RESEARCH REPORT

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Utilisation of low-quality aggregate in infra networks

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Foreword

This is the executive summary of the final report for the project ‘Utilisation of low-quality aggregate in infra networks’ (HUUMA).

The research project was started in the autumn of 2006 and completed on 31 October 2008. The research project was a part of development programme called UUMA, funded by the Finnish Ministry of the Environment. The research project also included cooperation with other projects included in the Uuma programme. The pilot site for the study was the Vuores district development site in Tampere, Finland. The contact person for the Vuores project was Sakari Koivisto of the City of Tampere, and the site planners were Pentti Häkkinen and Petri Tyynelä of Ramboll Tampere. Furthermore, cooperation with Metso Minerals, Heikki Onninen (Destia) and Ilkka Vertainen (Megawatti Oy) took place during the research project.

The responsible director at VTT was Research Manager Matti Kokkala up until 31 December 2006, after which the responsible director was Eva Häkkä-Rönnholm. The Project Manager was Markku Tuhola up until 31 December 2006, after which the Project Manager was Leena Korkiala-Tanttu. The research scientists were Harri Kivikoski, Markku Juvankoski, Markku Kiviniemi, Paula Eskola and Rainer Laaksonen.

The project steering group consisted of the project financers. The chairperson of the steering group was Tuomo Kallionpää (Finnish Road Administration), and the steering group members were Markus Alapassi (Ministry of the Environment), Risto Laaksonen (City of Tampere), Arto Hovi (Finnish Rail Administration), Juhani Ilmonen (Skanska Infra), Valto Tikkanen (Hyvinkään Tieluiska Oy/ Biomaa Oy) and Veli-Matti Uotinen (City of Helsinki). The special expert in the steering group was Jouko Törnqvist of VTT.

The parties involved in the project represented persons from a wide range of sectors. Such a composition ensured theoretical expertise and practical experience in the project. The research group would like to thank the financers, the members of the steering group and other cooperation partners for the fluent and constructive cooperation.

Espoo, September 2008

Authors

Contents

1 Introduction

Infrastructure construction entails handling major amounts of natural materials as excess which are low-quality from a technical viewpoint, such as frost-susceptible moraines and silts. Utilisation of such materials is difficult or at least time-consuming, and this is why most of the materials are transported to stacking areas. More effective utilisation of low-quality materials has so far been limited by the fact that materials of a better quality are relatively easy to obtain, and are affordable. There is currently an intermittent lack of high-quality crushed stone and natural materials, and on the other hand, there is also a lack of sites where low-quality materials can be stacked.

The utilisation of low-quality materials is also limited by the fact that not enough consistent, long-term development of the materials, the design and construction methods required by them has been done. This causes the following problems, for example:

- there are no generally approved dimensioning methods, and technical applicability of the materials in various applications has been uncertain,
- not enough attention has been paid in quality control of the materials and studying their quality characteristics,
- there is not enough information on all aspects of the materials' long-term behaviour, and
- construction sites utilising the materials have so far been test construction sites, and thus working techniques, products and methods have not been commercialised.

Other issues that have limited their use or caused problems include:

- liability issues, such as liability for damage generated when the structures are in use,
- so far, a lifecycle viewpoint has not guided selection of materials,
- local nature and the availability of the materials cause problems with capacity,
- single, separate construction projects are small and thus solutions are non-economic,
- lack of environmental and financial incentives,
- problems with communicating information pertaining to risks arising from slightly contaminated materials and suspicions regarding environmental impacts of the materials, and
- environmental permit practices being slow or feared to be slow, awkward, high-risk and dependant on the person handling the issue.

The objective is to develop methods to promote the utilisation of low-quality aggregates and seek solutions to eliminate the technical and environmental barriers to their utilisation. Refining and treatment methods applicable in improving the technical characteristics and usability of low-quality materials were assessed. In addition, the functionality of test structures manufactured from low-quality soil materials in previous research projects were assessed during the research project. This assessment was complemented by dimensioning methods. The assessment includes sandwich-type alternatives presented in InfraRYL 2006 (Rakennustieto 2006). The research focused especially on studying the utilisation of moraine.

2 Moraine

2.1 Generation and occurrence of moraines

The term moraine refers to poorly graded soil material crushed and transported by a glacier, with a particle size varying from clay to large boulders. Moraine has often stratified directly onto rock and follows the shape of the rock surface in a thin layer (Kauranne, 1972).

Moraine is the most common soil type in Finland; its share of the surface area of the country is approximately 48% (Road Administration, 1995). The name moraine refers to the geological history of the soil type. New EU standards (SFS-EN-ISO 2008) are based on the grain size distribution of materials, and thus the name moraine is not used in the standards. The standard has been translated into Finnish but no national application has been presented so far. The standard states that the name moraine will be replaced by a variety of combination names (such as silty, gravelly sand). The name moraine may be used in the future when one wishes to stress the origins of the material.

Due to its origins, ground moraine is compressed and often includes a high amount of fine aggregates. Surface moraine is often loose and sandy due to the flushing effects of melting water. The grain size distribution of ground moraine most often consists of silty sandy moraine. The surface part of ground moraine (often appearing as a layer of less than one metre thick) is rocky and contains less fine aggregates than the deeper parts (Road Administration, 1995).

Other moraine formations include, for example, lateral moraines, i.e. embankment-like ridges which follow the edge of a former glacier. Drumlins have been created during the active advancement of a glacier, or during the withdrawal stage of a glacier. Drumlins, which are most common in Savonia and Kainuu, usually consist of compact sandy moraine and/or silty sandy moraine with only a small number of stones (Road Administration, 1995). The materials included in lateral moraines and some drumlins vary and also include graded materials in addition to moraine (Kauranne, 1972).

Lateral moraines are transversal moraine formations created at the edge of a melting glacier, contrary to the direction in which the ice was moving. Large lateral moraines appear in connection with large edge formations, such as the Salpausselkä ridges. There are a large number of fairly small lateral moraines in Uusimaa and the Vaasa archipelago. Lateral moraines mainly contain moraine, but may also contain graded materials.

The thickness of ground moraine is at its lowest in the coastal areas in southern and south-western Finland. In coastal areas, the moraine layer may only be 0.5 to 1 metre thick. The average ground moraine thickness in southern Finland is two to three metres. The average thickness of moraine in inland Finland is a couple of metres more than in southern Finland. The thickest moraine layers in Finland are in the northern part of the country, where single local layers may be dozens of metres thick (Kauranne, 1972).

The grain size distribution of moraine layers in southern and central Finland is fairly homogenous. Non-homogenous points are mainly caused by sandy layers graded in the intermediate layers. Moraine in northern Finland may include sand and gravel layers several metres thick or peat and sand layers in between two layers of moraine of different ages, however (Kauranne, 1972).

2.2 Characteristics of moraine soil types

In accordance with the geotechnical soil type rating (GEO classification system), moraines are divided into gravel, sand and silt moraines (Korhonen & Gardemeister, 1975). The amount of boulders and stones in the moraine material depends on the bedrock of the area. The amount of clay and fine aggregates also depends on the bedrock. In Finland, moraine usually contains 0 - 5% of clay. The grains are usually angular or sharp-edged, due to their origins (Kauranne, 1972).

In addition to the grain characteristics, the geotechnical characteristics of moraines are largely dependant on their density. Tables 2.1 and 2.2 include some geotechnical characteristics of some moraine types. The compressibility of moraines is usually approximately the same as for rough-grained soil of the similar grain size.

Moraines containing fine aggregates are susceptible to disturbances during excavation, transportation and stacking. The susceptibility is highly dependant on the water content, however. Disturbances start to occur when the water content rises close to the flow limit. Water content of typical sandy moraine is approximately 11 - 13% (Kauranne, 1972). Furthermore, frost heave always occurs when the conditions are favourable for freezing and when the moraine contains more than 35% of fine aggregates (0.074/64) (Road Administration, 1993).

Table 2.1. Geotechnical characteristics of moraine types according to the structural engineering rating (RT) (Kauranne, 1972). The GEO classification system has been added to the table.

GEO classification system	RT rating	Porosity, %	Density, t/m^3	Natural water content, %	Friction angle, degree	
					Loose (1.5 - 7 t/m^3)	Compact (2.1 - 2.3 t/m^3)
SrMr	SrMr			5…15	31	43
HkMr	HkMr	29…47	1.8…2.2		29	41
SiMr	HtMr	23…41	1.9…2.2	15…25	27	39
	HsMr	38…52	1.8…2.1		25	37

Table 2.2. Certain geotechnical characteristics of moraines (Road Administration, 1993).

Name in accordance with the GEO rating	**SiMr**	**HkMr**	**SrMr**
Porosity, n, %	23 - 41	29 - 47	
Void ratio, e, -	0.3 - 0.7	0.4 - 0.9	
Specific gravity, ρ_s, kN/m^3	2.69 - 2.70	2.69 - 2.70	2.69 - 2.70
Unit weight, ρ, kN/m^3	19 - 22	18 - 22	20 - 22
Hydraulic conductivity, k, m/s [1)]	10^{-6} - 10^{-8}	10^{-4} - 10^{-6}	10^{-2} - 0^{-4}
Natural water content, w, %	5 - 25	5 - 15	5 - 15
Proctor density, $\gamma_{d\ max}$, kN/m^3	20 - 23	20 - 23	20 - 23
Optimum water content, w_{opt}, %	8 - 12	5 - 10	5 - 8
Cohesion, c, kPa	2 - 29	2 - 29	0
Friction angle, φ, ° [2)]	32±6	35±6	37±6
Capillary rise, h_c, m [3)]	> 1	(> 1) 0.5 - 2	(> 1) 0.5 - 2

1) Hydraulic conductivity depends on the density of the moraine and the fine aggregate content.
2) Effects of density: extremely dense +6°, dense +3°, medium dense +0°, loose -3°, extremely loose -6°
3) In loose, non-homogenous moraine 0.5 - 2 m; capillary rise in dense and fine-grained moraine may be several metres.

3 Refining and treatment processes and their applicability

3.1 Moraine refining

The refining and treatment methods for rock materials can be roughly divided into three categories: mechanical, chemical and combination methods. Mechanical methods aim at improving the characteristics of a material by changing its grain size distribution by means of separating, crushing, adding rough stone matter or washing the material to remove fine aggregates. Chemical methods, i.e. various stabilisation methods, aim at increasing the strength and rigidity of materials, and reducing their susceptibility to conditions (moisture, frost). The binding agents may be hydraulic or bitumen agents, or different kinds of material treatment agents.

The characteristics of moraine can be changed to better suit road construction by reducing the fine aggregate content by means of a mechanical or chemical (stabilisation) method. When the fine aggregate content is reduced, frost-susceptible moraine becomes non-frost-susceptible. The bearing capacity and stability of wet moraine will also be increased at the same time. Mechanical refining aims at reaching a desired grain size distribution for moraine.

When refining moraine, **separation** can be done by ragging, screening or washing. Separation removes too large stones or excess fine aggregates from the treated rock. When the roughest rock material is taken out, the amount of fine aggregates increases, and vice versa: when fine aggregates are taken out, the amount of rough material increases. Several separation methods are often combined to reach the desired final result (Road Administration, 1993).

The grain size distribution of moraine can be changed by **mixing** materials. When mixing, the starting point is that the characteristics of the mixed material must be better than those of either of the original materials. Mixing two ingredients usually suffices. Common mixing combinations include, for example, moraine and gravel; crushed moraine and crushed gravel; and crushed moraine and crushed rock. If suitable materials are available, mixing is an economic means to changing the grain size distribution of a material (Road Administration, 1993).

Mixing can be done onsite using either a variety of mixing devices (cf. stabilisation mixing machines where rotating blades mix the material). At its simplest, mixing can be done with the scoop of an excavator; the final results may significantly vary when using this method, however. Mixing can be done as stack mixing, meaning by spreading the materials layer by layer, and mixing them onsite. The best final results will be achieved when mixing is combined with screening or another method and the materials are alternated. This may somewhat reduce the profitability of screening because the share of passing materials will increase, and such materials will have to be transported to another treatment area.

Under good conditions the **crushing** of moraine is possible at any crushing plant. The high fine aggregate content of moraine and too high moisture content of a moraine deposit will cause problems for all types of crushing plants, reducing the effectiveness of the method and increasing the price of the final product. Experiences show that crushing becomes more difficult when the moisture content exceeds 6%. The effectiveness of crushing can be increased by combining the process with screening and/or ragging, and screening the incoming material's fine aggregate up to a grain size of 50 mm before crushing. This will increase the capacity of the front crusher, prevent the crusher from being blocked and reduce the wearing of the crusher's jaws (Suni & Salmenkaita, 1996).

Stabilisation makes the soil material rougher and causes the grains to partially adhere. Stabilisation improves the soil material's bearing capacity and reduces its frost-susceptibility. The stabilisation agent may be cement, bitumen, lime or blast furnace sand. Cement and bitumen are used in the stabilisation of fairly rough soil materials which only contain a small amount of fine aggregates, whereas lime stabilisation is best applicable for the stabilisation of fine soil materials containing silt. Small amounts of binding agents (1 - 3%) may be used to improve the stability of moraine and reduce its frost-susceptibility. If one wishes to increase the bearing capacity of moraine, higher binding agent contents must be used. In practice, the amount of binding agent required for reinforcement varies between 4 - 7% in cement stabilisation, 4 - 12% in lime stabilisation and 3 - 5% in bitumen stabilisation.

Stabilised materials may be used in all structural layers of a road, except as the permanent wearing course. Moraine stabilised with cement or bitumen is highly applicable as the subbase and base course in roads with less traffic. A layer of moraine stabilised with lime is also well applicable for busy roads (Road Administration, 1993).

3.2 Pavement quality requirements

The applicability of moraines in unbound pavements depends on their frost-susceptibility characteristics. Frost-susceptibility is usually defined based on the grain size distribution, in accordance with the guidelines of the Road Administration. As a general rule, a material suitable as a pavement material may not be frost-susceptible. The main criteria are that the fine aggregate content with a screen of 0.074 mm is less than 8%, and that the bottom end of the frost-susceptibility curve for the rougher soil type does not extend to the range of the finer soil type (Suni & Salmenkaita, 1996). According to InfraRYL (Rakennustieto 2006), the fine aggregate content of an unbound material in the base course with a screen of 0.063 mm may be a maximum of 6% for crushed rock and a maximum of 9% for crushed gravel when compressed into the pavement.

The applicability of moraines has been assessed based on experience obtained at construction sites of the Road Administration. Essential parameters include the amount of fine aggregate and the amount of stones. Crushable moraine must include as much stone as possible. There should be at least 25% stone and boulders of more than 64 mm and 10 - 20% of fine aggregates with a screening curve of 0 - 65 mm. On the other hand, the stones to be crushed may not be too large, because large stones cannot be crushed. Too large stones must be broken, blasted or removed.

4 Long-term behaviour of test structures

The research project studied the long-term behaviour of old moraine test sites (four sites) and one clay test site by means of damage inventories (all sites), measurements of evenness (moraine sites), frost heave levelling (stabilised moraine sites) and falling weight measuring (clay site). The test sites were 10 to 21 years old. The Peera moraine site was built during a project called Arktinen tie (Arctic Road) in 1986 and the three other moraine sites were built during a research project called TPPT (a research project on foundation structures and pavements of roads) in 1996 - 1997. The clay test site was built during a project called ‘Massastabiloitujen savien hyötykäyttö katurakenteissa’ (‘The utilisation of mass-stabilised clay in pavements’) in 1997.

Homogenisation of the subgrade, stabilisation of the subgrade with cement or Finnstab, intensified drainage, the impact of compacting and the use of reinforcements had been studied at the sites.

All the test structures have performed better or at least as well as the corresponding comparison structures where no such measures have been implemented.

Homogenisation of subgrade is a method where all stones in the subgrade are removed up until a depth which is no longer frost-susceptible. The surface should be compacted before adding the structural layers. There are no actual homogenisation devices available; instead, homogenisation is usually done with an excavator. The method has been locally applied. As an onsite method, it is an affordable, material-economical and easy means to significantly improving the performance of the structure. More extensive utilisation would be possible if the method and devices suitable for the method were separately developed. A more detailed description and guidelines for the method would also promote its utilisation.

Stabilisation of the subgrade and low-quality materials in the structural layers also usually improve the long-term behaviour of structures. The stabilisation depth is more important than the amount of binding agent when reducing the frost-susceptibility of the subgrade. Machines suitable for stabilisation have been developed to a significant extent in the past few years. The method increases the environmental impacts of road construction mainly because of the manufacturing and transport of binding agents. Furthermore, the prices of binding agents have increased lately, and thus the method is currently not as economical as before. The stabilisation of the structural layers may make the rehabilitation of roads and repairing of any pipelines travelling under the roads slightly more difficult.

Reinforcements clearly increase the service life and reduce the damage caused to structures, especially in cases where low-quality materials are used (Korkiala-Tanttu et al, 2003). Reinforcements are especially useful when one wishes to reduce the damage caused to structures by cracks. Reinforcements make the repairing of pipelines more difficult, however, and thus reinforcements in pavements with pipelines are not recommended. If reinforcements are used close to the surface of the structure, repaving may also be problematic.

5 Computational behaviour of moraine in pavements

The new InfraRYL guidelines enable the use of so-called wet materials together with drainage layers in pavements (Rakennustieto 2006). The purpose of the computational reviews was to find out the impacts of the position of the drainage layers in so-called sandwich structures where the subbase consists of moraine. Mixed moraine (where the material of the base course has been combined with the moraine in the subbase) and moraine used as subgrade were reviewed.

The review results show that a drainage layer under mixed moraine will reduce the water content of the entire subbase surface in a layer that is approximately 0.5 metres thick. Naturally, the affected depth depends on the location and fluctuation of the groundwater level. The water content will be reduced by approximately 7 per cent by volume at the road centre line.

A drainage layer in the middle part of a road will reduce the water content of the layers above and below the drainage layer. At the road centre line, the water content of the bottom part of the top layer will be reduced by approximately 8 vol -%, and that of the bottom layer by approximately 4 vol -%.

Horizontal drainage layers also improve the quality of the structure in other ways: the materials' susceptibility to the prevailing conditions during construction will be somewhat reduced, and the layered structure will dry out faster both during construction and during use.

If the crushed gravel in the base course is graded, the maximum difference between the strain modules may be approximately 80 MPa between different water contents. In the base course, this would mean a difference of approximately seven per cent in the bearing capacity. When the module of the crushed gravel in the base course is 320 MPa the bearing capacity is 228 MPa, and with the module 240 MPa the bearing capacity is 212 MPa.

Based on the results of the computational reviews, different kinds of drainage solutions may somewhat influence the amount of water contained in the structure, but the impact on, for example, frost heave will be minor because moraine is such a dominating material in terms of the moisture behaviour of the structure.

Drainage solutions will clearly level out the transversal-bearing capacity of a road by influencing the water content of the base course. A filtering layer under the base course, combined with a diagonal drainage layer in the slope, will reduce and level out not only the water content of the base course but also the water content of the mixed moraine layer. This will improve homogeneity of the structure and reduce its susceptibility to climatic stress.

6 Vuores pilot site

6.1 Presentation of the site and research objectives

Vuores is located on the border between the City of Tampere and the municipality of Lempäälä. It is a joint district development site of Tampere and Lempäälä. Vuores is one of the largest urban construction projects in Finland in the new millennium. The plan is to construct homes for 13,000 residents and facilities for companies employing 3,000 - 5,000 people in the area by the year 2015. Homes equipped with modern top technologies will be built in Vuores: small blocks of flats, terraced houses, semi-detached houses and detached houses. The City of Tampere has established a Vuores project to carry the responsibility of the area's design and construction (www.tampere.fi/vuores). The municipal engineering construction work should begin by the end of the year 2008.

A total of more than 1.5 million cubic metres of soil material will be handled in the Vuores area, and even based on a cautious estimate, there will be close to a million cubic metres of excess materials. Furthermore, approximately a million cubic metres of structural layer materials will have to be transported to the area. A soil bank was being planned for the area in order to clearly reduce the amount of material to be transported.

The objective with the HUUMA project was to develop methods to promote the use of low-quality soil materials in the area in cooperation with the Vuores project and the area's consultant (Ramboll Finland Oy). The task was to jointly assess the opportunities to utilise and refine the excess materials and study the schedules and available space. Another task was assessing the environmental, performance and cost-related benefits arising from the use of various refining methods.

6.2 Managing materials in the Vuores area

A general mass economy plan for the Vuores area was drafted at the beginning of the year 2007. An operating model proposal for the area was drawn up based on the model. The proposal suggested a soil bank system which could include all the parties operating in the area, including contractors. The soil bank system was designed in such a manner that the Street and Green Area Development Unit of the City of Tampere (KAVI) would manage it. The system was planned to serve a more extensive area in Tampere, Lempäälä and the surrounding areas. An essential part of the system was the establishment of a soil reception area. The plan was to include soil material refining and treatment activities and also possibly refining and treatment of cleared materials, stumps and small trees in the reception area. The principle with reception and handling fees was that only the costs of the activities would be covered. A material management tool was designed as the method to manage material data. Each of the parties - including the building firms operating in the area - could deliver information to the system. The plan was that the material data would be offered free of charge. Furthermore, the plan was that the treatment and storage of topsoil, stumps, small trees and any asphalt would also be managed by the organisation.

Implementation of the soil bank system in its planned form was cancelled in the beginning of the year 2008 when the City of Tampere decided to arrange a competitive bidding process for the road works of the entire Vuores area. At that time, KAVI deemed the preconditions for starting the soil bank organisation insufficient because KAVI's share of the road works was uncertain due to the competitive bidding. No final decisions have yet been made.

According to site investigations done in the Mäyränmäki district, most of the cross section materials in the area are loamy silt or lean clay. Some muddy silts were also observed. Furthermore, there was some moraine in the Palkkionmaankatu street area, mostly gravelly sand moraine. The amount of stones in the moraine is difficult to assess because sounding results only include a couple of findings of stones. It is likely that the soil layers include single stones or even boulders.

According to the Mäyränmäki district street plans, the moraine in the area could be utilised without refining as mixed filling material, in noise barriers and as ramp filling material in the area. The moraine will be usable, especially if excessively large stones are removed from it. When refined, the moraine could be used in filling the area's pedestrian and bicycle routes and their layered structures, for example. Furthermore, moraine could be placed in the yard structures of buildings. In addition to possible crushing, applicable refining methods include adding rough stone material.

6.3 Problems with utilisation in Vuores

Several problems or barriers to the utilisation of low-quality materials were observed during the Vuores pilot project. Such problems and barriers can easily ruin utilisation plans. In this case, the most major problems observed were permit practices; appeals connected to permits and land use planning issues; issues pertaining to schedules and storage space; competitive bidding requirements; lack of environmental and financial incentives; and the fact that the working techniques, products and methods for refining low-quality materials have not been commercialised. An additional problem is the lack of risk-sharing principles.

A major issue when preparing district development sites is the management of land use planning and permit procedures. People easily lodge complaints regarding the local detailed plans and complaints are often handled in several court instances which will postpone decision-making for an indefinite time. Another problem with district development sites is the fact that several parties will construct buildings on several plots of land, streets will be built and other construction projects will be ongoing at the same time. Each party has its own way of taking care of its material economy, and the material acquisition activities are based on the parties' private soil excavation sites or private acquisition networks. Each party will try to optimise its own project, especially from the economical viewpoint, and it is difficult to achieve a good final result to benefit the entire area based on such starting points. Thus, new and sufficiently controlling factors are required to manage the material economy as a whole. Such guiding factors may be the price level of soil reception sites, different types of waste taxes and requirements posed at the competitive bidding stage, environmental impact assessments or recommendations for material handling.

The soil bank system planned during the course of this project would have been an excellent opportunity to manage the materials in the Vuores area. The plan was ruined by the decision of the City of Tampere to arrange a competitive bidding process for the road works of the entire area, however. Thus, the statutory competitive bidding obligation of the public sector limits the creation of such non-profit material bank organisations working under the control of the public sector. An alternative could be offering such banks for the private sector. This would require an adequate supply of areas suitable for soil reception points, however.

7 Economical, environmental and performance assessments of comparison structures

7.1 General

The research project compared alternative road, pedestrian and bicycle route and yard structure implementation methods in which moraine has been utilised. Street structures were not included in the comparison, because a road is a reasonably good representation of such a structure. On the other hand, a road is clearly a more demanding structure than a street when kerb stones and/or pipelines are included. Production issues, economic efficiency, environmental impacts and performance of the comparison structures were compared in a computational manner. A description of the production issues is included in Chapter 4.

7.2 Road structure

The layer thicknesses of the selected road structure correspond to the test structure implemented in Kiuruvesi. The road was eight metres in width (pavement 7 metres). Pitch of the side ramps of the road was 1:3. The structures calculated during the comparison were 100 metres long. The road structure was compared to an alternative where the moraine used as the subgrade is treated in such a manner that the pavement can be made thinner (series A). Another studied series (B) were structures in which refined/treated moraine is placed in the subbase of the structure. Furthermore, an alternative in which the drainage of the structure is improved (C) was studied. The structures were compared to a so-called basic structure, i.e. a structure designed in accordance with the current guidelines (A.2).

Table 8.1. Compared road structures and their fabrication steps.

Alternative	A.1	A.2	A.3	A.4	A.5	A.6	B.1	B.2	B.3	B.4	C
Pavement and thickness, mm	AB 50	**AB 50**	AB 50	AB 50	AB 50	AB 50	AB 50	dense AB 50	AB 50	AB 50	AB 50
Amount of pavement, m^3	38	**38**	38	38	38	38	38	38	38	38	38
Pavement transportation distance, km	20	**20**	20	20	20	20	20	20	20	20	20
Base course, crushed gravel 0–32/50 thickness, mm	200	**200**	200	200	200	200	200	200	200	200	200
Subbase, crushed gravel 0–60	SrM	**SrM**	SrM	SrM	SrM	SrM	Mr	Mr	Mr	Mr	SrM
Thickness, mm	300	**300**	300	300	300	300	500	500	500	500	300
Filter layer, sand, thickness, mm	400	**400**	400	400	400	400	200	200	200	200	400
Other measures		*	**	†	‡	∩		∩∩	‡‡	***	‡‡‡

* Base homogenisation includes removal of stones from the moraine up to a dept of approximately one metre and compression of the surface.

** Homogenisation and adding rough stone matter (mixing old structural layers and crushing stones in the moraine), constructed onsite.

† Onsite homogenisation and adding rough stone matter, transportation to crushing plant and back 10 km.

‡ Homogenisation, adding 4% of universal cement and mixing onside, binding agent transportation distance 30 km.

∩ Homogenisation, adding 4% of blast furnace slag and mixing onside, binding agent transportation distance 60 km.

∩∩ HDPE geomembrane (plastic film) 1 mm and 1,200 g/m^2 of non-woven materials on either side of the films.

‡‡ Moraine in the subbase stabilised with 5% blast furnace slag.

*** Moraine on top of the subbase and base course, steel mesh B500H - 5/8 - 150/200.

‡‡‡ 200 m weeping drain pipes, diameter 100 mm, 10 manholes, diameter 400 mm, elevation 1,000 mm, surrounded by approximately 25 m^3 of weeping drain gravel.

Cost comparison

The costs of the comparison structures were compared in euro (VAT 0%), not binding, based on the cost level from constructing several kilometres of road. The unit costs comply with the price level in the summer of 2008. The cost estimate prices have been calculated as costs incurred to the client, i.e. including general costs and work costs. The cost comparison is presented in Table 8.2.

The most affordable structure in both comparison series (A and B) was the simplest one. In order to function, both structures require a homogenous foundation, i.e. a site where there is no need to homogenise the subgrade. In practice, Structure A.2 would be feasible if the subgrade was moraine. This is why the structures have been compared to comparison Structure A.2. Adding rough material onsite would only increase the price by approximately one per cent; if rough materials were to be added at a crushing plant, the price increase would be approximately 5 - 6 per cent. Thus, adding rough material (the assumed amount was approximately 8%) is a quite affordable means to improve the performance of a structure. Stabilisation with blast furnace slag and constructing weeping drains are also cost-effective means (price increase 9 - 10%) of improving the performance of a structure. Stabilisation with cement proved to be the most expensive subgrade improvement method.

Table 8.2. Compared road structures and their total costs.

Alternative Subgrade treatment	A.1 No homogenisa-tion	A.2 Basic structure, homoge-nisation	A.3 Homoge-nisation and adding rough material	A.4 Homoge-nisation and adding rough material at crushing plant	A.5 Homoge-nisation and stabilisa-tion with universal cement	A.6 Homoge-nisation and stabilisa-tion with blast furnace slag	C Weeping drains
Total costs, €/100 m	28.114	**31.989**	32.389	33.739	41.739	34.989	35.564

Alternative Subbase moraine	B.1 Basic structure	B.2 Plastic film under moraine	B.3 Stabilised with blast furnace slag	B.4 Steel mesh
Total costs, €/100 m	**20.611**	39.399	27.461	25.171
Total costs when homogenised, €/100 m	**24.486**	43.274	31.336	29.046

Using low frost-susceptible moraine in the structural layers is more affordable than using crushed rock, except in the case of the alternative including a geomembrane (B.2), even if the homogenisation of the subgrade is added to the costs. A homogenised moraine structure is approximately 24% cheaper than crushed rock structure. The performance of the structure can be further improved by adding steel mesh (B.4) or stabilising the moraine with blast furnace slag (B.3). Both improvement alternatives are approximately 15 - 22% more affordable as non-homogenised than the structure including crushed rock, and their functional characteristics are similar to that of the crushed rock structure.

Environmental loads of the compared structures

The environmental impacts of the compared structures were calculated by using an Excel-based software called Meli (Eskola et al, 1999; Laine-Ylijoki et al, 2000). The Meli software can be used to calculate and compare the environmental impacts of various road structure alternatives. The software is based on the assumption that average working methods and machinery are used, and the material database of the software is limited to the most commonly used road construction materials. The Meli software does not include some of the materials and fabrication steps of the compared structures. Because of this, Structure B.2 was excluded from the comparison, and the environmental impact data of weeping drain pipes and manholes is not included in the data for Structure C. A system called TRALCA, VTT's internal transport and construction machine lifecycle emission calculation system, was utilised for the missing data in the calculation (Mäkelä, 2008).

Table 8.3 includes the environmental loads of the road structures calculated by Meli. Figure 8.1 shows a rating of the environmental impacts of the structures with the weighting factors included in Meli; the factors allowed for calculating environmental quality ratings depicting the total environmental impacts. For a more detailed description of the method used, please see the report of Eskola et al. (1999).

Table 8.3. Environmental loads of the compared structures.

Total environmental loads	A.1	A.2	A.3	A.4	A.5	A.6	B.1	B.3	C.1
CO2, kg	12 239	12 372	12 780	15 390	36 588	12 925	9 129	9 710	12 302
CO, kg	27.1	27.7	29.8	32.7	94.1	30.9	14.0	16.8	27
NOx, kg	118	120	125	148	208	126	76.2	82.9	118
SO2, kg	13.9	13.9	14.4	14.9	20.0	14.6	11.3	11.3	14
Particles, kg	9.84	9.97	10.5	11.3	23.8	10.9	6.25	7.02	10
CH4, kg	0.00	0.01	0.01	0.03	0.97	0.30	0.02	0.23	0.00
HC+VOC, kg	22.6	22.9	23.8	25.3	24.5	24.3	17.0	18.2	23
N2O, kg	0.00	0.00	0.00	0.08	0.23	0.23	0.01	0.18	0.00
Used energy (non-renewable), GJ	114.8	116.6	118.4	123.2	231.9	117.2	94.0	95.8	114.9
Utilisation of natural materials*, tons	1772	1772	1772	1772	1851	1772	777	777	1817
Utilisation of by-product materials, tons	0	0	0	0	0	24	0.0	29.5	0
Utilisation of low-quality materials (moraine), tons	0	0	0	0	0	0	1063	1063	0

Structure C is not directly comparable with the others.

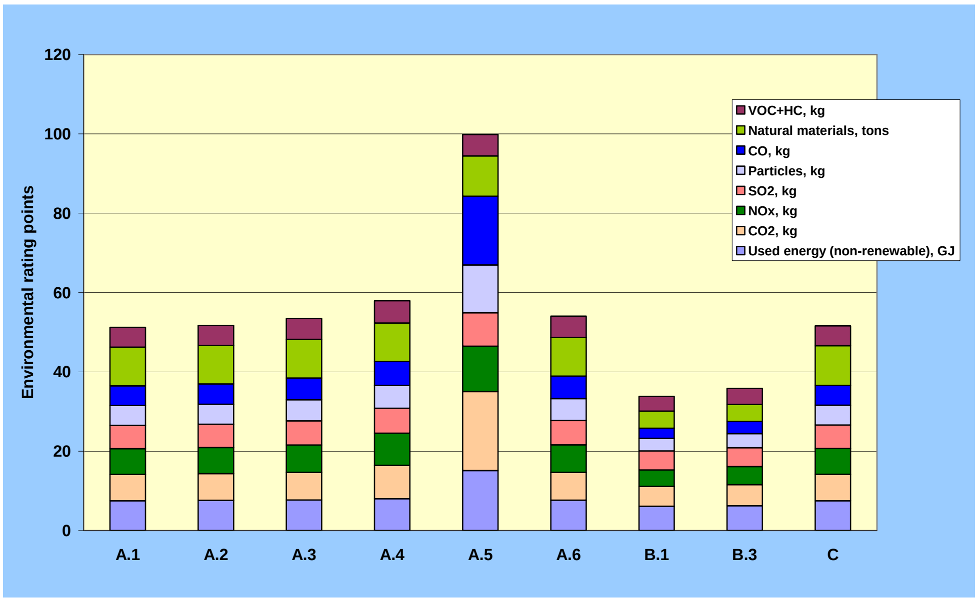

Figure 8.1. Rating for the compared road structures with the Meli software.

The relative weighting factors given in the Meli report by Eskola et al. (1999) have been used in calculating the environmental rating points given in Figure 8.1. When comparing the structures of Series A with each other, one can see that Structure A.5, the alternative where cement is used to stabilise the subgrade, has clearly the highest environmental impact. The environmental impacts are roughly double when compared to the basic Structure A.1; almost triple in the case of carbon dioxide emissions. The significant difference is almost completely due to the production of cement which requires a lot of energy. The good results for the blast furnace slag structure are based on the assumption that the production of the slag does not generate any environmental loads because it is a by-product. Using moraine in the structural layers (B.1 and B.3) is clearly a more environmentally friendly alternative (by approximately 15 - 18%) than improving the subgrade in the case of all the studied environmental impacts.

Performance comparison

The performance of the structures was compared by the project team and a consultant. The performance comparison was a classifying comparison, and the results are included in Table 8.3. Among the compared factors, compactibility, susceptibility to conditions during construction and problems with excavation work have hardly any influence on the service life of the structures. These qualitative results cannot be directly transferred into the service life of the structures. Quantitative data about the impacts of steel mesh in service life is available (Korkiala-Tanttu et al, 2003).

In this case, the structures were also compared in relation to Structure A.2. In the classification, the value 0 was the basic value, i.e. no impact could be discerned. If a structure was deemed to perform better, it received a positive value, and the maximum positive value was +++. Similarly, a structure deemed to perform worse was issued a negative value, a maximum of ---.

Based on the performance comparison, all the subgrade measures (A.3, A.4, A.5 ja A.6 and C) improve the performance of the structures, either to some extent or significantly. Using moraine in the subbase reduces the performance of the subbase to some extent in all alternatives. If a steel mesh is added to the moraine structure or if the moraine is stabilised with blast furnace slag, the performance will be somewhat or even significantly improved.

Table 8.3. Risks of the compared road structures in performance (+++, ++ ,+, +/-,-,--,---, 0 = basic value / no impacts discerned) in relation to structure A.2.

Alternative Subgrade treatment	**A.1 No homo-genisa tion**	**A.2 Basic structure, homog-enisation**	**A.3 Homoge-nisation and adding rough material**	**A.4 Homogeni-sation and adding rough material at crushing plant**	**A.5 Homoge-nisation and stabilisati on with universal cement**	**A.6 Homogeni-sation and stabilis-ation with blast furnace slag**	**C Weepin g drains**
Frost heave total	-	0	+	+	++	++	+
Risk of damage due to uneven frost heave	---	0	+	++	++	++	+
Fatigue susceptibility	+	0	++	++	++	++	+
Susceptibility to rutting	-	0	++	+++	++	++	+
Spring bearing capacity	0	0	+	+	++	++	+
Susceptibility to conditions during construction	+	0	+	+	0	0	0
Compactibility	+	0	+++	+++	++	++	0
Problems with excavation during rehabilitation	0	0	0	0	-	-	0

Alternative Subbase moraine	**B.1 Basic structure**	**B.2 Plastic film under moraine**	**B.3 Stabilised with blast furnace slag**	**B.4 Steel mesh**
Frost heave total	-	0	0	-
Risk of damage due to uneven frost heave	-	0	0	++
Fatigue susceptibility	-	-	+	+
Susceptibility to rutting	-	-	+	++
Spring bearing capacity	-	0	+	+
Susceptibility to conditions during construction	-	--	-	-
Compactibility	-	-	0	0
Problems with excavation during rehabilitation	-	--	-	---

7.3 Yard structures and pedestrian and bicycle route structures

The comparison structure selected for yard structures, D.1, was an asphalt pavement alternative recommended for residential construction in the InfraRYL guidelines. A solution where the crushed gravel in the subbase is replaced with low frost-susceptible moraine was developed as an alternative solution. The potential filling material under the structure was also low frost-susceptible moraine. In alternative D.3, a steel mesh was added to the moraine structure in between the base course and the subbase. The comparison was done by comparing the environmental impacts and costs from the construction of 1,000 m^2 of yard structures. Similar structural alternatives were developed for pedestrian and bicycle routes (Series E). The comparison of the structures is presented in Table 8.4.

Table 8.4. Contents and fabrication steps of the yard structure alternatives and the pedestrian and bicycle route structure alternatives.

Alternative	D.1	D.2	D.3	E.1	E.2	E.3
Pavement and thickness	AB 50 mm	AB 50 mm	AB 50 mm	AB 50 mm	AB 50 mm	AB 50 mm
Pavement transportation distance, km	15	15	15	15	15	15
Base course crushed gravel 0–32/50 Thickness, mm	150	150	150	250	250	250
Transportation distance	15	15	15	15	15	15
Steel mesh			B500H - 5/8-150/200			B500H - 5/8-150/200
Subbase	Crushed gravel 0–60	Slightly frost-susceptible moraine	Slightly frost-susceptible moraine	Crushed gravel 0–60	Slightly frost-susceptible moraine	Slightly frost-susceptible moraine
Transportation distance	15	0	0	15	0	0
Thickness, mm	250	400	400	300	400	400
Filter layer, sand, thickness, mm	200	300	300	300	400	400
Transportation distance, km	15	15	15	15	15	15
Base filling material (approximately 1 m)	Non-frost-susceptible filling soil, 1 m	No stones, low frost-susceptible moraine, 0.75 m	No stones, low frost-susceptible moraine, 0.75 m	Non-frost-susceptible filling soil, 1 m	No stones, low frost-susceptible moraine, 0.8 m	No stones, low frost-susceptible moraine, 0.8 m
Transportation distance	15	0	0	15	0	0

Cost comparison

The costs of the yard structures (Series D in Table 8.5) correspond to the construction costs of 1,000 m^2 of yard space, and the pedestrian and bicycle route structures (Series E) correspond to the construction of 100 metres of such route.

Table 8.5. Total costs of the yard structures and the pedestrian and bicycle route structures.

Yard structures	D.1 Crushed structure	D.2 Moraine structure	D.3 Steel mesh
Total costs, €/100 m	43,680	**35,200**	40,000
Pedestrian and bicycle route	**E.1 Crushed structure**	**E.2 Moraine structure**	**E.3 Steel mesh**
Total costs, € / 100 m	23,824	**18,143**	20,111

In both series, the most affordable structures were those including low frost-susceptible moraine available onsite. The costs increased by approximately 11% when steel mesh was added to the structure on top of the subbase. The structure including crushed gravel was approximately 8 - 9% more expensive than the structure including steel mesh and moraine.

Environmental loads

For the pedestrian and bicycle routes, an embankment with a total width of four metres, of which three metres were paved, was studied. The other structural dimensioning principles were the same as for the yard structures. The review was based on the assumption that the moraine is available onsite and can be refined onsite, if necessary. The Meli software does not include the raw material amounts required when manufacturing steel mesh, and thus the utilisation of steel mesh is not included in the consumption of natural resources. Figure 8.2 includes the results rated by using the weighting factors (environmental quality points).

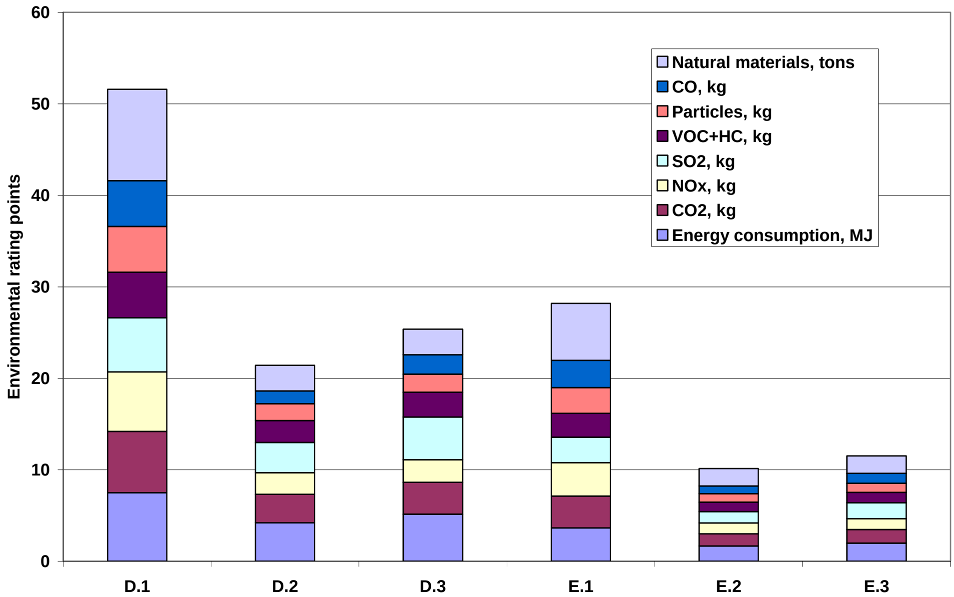

Figure 8.2. Rating of the yard structures and pedestrian and bicycle route structures with the Meli software.

Replacing stone material with moraine clearly reduces the environmental impact of structures. The reduction is due to the fact that emissions caused by stone material excavation, crushing and transportation can be avoided.

Performance comparison

As above, the performance comparison (Table 8.6) was done by comparing the alternative structures to each other. In this case, the comparison structures used where crushed material structures D.1 and E.1.

Table 8.6. Performance assessment for the yard structures and pedestrian and bicycle route structures in relation to the type structure (+++, ++ , +, +/-,-,--,---, 0 = basic value / no impacts discerned) in relation to structures D.1 and E.1.

Yard structures	**D.1 Crushed structure**	**D.2 Moraine structure**	**D.3 Steel mesh**
Frost heave total	0	-	-
Risk of damage due to uneven frost heave	0	-	+
Fatigue susceptibility	0	-	-
Susceptibility to rutting	0	-	-
Spring bearing capacity	0	-	0
Susceptibility to conditions during construction	0	--	--
Compactibility	0	-	-
Problems with excavation during rehabilitation	0	0	---
Pedestrian and bicycle route	**E.1 Crushed structure**	**E.2 Moraine structure**	**E.3 Steel mesh**
Frost heave total	0	-	-
Risk of damage due to uneven frost heave	0	-	+
Fatigue susceptibility	0	-	-
Susceptibility to rutting	0	-	0
Spring bearing capacity	0	-	0
Susceptibility to conditions during construction	0	--	--
Compactibility	0	-	-
Problems with excavation during rehabilitation	0	0	---

One can assume that the moraine structures will perform slightly worse than crushed rock structure in almost all aspects, and thus the comparison includes more negative than positive values. One can say, however, that the service life of the moraine structure with a steel mesh is similar to that of the structure with crushed material.

8 Further utilisation potential of moraine refining

A team consisting of members of the project steering group and researchers was posed questions in a workshop regarding the opportunities to increase the utilisation of unrefined moraine and refined moraine. According to the results, the utilisation of moraine can be increased the most on public roads by means of refining, by almost 15 percentage points, which means that the utilisation can be almost doubled. The available increase in the cases of streets, private roads and access roads is approximately five percentage points, and the available increase in railroads is almost the same.

9 Conclusions

The objective with the research project was to study and promote the utilisation opportunities of low-quality materials as materials replacing more high-quality materials (sand, gravel, crushed stone and crushed rock). Utilisation can reduce the need to stack materials and the amount of materials to be transported. When materials are utilised onsite, costs will also be reduced and the environmental impacts due to transportation will be lower.

A proposal on the opportunity to utilise moraines, in particular, in the structural layers of roads and streets and in other sites requiring filling soil was drafted during the research project. There are clear opportunities to increase the utilisation of both refined and unrefined moraines in infraconstruction in Finland. It was estimated that there is potential to increase the utilisation of refined moraine by approximately 15%. The utilisation of unrefined moraines can also be increased. So far, the attempts to refine moraine have been scattered, and the refining methods have not been commercialised nor have any guidelines for the methods been compiled.

The utilisation of moraines is often made more difficult by their high fine aggregate content and the amount of stones in them. Onsite refining methods include crushing, removal of fine aggregate (with certain reservations) and stones, mixing rougher material with moraine and stabilisation. Already existing moraine can be affordably refined as the subgrade by means of homogenisation.

Low frost-susceptible moraines can be used in structural layers, provided that sufficient drainage is achieved. The computational reviews show that drainage layers can somewhat reduce the amount of water in the structure and level out the road’s transverse bearing capacity. The service life of such structures can be further increased by using reinforcements. The damage caused to the structures can also be reduced at the same time.

In a comparison of the costs, performance, production loads and environmental loads, low frost-susceptible moraine structures proved to be cost-efficient, functional and more environmentally friendly than the normally used structures including crushed stone in roads, in pedestrian and bicycle routes and in yard structures. Structures including steel mesh and moraine in the subbase, whose performance was assessed as similar or better, were approximately 10% cheaper than similar structures utilising crushed stone.

The most important barriers to the utilisation of the moraine-containing structures presented in this study are the lack of experience in their utilisation and performance risks. Since the service life of soil structures is long, one does not wish to risk any adverse effects in the long term. The actual utilisation of moraine cannot be significantly increased without the trust of clients and contractors in the performance of the structures; in such a case, the only means to increase its utilisation is using it at secondary sites. The performance of the structures can only be proven by constructing test structures and by monitoring the structures in a coordinated manner in the long term.

Other barriers to the utilisation of low-quality materials or problems with their utilisation were also observed during the research project. In this case, the most major observed problems were permit practices; appeals connected to permits and land use planning issues; issues pertaining to schedules and storage space; competitive bidding requirements; lack of environmental and financial incentives; and the fact that the working techniques, products and methods for refining low-quality materials have not been commercialised.

A major issue in the case of district development sites is the management of land use planning and permit procedures. Areas reserved for soil management activities and temporary storage must be allocated at the land use planning stage. Another problem with district development sites is the fact that several parties will construct buildings on several plots of land, streets will be built and other construction projects will be ongoing at the same time, and each party will optimise the economical aspects of its own project. Conditions for participation in local material handling arrangements should be considered as a prerequisite for the surrender of a plot of land.

The refining and utilisation of low-quality materials must also be promoted by changing the competitive bidding procedures. The public sector must start to select the most comprehensively feasible offer and also take into account the utilisation of natural materials and the transportation required by the offered alternatives when rating quality issues. Another alternative is controlling the activity by means of soil material reception fees or waste taxes; these would increase the costs in the short term, however.

The most important arguments in favour of increasing the utilisation of low-quality soil materials are saving the natural resources and the reduction of detrimental environmental impacts. In addition to the development of single techniques, the authorities and other parties operating in the sector must commit to the utilisation, and measures to reach the environmental objectives must be defined.

10 Proposed further research projects

In the future, more clearly defined assessment methods and computational tools will be needed in order to assess the environmental impacts of alternative solutions, and the benefits that can be reached by using and refining local materials. The clients' interest in using ecological efficiency as one selection criterion in road investments will also increase the need to develop these systems and tools.

Ecological efficiency can only be taken into account in the acquisition process if there are guidelines or generally approved methods for including the environmental impact in the decision-making process pertaining to acquisitions. There probably will be such procedures for each sector and contract type based on the generally approved rules of the game. Thus, the procedures should be developed in cooperation with the sector.

An increase in the utilisation will also require the commercialisation of moraine refining methods and guidelines pertaining to the methods supported by the development of equipment and methods.

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