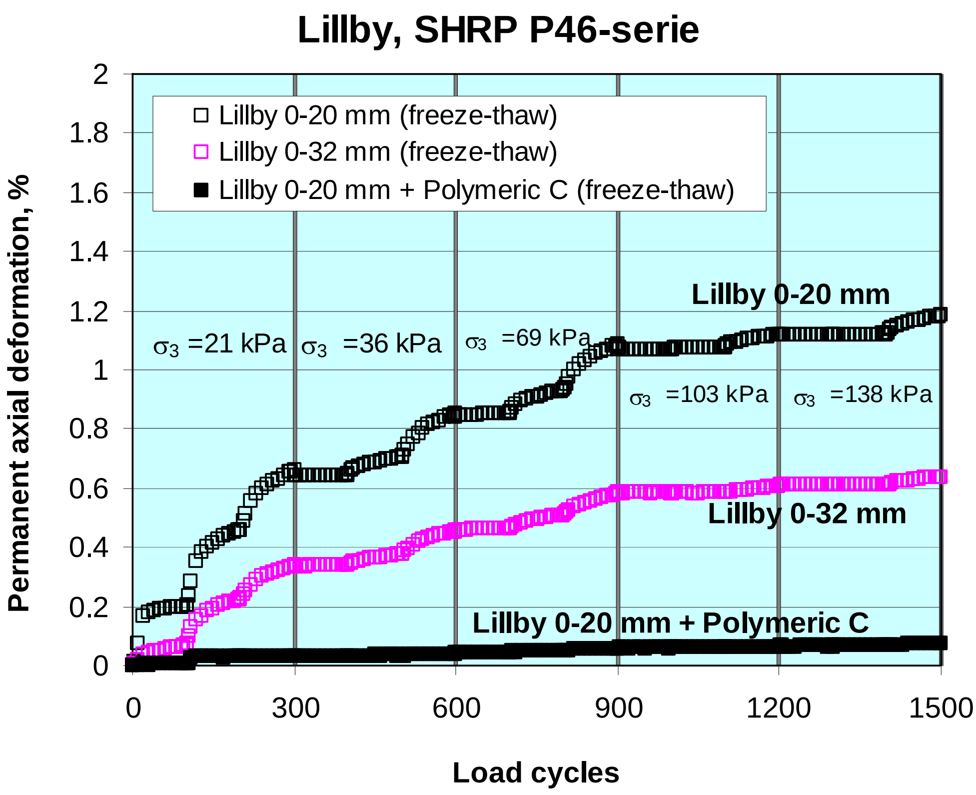

Figure 13. The permanent deformations measured during the resilient deformation test performed after the freeze-thaw cycle in the test specimens made of Lillby aggregate.

After the resilient deformation test the idea was to apply a permanent deformation test series consisting of 100 000 load pulses with 300 kPa deviator stress under a constant confining pressure of 50 kPa. As can be seen in figure 4.8, the intended deviator stresses were not quite realised. However, the figure clearly indicates that the Lillby 0-20 mm test specimen that had been experiencing large permanent deformations already during the resilient deformation test was collapsing very quickly and the test had to be interrupted. However, the coarser grained test specimen Lillby 0-32 mm seemed to just barely withstand the permanent deformation test but even in that case the permanent deformation was continuously increasing. The most important observation from Figure 14 is, however, that the test specimen treated with polymeric treatment agent C survived the permanent deformation test very well. The obvious reason for this is that the treatment agent had prevented frost heaves, and the consequent loosening and wetting, from developing in the test specimen. In addition, the treatment had also increased the strength of the test specimen slightly. According to the results presented in figures 9, 10, 13 and 14 the polymeric treatment agent C seems to be very promising in improving the performance of aggregates suffering from moisture susceptibility (Vuorimies et al. 2004).

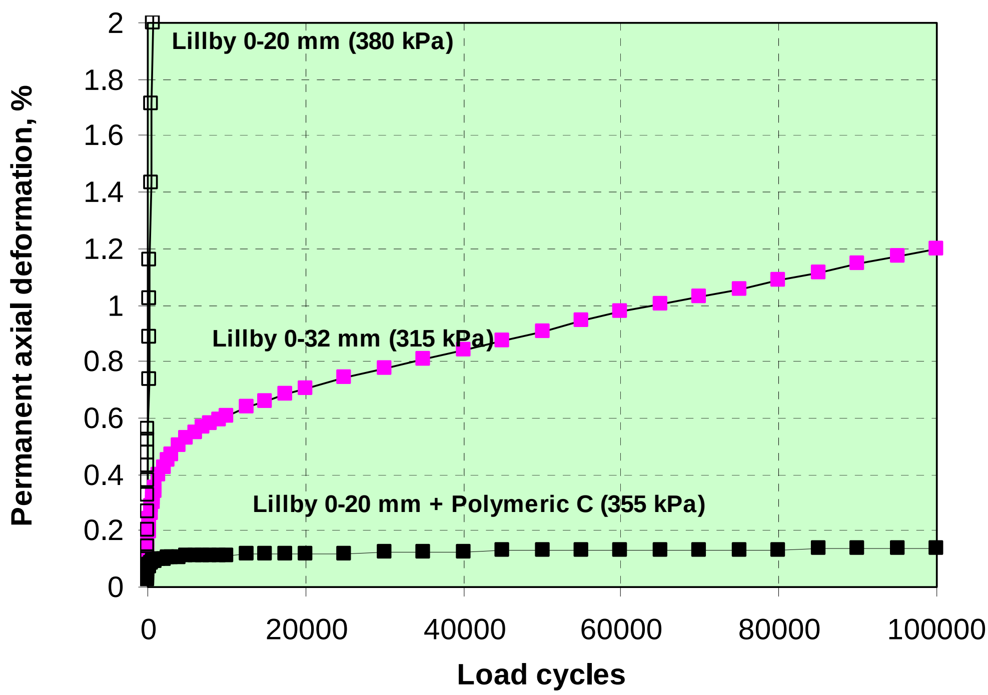

Figure 14. The permanent deformations developed in the Lillby aggregate test specimen during the permanent deformation test series performed after the freeze-thaw cycle. The constant confining pressure during the loading series was 50 kPa while the deviator stress was 300 kPa. The stress values presented in the parenthesis indicate the realised values of deviator stress during each test.

5 Conclusions

Most of the information presented in this report is based on the results of a literature survey and the results of Tube Suction tests and a limited number of repeated load triaxial tests simulating the effect of seasonal variations. Unfortunately, well documented long-term test results concerning the in-situ performance of the non-traditional treatment agents are very sparsely available. The lack of long-term experiences concerning the effect of various types of treatment agents also applies to the laboratory test results presented in this report.

It is obvious that different types of treatment agents are needed for different types of aggregates and soil materials. In addition to the classification of the treatment agents it also seems necessary to classify the aggregates and soil materials into at least four different categories. Non-plastic coarse grained materials could be divided in two classes based on the fines content of 5-12% and 12-25% respectively. In addition, the plastic fine-grained materials could also be classified in two classes. In one of the classes the fines content could be 15-30% and the plasticity index less than 10(12) while the other class would include the materials containing more than 25% fines and having a plasticity index higher than 10(12).

The main conclusions that can be drawn regarding the application potential of the non-traditional treatment agents in improving the performance of the low volume roads in the Northern Periphery area are as follows:

- Most of the commercially available treatment agents require a great proportion of fines to be efficient and, therefore, are probably not very applicable for base course materials in areas with seasonal frost action.
- Many treatment agents require fairly long curing/drying times. This limits their potential usage in moist climates.
- Enzymes and ionic stabilisers are not recommendable for use on coarse grained materials, but they may be efficient on fine grained soils.
- Polymers are the largest commercially available group of stabilisers. Based on the experiences in connection with this research, it seems that the most promising stabilisers in reducing the effects of moisture and freeze-thaw cycles can be found in this group. At least the polymeric treatment agent that was tested performed very well with Lillby and Troms aggregates. Polymers are also claimed to be environmentally friendly.
- Clearly the non-traditional stabilisers have potential to become technically and economically competitive alternatives in the rehabilitation of low-volume roads in the Northern Periphery area. However, quite a lot more research should still be done, since the current trial and error approach, which does not take into consideration fundamental reactions in treated structures, may lead to false conclusions. It is in this way that many potentially useful stabilisers are found to be unfit.

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