Seasonal changes in water content of subsoil beneath old slab-on-ground structures in Finland

Virpi Leivo*, Research Scientist, Tampere University of Technology, Structural Engineering, P.O.Box 600, FI-33101 Tampere, Finland

Jukka Rantala, Principal Lecturer (Research), Innosteel, Hame University of Applied Sciences, Laajamäentie 1, 13430 Hämeenlinna, Finland

*Corresponding author, tel. +358 3 3115 2961, Fax. +358 3 3115 2811, Email. virpi.leivo@tut.fi

Abstract (100 words) The objective of study was to determine the normal level of water content of the subsoil beneath old slab-on-ground structures and discuss impact of the thermal and moisture conditions. According to the measurements the water content of subsoil beneath a slab-on-ground structure equals or exceeds the hygroscopic equilibrium moisture content of the material in RH 100%. The high water vapor content with warm subsoil temperature can cause moisture damages to the floor covering. In fine-grained soils where capillary action is possible often some excess capillary water is detected at the samples. The amount of capillary bound water and risk for damage is dependent on distance from the ground water table.

Key words: Slab-on-ground, Water content, Subsoil, Capillary, Diffusion

Author Biographies

M.Sc. Virpi Leivo is a Research Scientist at the Laboratory of Structural Engineering in Tampere University of Technology. Her main research for the last 6 years has been study of the thermal and moisture behavior of slab-on-ground structures.

Ph.D. Jukka Rantala is a Principal Lecturer (Research) in Hame University of Applied Sciences. His main research during the past decade have involved study of foundation structures and the building physics of slab-on-ground structures.

Seasonal changes in water content of subsoil beneath old slab-on-ground structures in Finland

INTRODUCTION

Slab-on-ground structures are always in contact with moist subsoil. The thermal and moisture conditions of the soil dictate the physical behavior of the slab-on-ground structure above it. The transfer of moisture from the soil to the slab structure above can be as capillary water or as hygroscopic water vapor, or both. Usually the direct capillary flow of water has been prevented by use of a coarse-grained capillary break layer under the slab structure. In many cases involving moisture damage the capillary break has only partly prevented capillary action which has led to various moisture and mold problems. Also hygroscopic (diffusion) moisture transport from the warm subsoil to the interior can cause similar moisture and mold problems in the space above the slabs. While deliberating the repair methods that should be used for the damaged slab-on-ground structure the actual cause of the damage in question should be carefully examined in order to find the best solutions.

In order to examine thermal and moisture behavior of a slab-on-ground structure, the thermal and moisture conditions of the fill and drainage soil layers beneath the structure in normal operating conditions should be known. Several research series concerning thermal and moisture behavior of the slab-on-ground structures have been made over the years at the Tampere University of Technology. Both capillary and hygroscopic equilibrium curves for typical Finnish coarse-grained fill and drainage materials (Leivo, V., Rantala, J. 2003) (Rantala, J., Leivo, V. 2004), as well as the thermal and moisture changes beneath slab-on-ground structure during the first year after construction (Rantala, J., Leivo, V. 2004) have been determined in previous studies.

The objective of this study was to examine the actual water content of the subsoil in contact with existing slab-on-ground structures and the effect of seasonal changes on these results and discuss impact of the thermal and moisture conditions beneath ground floor to structural behavior. The knowledge of normal thermal and moisture conditions beneath slab-on-ground is essential in designing structures and planning repairing methods.

FIELD TEST BUILDINGS AND TESTING PROCEDURE

Examined Buildings

In order to examine the water content of the subsoil and seasonal changes under slab-on--ground structures data was obtained for 35 ground slabs of actual buildings. The examined buildings were chosen from 7 cities, named Helsinki, Turku, Lahti, Tampere, Jyväskylä, Kuopio and Oulu (Figure 1). In most of the buildings there were no detected moisture problems related to the ground slabs. Most of the buildings were public structures, such as schools and day-care centers, and some were apartment buildings. The age of the buildings varied greatly; the year of construction ranged from 1910 to 2005. The structural composition of the slab-on-ground structures varied but they can be roughly divided into 3 groups. Distribution of the buildings by age and by the type of the slab-on-ground structure is presented on Figure 2. The three basic structural types are presented on Figure 3. Structure type 1 is a thermally insulated slab, which is now commonly used in contemporary structures in Finland and other cold region countries. According to existing Finnish building regulations no moisture barrier is required to be placed under the slab structure. In buildings of this type, a moisture barrier of plastic sheeting, if used, was placed either above or below the thermal insulation layer. In most of the examined slabs of this type expanded polystyrene (EPS) was used as the insulation material. In a few cases mineral wool insulation was used. All of the slab structures in new buildings were this type. The structures of the old buildings (1910-1960) were different belonging the other two types identified. Type 2 consisted of an un-insulated slab, which was commonly used for old buildings. Type 3 consisted of a so-called double slab, where a lower thicker concrete slab was employed for bearing or for transferring loads to the supporting ground piles. Various materials were used between the lower and upper slabs: thermal insulation, plastic sheeting, a bitumen coat, paper or there is a cold joint (top slab is poured on the base slab). In 89 % of all cases the soil material of the fill or drainage layer beneath the examined slab-on-ground structures was not coarse enough to stop all capillary flow from the soil mass below, even though the recommended grain size distribution curves for the soils to be used as capillary break layers beneath ground slabs has been known for many years.

Testing Procedure

The moisture content of the subsoil beneath the slab-on-ground structures was determined twice for each building: the first time in early spring and the second time in late summer 2005. The first measuring round, beginning in the southern cities was performed while the ground around the buildings was still frozen or the thawing has just began between mid March to mid April. The second round of measurements was performed in August.

A 100 mm diameter hole was drilled through the concrete slabs and 2 samples of the soil were taken and stored in watertight plastic bags. The water content was determined by measuring the weight loss of the sample by oven drying. The drill holes were then carefully sealed and the sampling was made from the same holes during the second round of measurements. In the first round of visits the moisture content was able to be determined only from the insulated slabs or slabs with plastic sheet below them because drilling through the concrete required some water for cooling and this water wetted the soil mass.

TEST RESULTS

Figure 4 presents the moisture content obtained for the subsoil in the Spring 2005 visits for the cases where the thermal insulation or the moisture barrier under the subsoil prevented wetting during drilling. The moisture content has been presented as a percentage of the dry weight of soil. The typical density of the coarse-grained soil was between 1600 to 2000 kg/m^3.

Figure 5 illustrates the determined moisture content obtained for subsoil in the Autumn 2005 visits for all the cases studied.

The change in moisture content between the two visits could be reliably determined for only 19 cases. These changes in water contents between the Spring and Autumn 2005 visits are presented in Figure 6.

It can be seen from Figure 5 that the moisture contents of the coarse-grained soil samples were lower (0,3 … 0,6 weight-%) than in the fine-grained soils (0,1 … 13,8%). The moisture contents of the coarse-grained soil samples correspond to the hygroscopic equilibrium moisture content (Figure 7, drainage gravel) at 100 % relative humidity (RH), as determined in the laboratory test series (Rantala, J., Leivo, V. 2004). In fine-grained soil samples the moisture content was in most cases higher than the hygroscopic equilibrium moisture content (EMC) at RH 100% (Figure 7, fine sand). In only Case 26 was the moisture content less than the equilibrium hygroscopic moisture content. That particular sample was taken beneath the heat distribution room with plenty of heat pipes, some of which were poorly uninsulated, crossing under the slab. According to the previous laboratory tests (Rantala, J., Leivo, V. 2004), the transport of capillary water is strongly dependent on the distance from the free water table (Figure 8). Only the smallest capillary pores (micro pores) can transport water to the upper limit possible by capillary action while soils having larger pores only achieve equilibrium in the hygroscopic moisture range. The moisture content of most fine-grained soil samples is such that the capillary rise has occurred only to some degree. The moisture content of samples 8, 10 and 11 was higher and in these cases it was also evident that the ground water table was very close to the soil surface at the building site. Besides capillary rise from the ground water table, moisture in the soil mass can also be transported vertically from above from melting snow, surface water and other sources of free water.

Seasonal changes (Figure 6) in water content of the subsoil samples were quite small. The samples measured in the Spring 2005 visits were exceptionally dry and the total rainfall records during the summer and autumn of 2005 (as provided by the Finnish Meteorological Institute, 2005) demonstrated that heavier usual rainfalls occurred in the cities where the case buildings were situated (Figure 9), though most of the heavy rains in August 2005 occurred after the second measuring round. In some cases (17, 23) the higher water contents were detected in the spring when the snow cover and ground frost were melting.

DISCUSSSION

Water vapor diffusion from the soil layer to the above slab-on-ground is dependent on temperature of the soil layer. According to previous research (Rantala, J., Leivo, V. 2004) the heated building warms the soil layer beneath. If there is no thermal insulation in the structure the soil temperature is near indoor temperature. Even if the 50…100 mm of EPS is used the temperature varies in level +12…+16 ºC, depending on outdoor temperature and thermal conductivity of the subsoil. Above mentioned temperature levels with high relative humidity (RH 100%) dictate that the water vapor content of the soil layer is yearly in many cases higher than water vapor content of the indoor air. Specially indoor air is very dry (RH < 30%) in winter times. Therefore the direction of the water vapor diffusion is upwards and can cause moisture damages, especially under water vapor tight floor covering. The higher the soil temperature the larger is the diffusion flow and thereby risk for moisture damage.

Capillary action can transport large amounts of water to the upper structures. A plastic sheet or thermal insulation (EPS) layer between soil layer and concrete slab prevents capillary transport to the concrete slab even if the soil material is capillar. If there is no capillary break the amount of transporting water to the concrete slab and thereby risk for moisture damage is dependent on portion of capillary saturated pores at the soil layer contacting the slab. For instance, maximum capillary water content of the fine sand presented on Figure 8, is about 28 weight-%. Capillary water content at level 0,5 meters from the ground water table is only 8 weight-%. Thus only about 29% of the total capillary pores are filled with water and can capillary transport water to the upper layers.

CONCLUSIONS

According to the performed field test measurements the water content of soils and fill layers used beneath slab-on-ground structures were equal to or higher than the hygroscopic equilibrium moisture content of the material at a relative humidity of RH = 100%. This indicates that the relative humidity of the air in the pores of these layers is near 100 % at all times. Thus, relative humidity measurements do not give accurate information on the existing moisture conditions at these layers, as the same high humidity value can be measured in both the hygroscopic conditions (RH = 100 %), while the actual absolute water content of the material may still be relatively low, w = 0,4 %, and at the almost saturated state, where the absolute water content may be significantly higher, w = 15 to 20 %. Therefore the only reliable method to determine the moisture conditions in the fill layers beneath the ground slab is to measure the actual water content of the material.

In fine-grained soils where capillary transport is possible, the measured water contents often exceeded the hygroscopic equilibrium water content of the material. In these cases the water content of the soil is likely more dependent on the season and the weather conditions before the measurements took place.

However, the thermal and moisture behavior of the entire slab-on-ground structure should not be evaluated only by measuring the water content of the subsoil. The thermal and moisture conditions of the structural layers: the slab, the insulation and the floor covering, are the best indicators when determining the overall behavior of a slab structure. However, the water content of the fill layer may indicate whether or not the subsoil is the active source of moisture problems detected in the structures above and if the transport mechanism of the water from the subsoil is by diffusion or by capillary action (or both). These facts are important when determining the required repair methods for each individual structure with moisture problems arising from entry of moisture through the slab-on-ground.

REFERENCES

Leivo, V., Rantala, J. 2003. Moisture Behavior of Slab-on-ground Structures. Tampere University of Technology, Laboratory of Structural Engineering. Research Report 122. 112 p. Tampere.

Rantala, J., Leivo, V. 2004. Thermal and Moisture Conditions of Coarse-grained Fill

Layer Under a Slab-on-ground Structures in Cold Climate. Journal of Thermal Envelope and Building Science, Vol. 28 (1):45-60. SAGE Publications.

Finnish Meteorological Institute. 2005. Climate statistics. http://www.fmi.fi/weather/climate.html, 20.10.2005.

SYMBOLS

RH Relative humidity [%] w water content [% by weight or kg/m^3]

ρ unit weight [kg/m^3]

ABREVATIONS

EPS Expanded Polystyrene

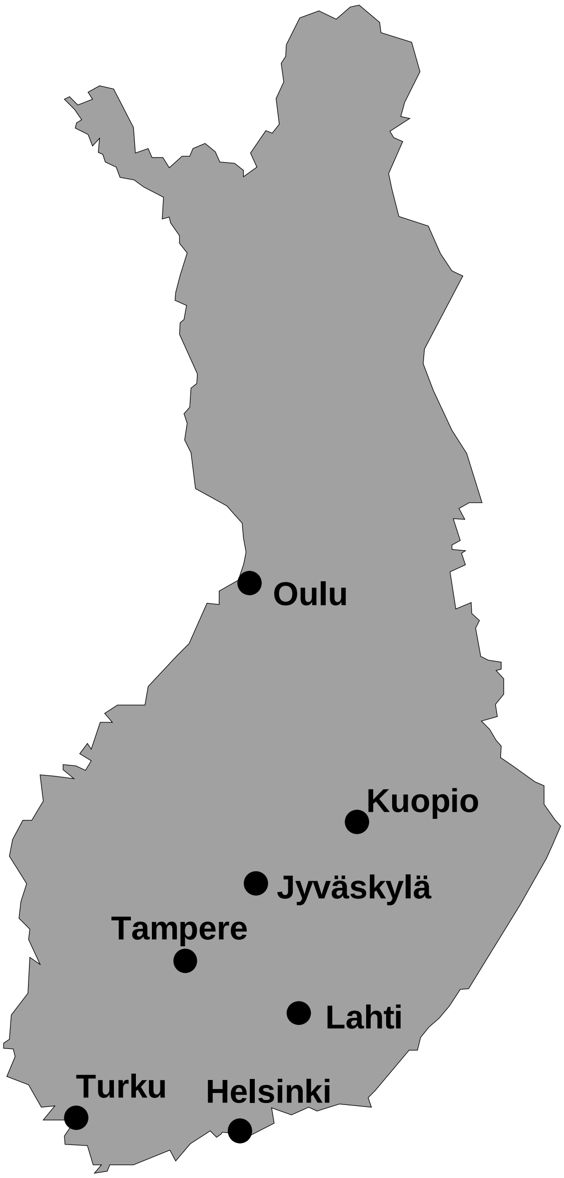
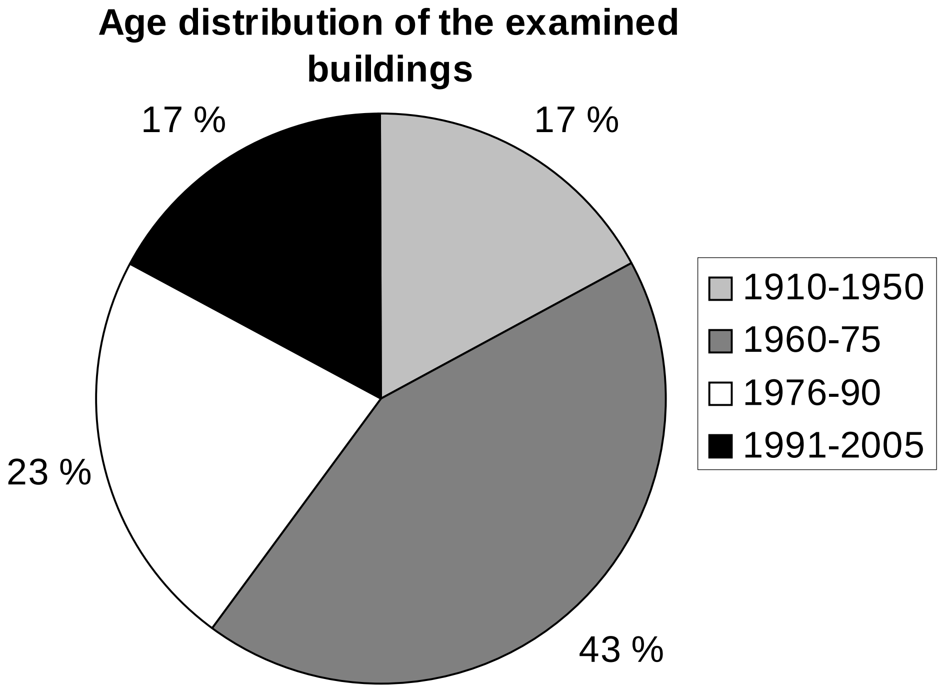


Figure 1 Location of the examined buildings.



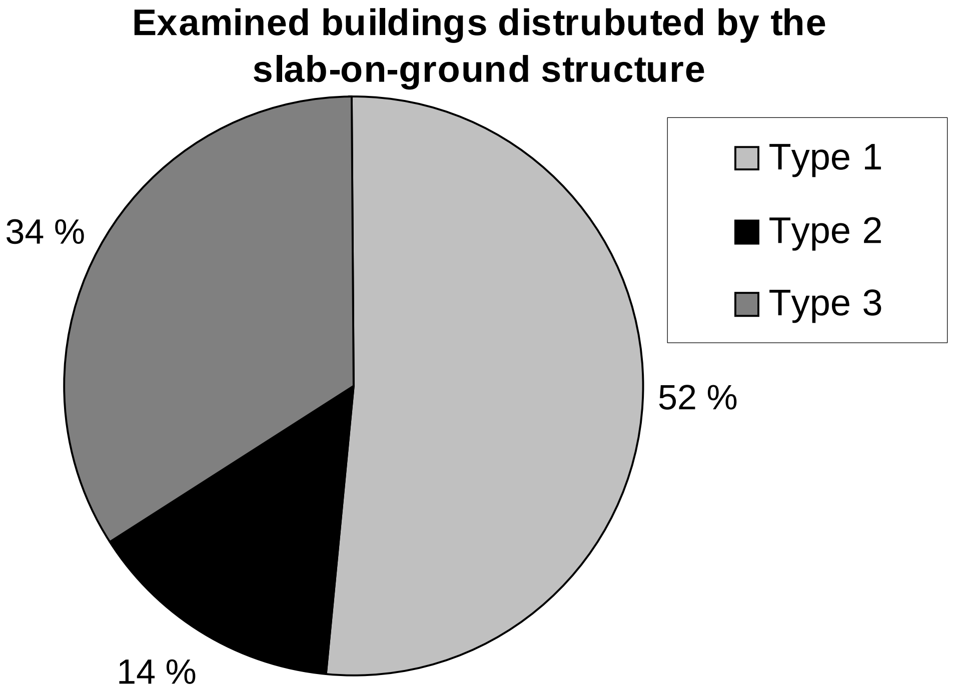
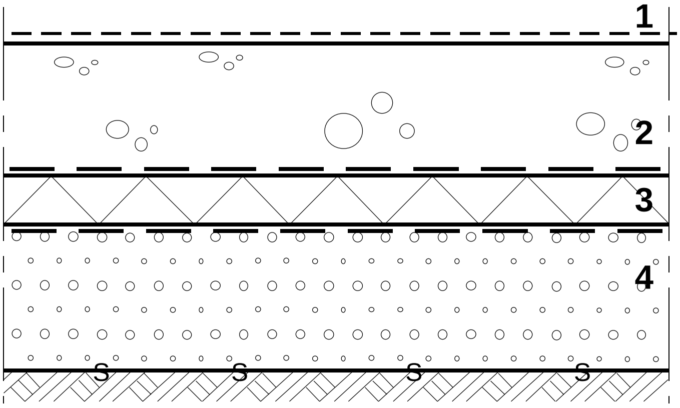


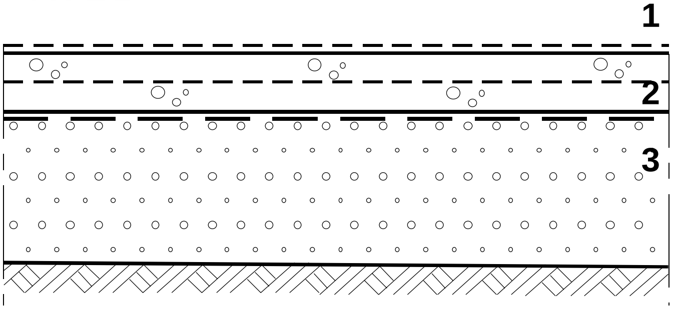
Figure 2 Examined slab-on-ground structures distributed by age and structure type (Figure 3).

TYPE 1



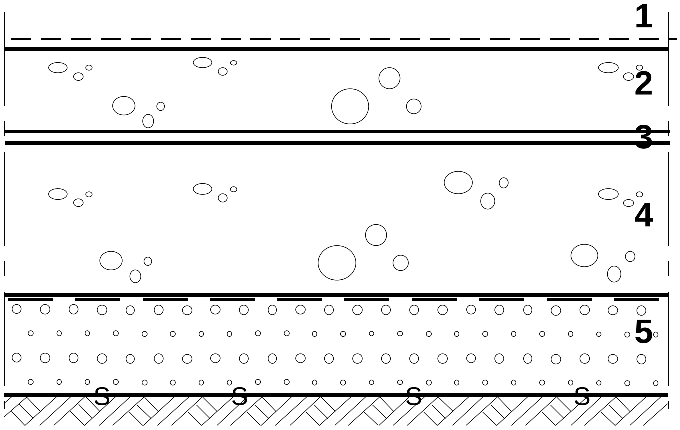
1 Floor covering
2 Concrete slab
Optional moisture barrier
(plastic sheet)
3 Thermal insulation
Optional moisture barrier
4 Drainage layer

TYPE 2



1 Floor covering
2 Concrete slab
Optional moisture barrier
(plastic sheet)
3 Drainage layer

TYPE 3



1 Floor covering
2 Concrete slab
3 Thermal insulation
Optional moisture barrier
4 Concrete slab
5 Drainage layer

Figure 3	Basic structure types of the examined slab-on-ground structures.

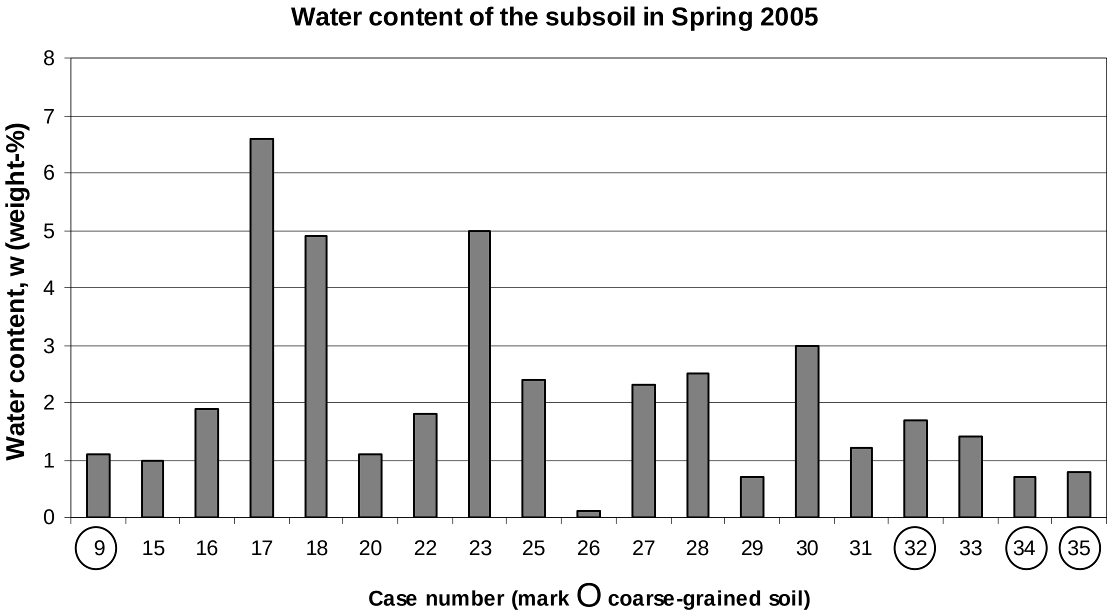


Figure 4 Water content of the subsoil in spring 2005.

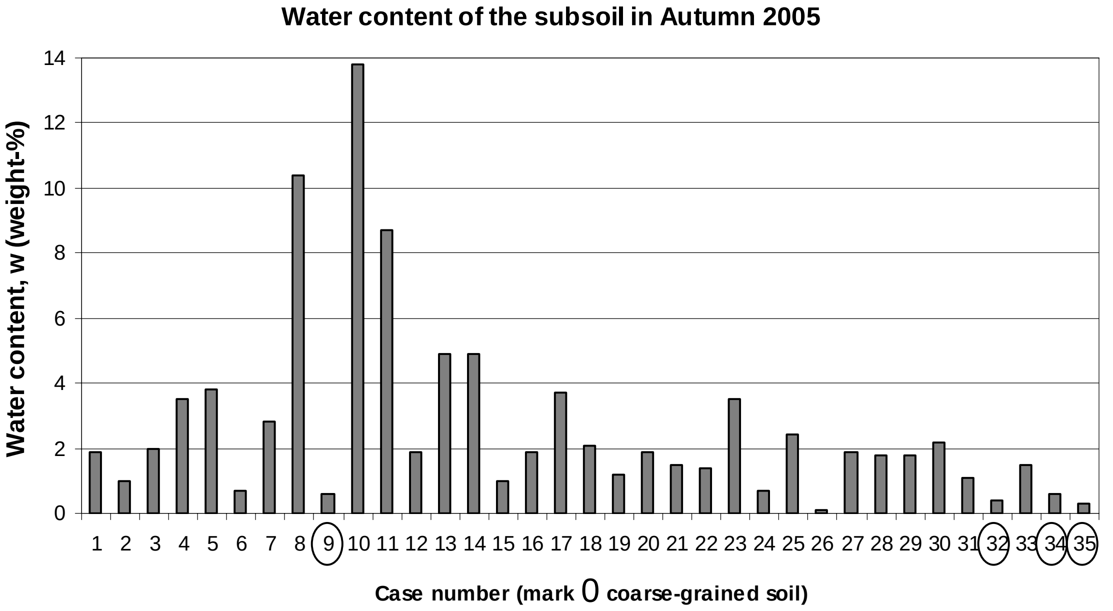


Figure 5 Water content of the subsoil in autumn 2005.

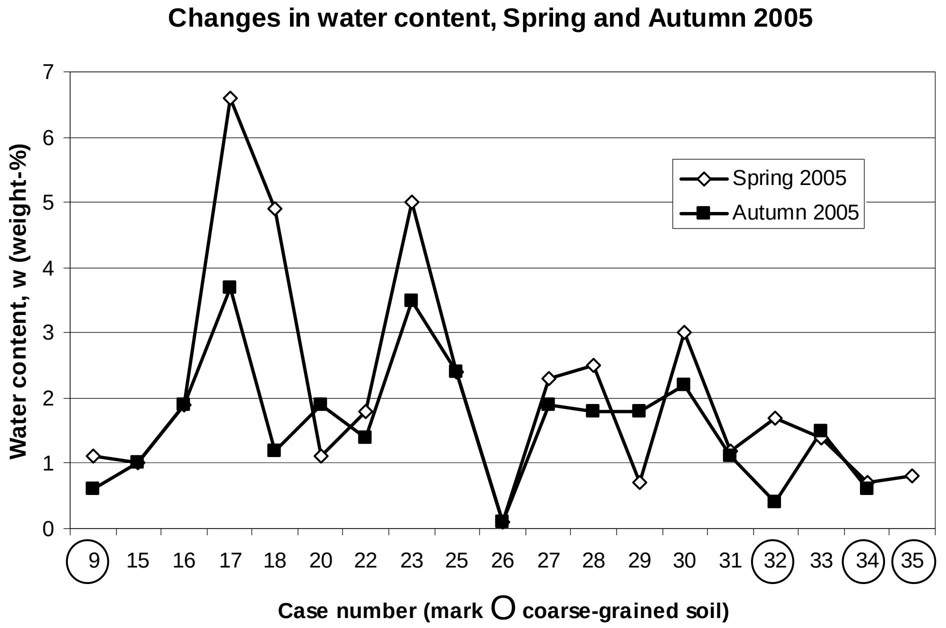


Figure 6 Changes in water content between spring and autumn.

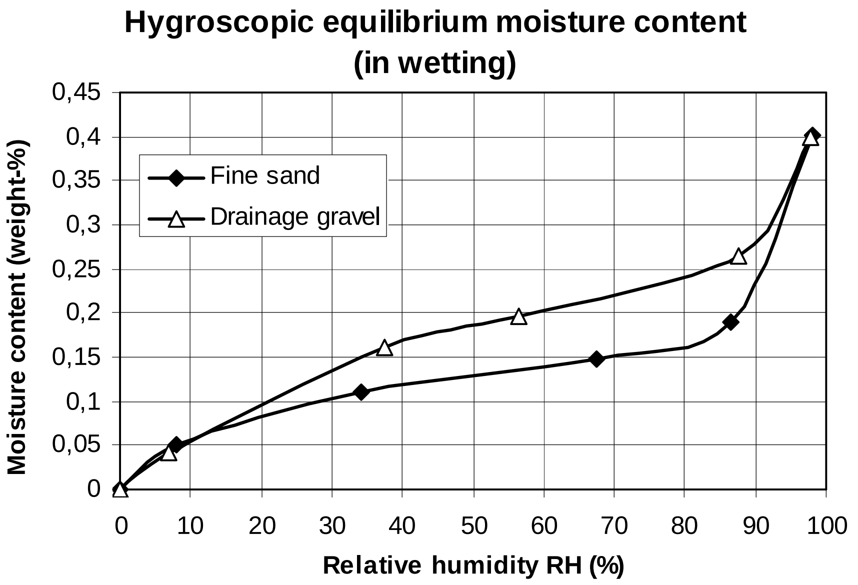


Figure 7 Hygroscopic equilibrium moisture contents of typical coarse-grained (drainage gravel) and fine-grained (fine sand) soil (Rantala, J., Leivo, V. 2004).

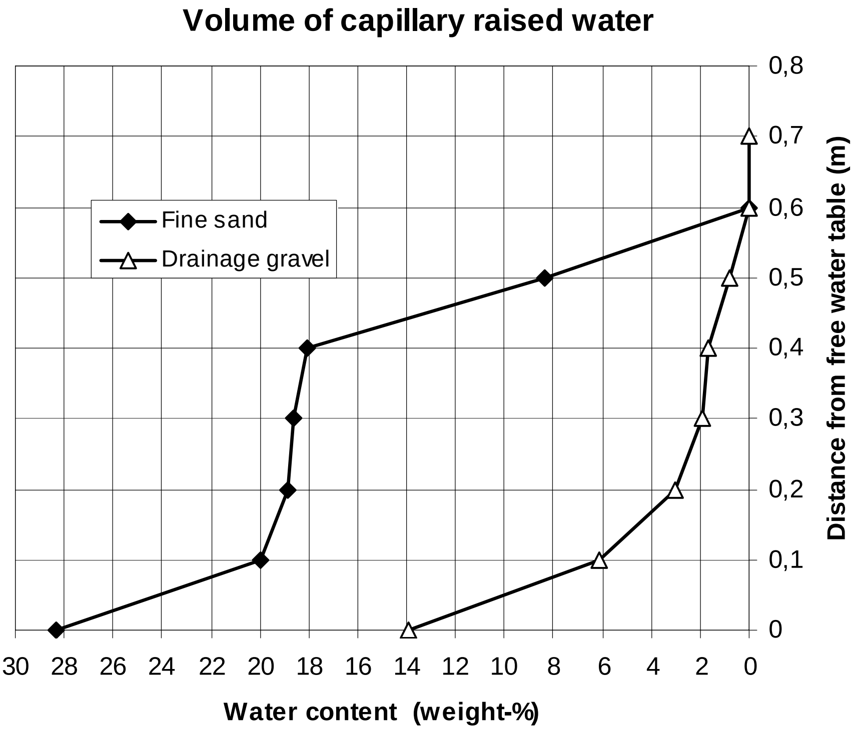


Figure 8 Volume of capillary rise of typical coarse-grained (drainage gravel) and fine-grained (fine sand) soil (Rantala, J., Leivo, V. 2004).

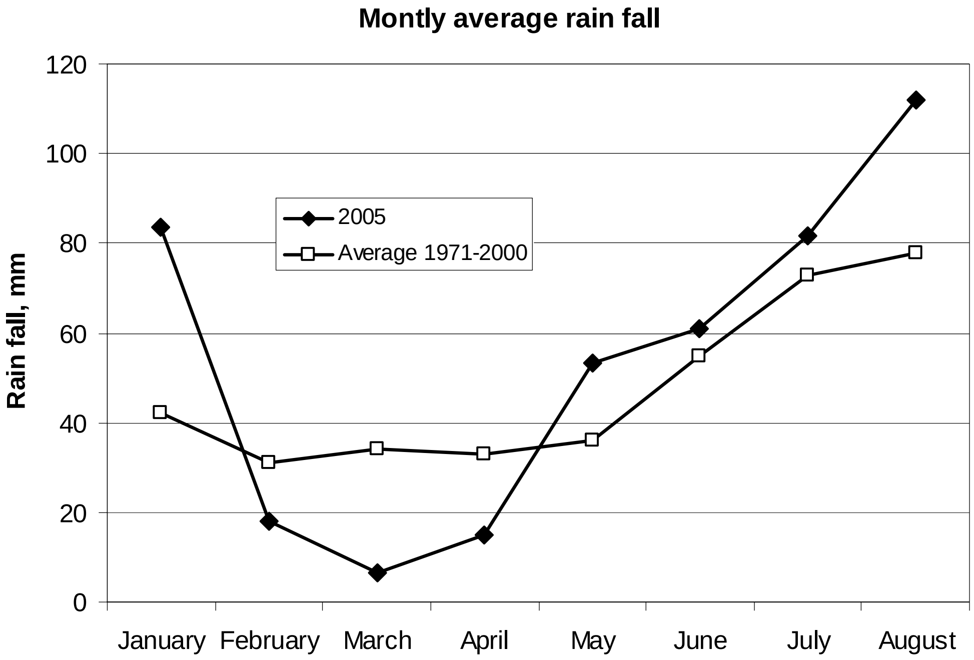


Figure 9 Monthly average rainfall in 2005 and 1971-2000 in Finland.