NOTE

Draining function of porous asphalt during snowmelt and temporary freezing

M. Bäckström and A. Bergström

Abstract: Urban runoff creates problems with flooding and pollution of receiving waters. Furthermore, cold climate conditions have a degenerating effect on stormwater systems and road constructions. Porous asphalt has been used as a wearing course on highways and in porous pavement constructions all around the world. The main focus of this study was to evaluate the function of porous asphalt in cold climates. Measurements of the draining function of porous asphalt were carried out in a climate room with adjustable temperature in the range –10°C to +20°C. At freezing point, the infiltration capacity of porous asphalt was approximately 50% of the infiltration capacity at +20°C. When the porous asphalt was exposed to alternating melting and freezing during 2 days, conditions similar to the snowmelt period, the infiltration capacity was reduced by approximately 90%. Based on the results of this study and previous studies, the infiltration capacity of porous asphalt was estimated to be 1–5 mm/min for snowmelt conditions.

Key words: cold climate, infiltration, porous asphalt, porous pavement, stormwater.

Résumé : Les écoulements en zones urbaines créent des problèmes avec les inondations et la pollution des eaux captées. De plus, les conditions d'un climat froid ont un effet dégénératif sur les systèmes d'eau de tempête et les constructions routières. Un asphalte poreux a été utilisé comme une couche de support sur les autoroutes et dans les constructions de chaussées poreuses partout dans le monde. L'objectif principal de cet article fut d'évaluer la fonction de l'asphalte poreux dans des climats froids. Des mesures de la fonction de drainage de l'asphalte poreux furent effectuées dans une chambre de climat avec des températures ajustables dans une amplitude de –10°C à +20°C. Au point de congélation la capacité d'infiltration de l'asphalte poreux était à peu près 50% de la capacité d'infiltration à +20°C. Quand l'asphalte poreux fut exposé à des conditions de gels et dégels alternantes durant deux jours, similaires à la période de dégel, la capacité d'infiltration fut réduite par environ 90%. Basé sur les résultats de cette étude et des études précédentes, la capacité d'infiltration de l'asphalte poreux fut estimée d'être entre 1 et 5 mm/min durant des conditions de dégel.

Mots clés : climat froid, infiltration, asphalte poreux, chaussée poreuse, eau de tempête.

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Introduction

The area of paved surfaces has greatly increased as a result of urban development. This has led to an increased amount of surface discharge. The urban runoff creates problems such as flooding, streambank erosion, and pollutant discharge to rivers and other aquatic systems. One way to prevent these problems is to take care of the urban runoff by infiltration. Stormwater infiltration is the artificial forcing of urban runoff away from surface discharge and into the underlying soil. By returning runoff to the earth, it decreases pollutant discharge and replenishes ground water supplies (Fujita 1994).

One way to decrease the amount of urban runoff is to use porous pavements in municipal regions. One type of porous pavement consists of an open-graded asphalt concrete (porous asphalt) over an open-graded aggregate base. This construction can be used, for example, at parking lots, light traffic streets, and pedestrian paths. The installation and maintenance costs for this construction may be greater compared with other types of pavements. On the other hand, porous paving is less expensive considering the need of a simplified storm drainage system (Göransson and Jonsson

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1990). Porous asphalt has also been used as a wearing course on highways and airfields. By laying the porous asphalt on top of an impervious asphalt, rainwater is drained off efficiently to the shoulder of the road.

Porous asphalt has a low amount of filler (grain size < 0.075 mm) compared with conventional, dense asphalt. Stormwater infiltrates through pores in the asphalt (15–25% pore space). Hogland and Wahlman (1990) reported an initial infiltration capacity of 500–700 mm/min, but after a few years in operation the infiltration capacity decreased to approximately 10% of the initial value. It is possible to clean porous asphalt by vacuum cleaning or by using high-pressure water equipment.

In northern territories, cold climate has a degenerating effect on road constructions. Freezing and thawing processes as well as soil frost break down the construction. Frost heave around storm drainage system components is a common cause of road damage (Hanaeus and Stenmark 1989). The yearly costs to repair this damage are very high. A major part of the surface discharge in northern regions occurs during snowmelt. It is therefore very important that the drainage function of the porous asphalt is sufficient during the snowmelt period. It may be affected by, for example, the formation of ice at the road surface.

This paper presents the results from studies in laboratory on porous asphalt performance in cold climates.

Research objective and scope

The aim of the study was to investigate how cold climate and low temperature conditions influence the draining function of a porous asphalt. For practical applications, the snowmelt period with high runoff flows and temporary freezing was of special interest.

The investigations were done in laboratory scale in a climate room. This procedure was chosen in order to minimize the influence of parameters other than temperature and precipitation/snowmelt. The lab-scale procedure also made it possible to perform multiple experiments in similar conditions, which increased the certainty of the results.

Previous studies on porous asphalt under cold climate conditions

Shao et al. (1994) reported that porous asphalt responded much more quickly to the variation of its surrounding temperature than impervious (dense) asphalt. Stenmark (1995) measured the infiltration capacity of porous asphalt pieces in a climate room at a temperature between –1.1°C and –1.9°C. The initial infiltration capacity of 290 mm/min at room air temperature (+20°C) decreased to 130 mm/min. The asphalt pieces were kept at the colder temperature and the tests were repeated for 2 days without drying the asphalt. After 1 day the infiltration capacity had decreased to 5 mm/min, and at the end of the experiment the asphalt was completely clogged by ice.

There are indications that roads with porous asphalt become free from snow and ice earlier than conventional roads. This has been observed in several ocular inspections in different parts of Sweden (Hogland and Wahlman 1988). Melted water infiltrated immediately through the porous asphalt, which caused fewer problems with slipperiness, as there were no water on the road surface that could freeze, for example, during cold nights.

Noort (1996) has described the temperature behaviour of porous asphalt pavements in the Netherlands. The porous asphalt is used as a surface layer in which stormwater can flow horizontally to the shoulder of the road. There were no problems with ice formation and slipperiness on porous asphalt during normal winter conditions. Only in the case of freezing rain have there been problems.

Laboratory studies

The purpose of the laboratory studies was to simulate what happens during a snowmelt period. Two asphalt pieces (0.4×0.4 m^2) were cut out in late 1996 from a porous asphalt pavement using a mobile asphalt-cutting tool. The pavement was situated in a residential area in the outskirts of Luleå town in Sweden and has been in operation since 1994. The thickness of the porous asphalt was 45 mm and the porosity was 18%.

One of the pieces was mounted in a wooden box and equipped with a temperature probe (accuracy ±0.2°C) within the asphalt layer (Fig. 1). The second asphalt piece was mounted in a similar wooden box with a sloping plate below the asphalt. The plate directed the infiltrated water to a rectangular opening on one side of the box. The wooden boxes were then placed in a climate room in which the air temperature could be adjusted in the range –10°C to +20°C. Three experiments were performed.

Experiment 1: effect of ambient air temperature on the infiltration

Measurements of infiltration were done at +20°C, +5°C, ±0°C, –5°C, and –10°C. The time for 6.25 mm of water to infiltrate was measured. The water used was drinking water from Luleå, Sweden. The temperature of the infiltrated water was in the range +0.2°C to +3.0°C. The experiment was repeated to improve the accuracy.

Experiment 2: simulation of the infiltration during the snowmelt period

A "worst case" was assumed where the air temperature was ±0°C and where water came in contact with the asphalt. The temperature of the water was in the range ±0.0°C to +4.2°C. To simulate the melting periods, 0.625 mm of precipitation was applied to the asphalt every 30 min for 3 h. Between the water application periods there were periods with freezing conditions (–4°C) for 21 h. The simulation continued for 48 h. The infiltration rate was measured in the same way as in experiment 1 at 0, 24, and 48 h. This simulation sequence was done twice.

Experiment 3: effect of temperature on the drainage process

In this experiment, 12.5 mm of water at +2°C to +4°C were applied to the asphalt surface and after defined time intervals the infiltrated amount of water was collected in a plastic container and weighed. The time intervals were 30 s,

Fig. 1. Section of test box with 0.4 × 0.4 m^2 porous asphalt piece.

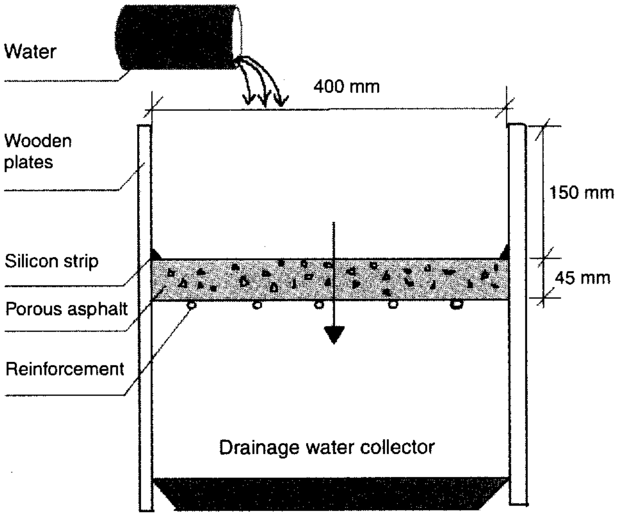
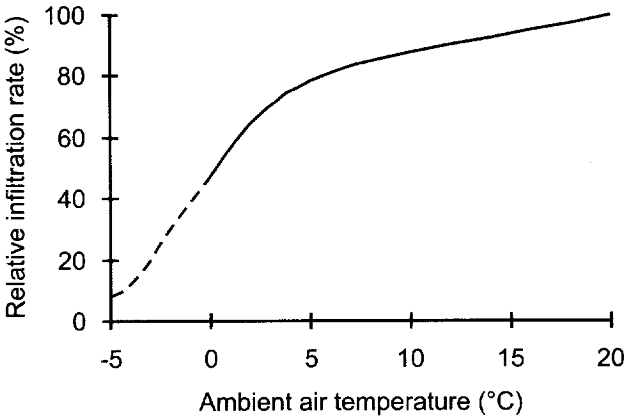


Fig. 2. Relative infiltration rate of porous asphalt at different ambient air temperatures. Infiltration rate at +20°C was set to 100%. Dotted line represents the region where ice formation occurs.



1, 2, 3, 4, 5, 10, 15, 20, and 30 min. Following this procedure the remaining amount of water in the asphalt after a certain time could be calculated. The experiments were done at air temperatures of +10°C, +5°C, and ±0°C. At each temperature, five similar experiments were performed at 2 h intervals.

Findings

The infiltration rate at the freezing point was about 40% (7.4 mm/min) of the infiltration rate at +20°C (19 mm/min) (Fig. 2). When the temperatures were –5°C and –10°C, the infiltration rate was radically decreased as a result of ice formation in the asphalt. This made it difficult to measure the infiltration capacity accurately. Even if the infiltration rate decreased significantly, the asphalt was not completely clogged at temperatures a few degrees below freezing. This indicated that the porous asphalt still had a draining function in cold temperatures. However, the infiltration capacity was practically zero at temperatures below –5°C.

Fig. 3. Draining function of porous asphalt at +20°C and at ±0°C (ambient air temperature). The variation of ambient air temperature during the experiment was ±1°C (n = 5).

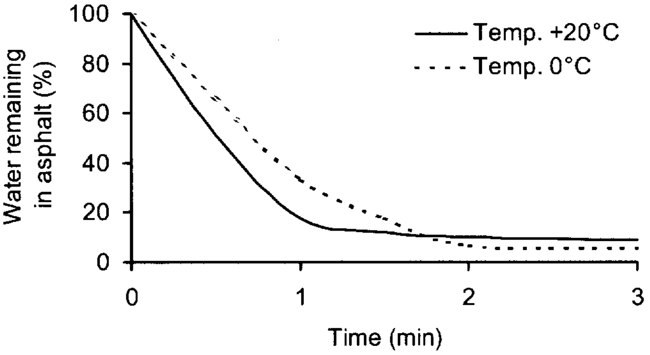
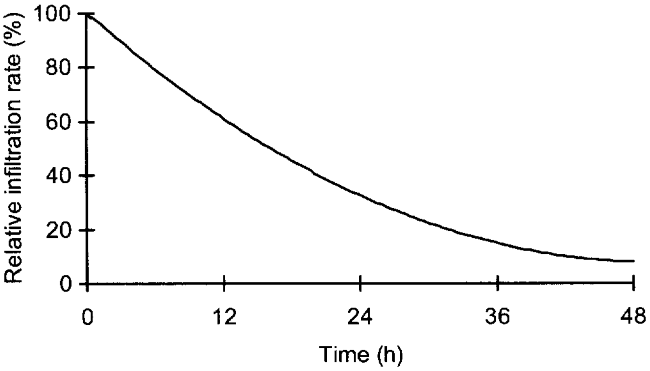


Fig. 4. Relative infiltration rate during the worst case simulation. Infiltration rate at 0 h and ±0°C was set to 100%.



The laboratory measurements of draining behaviour (experiment 3) showed that the drainage through the asphalt was a rapid process and there was no significant difference between the test runs at +20°C and ±0°C.

The amount of water remaining in the porous asphalt during the first 2 min after water application is shown in Fig. 3. The asphalt retained slightly more water in the pores at the colder temperature during the first 2 min after water application. More than 90% of the water applied to the asphalt drained off within 2 min in all the measurements that were performed.

The pore volume of the asphalt piece used in the laboratory testing was 1.44 × 10^{-3} m^3. A calculation of the retained amount of water able to freeze was performed. As mentioned before, the drainage of water through the porous asphalt was delayed during the first 2 min at ±0°C compared to +20°C. This was in line with the results from experiment 1. However, after 5 min of drainage the colder temperature gave smaller amounts of water in the pores. After 30 min of drainage at ±0°C, it seemed like the asphalt contained three times less water than at +20°C.

The worst case simulations (experiment 2) showed that the draining function of porous asphalt could decrease significantly during a melt–freeze–melt–freeze period (Fig. 4). The two experiments that were performed gave similar results. After 1 day the infiltration capacity was decreased to 30% of the initial value, and after 2 days only 7% of the initial infiltration capacity remained.

Table 1. Maximum snowmelt runoff from snow-covered ground (Westerström 1984).

	Runoff	
Time (h)	(mm)	(mm/min)
1	1.5	0.025
12	12	0.017
24	15	0.010

Discussion

The infiltration capacity of the porous asphalt measured in the laboratory studies was approximately 19 mm/min at +20°C, which was lower than expected. The initial infiltration capacity of porous asphalt is at least 10 times greater than this value (Hogland and Wahlman 1990). This can be explained by the fact that the asphalt pieces used in the laboratory studies were taken from the field site road, which had been in operation for 2 years. No asphalt cleaning operations (high-pressure washing or vacuum cleaning) were done during this period. Therefore, the asphalt was clogged to some extent.

Since the laboratory studies were aimed at investigating critical situations in cold climates, namely the snowmelt period, the normal infiltration test was slightly modified. To be able to simulate snowmelt conditions, the volume of water applied on the porous asphalt during each infiltration capacity measurement was limited. The applied water volumes were equivalent to 6–12 mm of rain or meltwater.

The equipment normally used to measure infiltration capacity is the double ring infiltrometer (Ferguson 1994). The most common way of operating the double ring infiltrometer is to maintain a constant water depth in the inner ring. The water in the outer ring creates a peripheral pressure so that the infiltrated water from the inner ring only flows vertically. A consequence of the use of a specialized measuring method in this study is that the infiltration capacity results are not fully comparable with the results of other studies.

However, the main focus of this work was to investigate the draining function of porous asphalt in cold climate in a general sense. The major finding of this laboratory study was that the infiltration capacity of the porous asphalt was decreased by 90% when the ambient air temperature was decreased to a few degrees below freezing. Based on the results presented in this paper and the previous work by Stenmark (1995), one can assume that the porous asphalt have an infiltration capacity of at least 1–5 mm/min during the snowmelt period.

Westerström (1984) measured snowmelt runoff in a residential area in Luleå, Sweden. The observed maximum hourly, 12-h, and daily snowmelt runoff rates during spring 1983 are presented in Table 1.

The porous asphalt used in the laboratory tests was taken from a residential site outside Luleå. The total drainage area was 33 000 m^2 and the area of the streets and roadside swales was 4900 m^2. Assuming a worst case where all melt water from the drainage area is directed to the road area, the amount of snowmelt runoff that must be infiltrated in the road area will then be (33/4.9)(0.025) mm/min = 0.17 mm/min. In this example, the porous asphalt has an infiltration capacity that is enough (about 1 mm/min with a 10% function) during the snowmelt period.

Another important finding was that the water applied on the porous asphalt flowed through the asphalt quickly. The draining function appeared to be almost the same at an ambient air temperature of +20°C as at freezing point. This indicates that the formation of ice within the pores of the asphalt is a slow process, probably due to the high level of latent heat in the infiltrating water.

The evaporation of water from the asphalt surface during the experiment was not measured. The evaporation could be a source of error in the drainage tests performed at +20°C but probably not at ±0°C.

Porous asphalt gets clogged as a result of passage of vehicles, construction works, and winter maintenance (Hogland and Wahlman 1990). Some kind of regular cleaning operations are therefore inevitable. High-pressure water cleaning is widely used and the infiltration capacity can be regained to a large extent. It is recommended that the porous asphalt should be cleaned approximately every 2 to 4 years (depending on traffic load, etc.) and the friction material applied during winter should be of a coarse fraction (2–4 mm).

Conclusions

The results show that porous asphalt retains some of its infiltrating function during wintry conditions. The infiltration capacity at freezing point was approximately 40% of the infiltration capacity at +20°C.

When the porous asphalt was exposed to alternating melting and freezing cycles for 2 days, conditions similar to the snowmelt period, the infiltration capacity was reduced by approximately 90%.

It is difficult to give an exact value of the infiltration capacity of porous asphalt during the snowmelt period. However, based on the results of this study and previous studies, the infiltration capacity of porous asphalt could be estimated to be 1–5 mm/min for snowmelt conditions. This represents the maximum hourly snowmelt runoff from 40 to 200 m^2 of snow-covered ground in northern Sweden.

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References

Ferguson, B.K. 1994. Stormwater infiltration. CRC Press, Inc., Boca Raton, Fla.

Fujita, S. 1994. Infiltration structures in Tokyo. Water Science and Technology, **30**(1): 33–41.

Göransson, K., and Jonsson, H. 1990. Miljökonsekvenser vid användande av dränerande vägbeläggning-en litteraturstudie. Vatten, **46**(1): 27–35. (In Swedish.)

Hanaeus, J., and Stenmark, C. 1989. An alternative road section for northern Sweden. Preprints of the International Conference on Urban Hydrology under Wintry Conditions, Narvik, Norway, March 19–21.

Hogland, W., and Wahlman, T. 1988. Enhetsöverbyggnad efter några års användning - studier utförda 1986. Report 3117, Tekniska och Naturvetenskapliga Högskolan i Lund, Lund. (In Swedish.)

Hogland, W., and Wahlman T. 1990. Enhetsöverbyggnad - hydrologiska och vägtekniska egenskaper (Unit Superstructure). Report R90:1990, Byggforskningsrådet. ISBN 91-540-5264-5. (In Swedish.)

Noort, M. 1996. Winter maintenance on porous asphalt. Proceedings of the Fourth International Symposium on Snow Removal and Ice Control Technology, Reno, Nev., August 11–16, pp. 33–40.

Shao, J., Lister, P.J., and McDonald, A. 1994. A surface-temperature prediction model for porous asphalt pavement and its validation. Meteorological Applications, **1**: 129–134.

Stenmark, C. 1995. An alternative road construction for stormwater management in cold climates. Water Science and Technology, **32**(1): 79–84.

Westerström, G. 1984. Snowmelt runoff from Porsön residential area, Luleå, Sweden. Proceedings of the Third International Conference on Urban Storm Drainage, Göteborg, Sweden, June 4–8, pp. 315–324.