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Road and Bridge Heating Using Geothermal Energy. Overview and Examples.

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ABSTRACT

Winter maintenance today is normally based on mechanical snow clearance together with the use of salt. The spreading of salt causes impacts on plants and the ground. Wintry traffic situations lead to reduced speeds, traffic jams and therefore to losses of time. New economical and environment-friendly solutions are needed in winter maintenance to increase road safety and mobility. Winter maintenance "from the bottom" using renewable and free geothermal heat is an obvious solution and a chance to achieve these goals.

Geothermally heated outside surfaces are typically based on hydronic heat exchanger installations in the pavement. The installed heating capacity depends on the climatic conditions and the system specifications. Snow melting needs higher system temperatures than simple prevention of ice-formation. Low system temperatures implicate an anticipatory operation control.

A conceptual system design takes into account all relevant heat sources that are available in the neighbourhood of the planned road heating: e.g. natural hot water, ground-water or closed-circuit systems. A number of pilot plants for geothermal snow melting and/or geothermal de-icing have been built all over the world. A well known and well documented geothermal installation is the SERSO pilot plant in central Switzerland, which went 1994 into operation and is now still running.

Geothermal road, bridge or outside surface heating is a feasible and approved possibility to increase traffic and public safety. Although the initial costs are high, such systems are not uneconomical. Social and macroeconomic benefits are given.

1. INTRODUCTION

Every year again, ice and snow cause several times obstructions of traffic all over central Europe. Ice and heavy snow fall are responsible again and again for traffic jams and traffic accidents. To keep all the roads and bridges usable during winter for all vehicles is a logistical challenge for equipment and staff and cause high costs every year. The traffic jams in winter and the unavoidable use of de-icing salt of today form an environmental threat.

New economical and environment-friendly solutions are needed in winter maintenance to increase road safety and mobility. To use of geothermal energy is a chance to achieve these goals.

Geothermal energy is free of harmful emissions and carbon as well as climate neutral. Geothermal energy is renewable and is everywhere obtainable: independent from the weather over the whole year and during 24 hours a day.

If a heating system is installed, the pavement may be cooled in summer. This reduces the intensity of ruts and may lead to a longer lifespan of the pavement.

2. ROAD CONDITIONS IN WINTER

If the first cold drops happen, the road users have normally not adapted to the changed traffic conditions yet. Bridges use to cool down earlier than the normal roads. Thus icy surface conditions can occur on bridges even when the normal roads don't show any problematic surface conditions. These different road conditions are very critical and cause many and even severe traffic accidents.

Accurate winter maintenance is a crucial factor to guarantee certain mobility on the roads. A first intervention of the winter maintenance vehicles is needed on bridges, on strong inclines and on important traffic nodes. Obstructions in traffic due to snow and ice may also constrain the use of maintenance and emergency vehicles. Consequently the number and the length of the hold-ups are increasing instead of decreasing. This may lead to a complete breakdown of public and private traffic.

Also freezing rain stops traffic within minutes – even in large urban areas. The traffic comes to a halt – for hours. The maintenance service is no longer able to clear the roads. Emergency vehicles are stopped (see figure 1).

Especially important traffic nodes and express ways in urban areas need to be clear of snow and ice to prevent a complete break down of public and private traffic.

Figure 1: Traffic hold-up caused by heavy snow fall. Even maintenance vehicles are stopped.

Not only are the winter maintenance of roads and bridges important. Even carports, ramps or car accesses to a building or a garage need special attention during the cold seasons. Snow and ice cause delays in professional work.

Delayed flights due to snowy and icy airports or runways are annoying and expensive.

Last but not least, sidewalks, public areas, waiting areas for pedestrians need to be cleared of snow and ice to prevent accidents during day and night time.

A wintry traffic situation leads to reduced speeds, traffic jams and therefore to losses of time. Every jam hour costs about 10 Euros per vehicle (Klotz and Balke, 2004). Every improvement in the status Quo has a positive effect on the roadworthiness, the traffic processes and so on our society.

3. ACUTAL WINTER MAINTENANCE

Winter maintenance today is normally based on mechanical snow clearance together with the use of salt – and - the precautionary spreading of salt on highways, bridges and important traffic nodes to prevent ice from forming.

A sensor-controlled spreading of the salt has strongly reduced the yearly salt consumption. Today only about 10-20g/m^2 salt is used (comparison: the spreading rate in the in the 60ies was about 40g/m^2).

Normally common salt (NaCl) and sometimes MgCl are used. The spreading of salt nevertheless causes impacts on plants and the ground (see figure 2). The yearly loads and damages resulting from the use of salt are estimated at approx. 450 million Euros in Germany only (Huckestein and Verron, 1996).

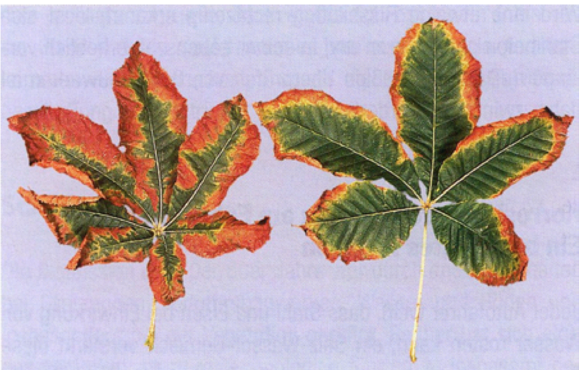

Figure 2: Salt caused damages on chestnut leaves.

Many highways are equipped with ice alarm systems which allow a fast response of the maintenance services.

In very critical locations, typically on express ways, thawing agents spray systems are sometimes installed. These are fully automatic systems controlled by the sensors of an ice alarm system. Brines (salt in a water solution) are typically used as thawing agents.

In most countries, a legal duty to keep the roads clear of snow and ice does not exist. Drivers are obliged to adapt their ways of driving to the actual road conditions.

In many countries, electrical resistance heaters are installed to keep access roads, ramps, etc. free of snow and ice. In some other countries (e.g. Japan) oil- or gas-based road heating systems are used.

3. BASICS OF A ROAD HEATING

In principle, a road, bridge or similar outside surface heating system consists of the same basic elements like a building heating (see figure 3):

- Heat source
- Heat exchanging tubes embedded in the pavement ("floor heating")
- sensors for measuring the actual weather
- system control

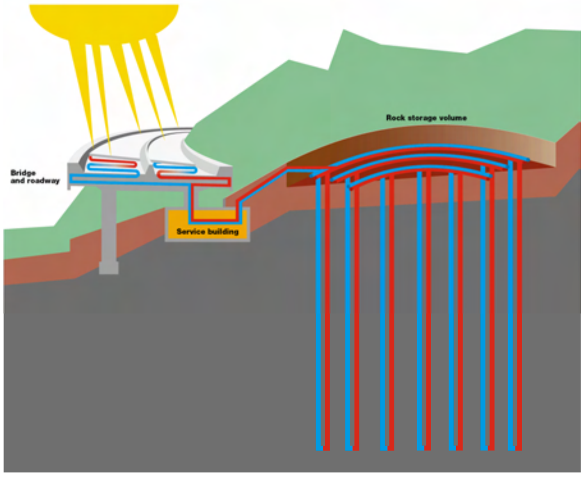

Figure 3: Basic scheme of a road heating system (here: scheme of the SERSO system).

A road heating is typically a hydronic heating systems, i.e. the heat is transferred in a water-filled tubing system. Electrically resistance heaters are feasible for small areas.

The installed heating capacity depends on the technical system specifications: snow melting at a specific snow fall rate, de-icing, keeping clear of ice etc.). ASHRAE Handbook (1991) lists different design output rates for different locations and different applications; e.g. 729 W/m^2 for a commercial building in Boston, MA, 224 W/m^2 for a residential application in Albuquerque, NM, or 1'104 W/m^2 for a industrial application in Oklahoma City, OK.

These very high design outputs are only suitable for conventional oil- or gas-based heating systems. Any other system, using renewable energy of low enthalpy, must adapt the system basics.

4. GEOTHERMAL ROAD/BRIDGE HEATING

Winter maintenance, snow melting and de-icing "from the bottom" using renewable and free geothermal heat is an obvious solution.

The safety of waiting or walking pedestrians as well as the security of the running traffic may be increased with a reliable, sustainable and environment-friendly method.

Geothermally heated outside surfaces are typically based on hydronic heat exchanger installations in the pavement. The installed heating capacity depends on the climatic conditions and the system specifications. Snow melting needs higher system temperatures than simple prevention of ice-formation. Low system temperatures implicate an anticipatory operation control.

Various system designs are suitable. Various sources may be used (see figure 4): Direct use with geothermal hot water (normally bound to special geothermal conditions); direct use of warm or cold groundwater; direct use of borehole heat exchangers or energy piles. A combination with a heat pump may be considered. Underground thermal energy storage (UTES) is suitable. Then the heated area could be cooled in summer.

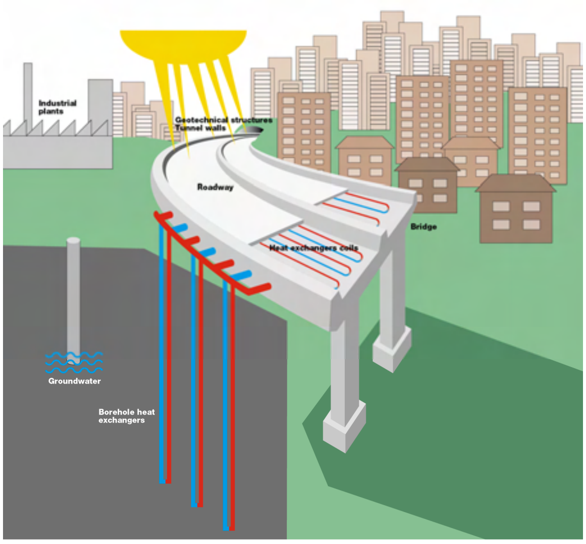

Figure 4: Various system designs are suitable. Various sources may be used (here: adapted SERSO scheme for SERSO PLUS).

Other heat sources – like waste heat – may be taken into account if a reliable delivery over the whole design service life is guaranteed.

The first step in system design consists of the definition of the plant specifications – as accurate as possible. The next step is an estimation of the yearly runtime and the typical and maximal heat output of the heating system.

A conceptual system design takes into account all relevant heat sources that are available in the neighbourhood of the planned road heating: e.g. natural hot water, ground-water, closed-circuit systems (borehole heat exchangers, energy piles, geostructures etc.). The choice of the heat source leads to an expected supply temperature of the heating systems. The supply temperature with/without heat pump, the depth of the heating tubes in the pavement, the length of each tube, the distance from tube to tube etc. affect each other and are subject to optimization. The heat distribution and the heat source need to work together.

For larger installations it is recommended to use a simulation tool for the final system layout. Small outside surface heating systems may be designed by rules of thumb.

5. EXAMPLES

A number of pilot plants for geothermal snow melting and/or geothermal de-icing have been built all over the world.

In the USA a few projects for geothermal road and bridge heating have been realized. Some of these are combined with heat pumps. Some of these are using seasonal heat storage (Minsk, 1999; Spitler and Ramamoorthy, 2000). The oldest documented geothermal snow melting installation was built in 1948 using natural hot geothermal water (Lund, 1999).

In the 1990ies several pilot plants for geothermal heat pump based snow melting installations were realized in Japan (Morita, 2000; Morita, 2005), where active snow melting using non renewable sources have a long tradition.

A well known and well documented geothermal installation is the SERSO pilot plant in central Switzerland, which went 1994 into operation and is now still running (Eugster and Schatzmann, 2002; Eugster, 2002). Aim of the installation was to prevent ice-formation on a high-way bridge surface.

A few studies on geothermal road/bridge heating have been carried out in Germany (NRW, 2005) and Switzerland (TBA, 2006). The subjects of the studies still wait on their realisation.

A geothermal heating of a train platform was realised in Germany in 2005.

5.1 SERSO: Bridge Heating in Switzerland

SERSO is in a way the mother of the geothermal bridge or road heating systems. The SERSO system was developed and designed in the early 1990ies and went into operation in 1994. SERSO is working since 1994 without interruption until today. Aim of the installation was to guarantee the same road surface conditions on the heated bridge as on the subsequent road sections.

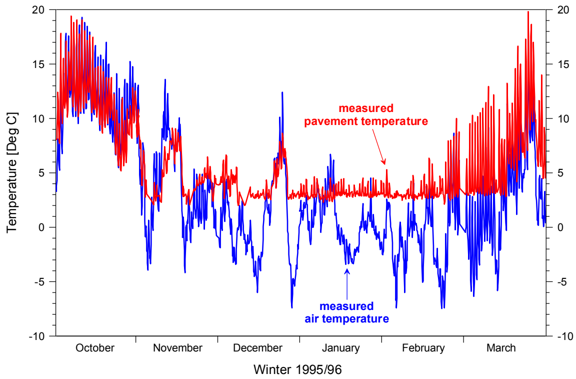

Figure 5: The road surface temperatures are controlled by the SERSO system.

The SERSO system collects from just beneath the road surface the excess heat from solar warming in summer and stores it underground in a rock storage volume. The stored heat is then re-used in winter to control the temperature of the surface. The surface temperature is stabilised just above 0°C, thus hindering ice formation and the freezing of compacted snow (see figure 5). In this way de-icing is assured and traffic interruptions to a large extent avoided. Experiences from the operation of SERSO justify this claim. In the climate of central Europe, it is in general possible to extract more heat from the roadbed in summer than necessary for the following winter. It has also been confirmed moreover, that SERSO operation brings a significant stabilisation of the road surface temperature throughout the year. This implies that, compared with the standard situation, the maximum temperatures are reduced in summer and the minimum temperatures raised in Winter, resulting in an extension of the lifetime of the road's bituminous running surface.

The heated area extends over 1'300 m^2. The heat is stored in a rock volume of roughly 55'000 m^3, which is tapped by a field of 91 borehole heat exchangers with a depth of 65 m each.

The yearly runtime of the system is less than 1'000 hrs per year in winter and another 1'000 hrs for cooling in summer.

In winter the installation operates on demand (see figure 6). The supply temperature of the heat transfer fluid is regulated according to ambient air temperature, lying generally below 10°C. Ice formation is not possible under these conditions. The amount of energy demanded by the roadway varies strongly with the severity of the winter from 30 MWh up to more than 100 MWh. The typical average heat output of the system is around 100 W/m^2.

Figure 6: The SERSO system in operation.

This gentle and cautiously forward-looking type of winter operation avoids the sudden demand for high rates of heat delivery at high temperatures to thaw out sudden ice formations or frozen snow covers. In addition it is possible thus to avoid the need for a heat pump.

The installation costs of the SERSO pilot plant were – as expected - rather high: more than 2'500 Euro/m^2. A second identical installation would half the costs. The operating costs are with roughly 4 Euros/m^2/year for electricity and maintenance reasonable.

5.2 Japan: Sidewalk heating in Aomori City

In 2002, two sidewalk heating systems were completed in Aomori City, Japan, for melting snow on sidewalks. This city is said to be the snowiest city in the world among cities with populations of about 300 thousand or more. Annual snowfall sometimes exceeds 10 m.

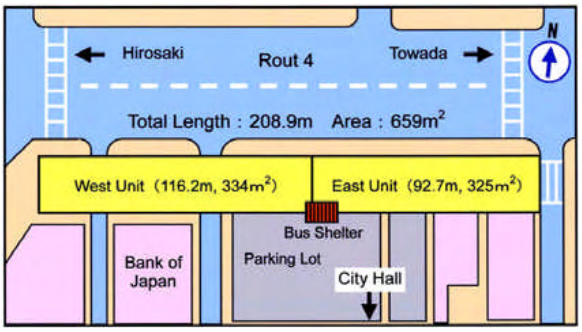

Figure 7: The schematic plain view of the site.

Figure 7 shows a schematic plain view of the site. The total area of the snow-melting section is 659m^2. Here, two units, the West Unit and the East Unit, each covering 334 m^2 or 325 m^2 were installed.

Each unit employs four borehole heat exchangers each 150 m long and one electric heat pump with a electrical capacity of 22.5 kW$_e$. The number of borehole heat exchangers and the required size of heat pumps were determined based on numerical simulations for each system. The design heat output of the system is 170 W/m^2. The annual operation time was around 500 hrs during the first two years. The total heat output of a unit was roughly 35 MWh. The installation worked without complaints (see figure 8).

Figure 8: The Japanese sidewalk heating in operation.

The operating costs of this sidewalk heating system are given with 6 Euros/m2/year for the electricity consumption only. The total initial investment costs are not known.

5.3 Germany: Geothermal Train Platform Heating

In 2005 the first geothermal outside surface heating system in Germany went into operation. A platform of a train stop in the Harz region has been equipped with a geothermal heating system. This pilot project uses exactly the same idea as the SERSO plant: during summer heat is extracted from the train platform and stored in the underground. In winter the heat is re-used to heat up the platform and to melt snow and ice.

The platform has an extent of 200 m. The underground heat storage is tapped with 9 borehole heat exchangers with a length of 200 m each.

The project is actually working (see figure 9). Exact investment costs and the operating costs are not published.

Figure 9: The Harz platform heating in operation.

5.3 Switzerland: Access Way Heating

Geothermal snow melting on a access road to a private parking area near Zurich (Switzerland). The heated surface extends over 25 m^2. The installation should provide a full snow melting service. In summer the road surface is cooled. The gained heat is stored in the underground. The use of a heat pump is not allowed..

Design data: heat output 9 kW, total operation time in winter: 600 hrs.

Geothermal heat source: one borehole heat exchanger with a depth of 260 m. Total costs for drilling and installing the borehole heat exchanger, for piping and heating installation in the pavement; for the control system and the commissioning: 855 Euro/m2. Electricity need per year is roughly 350 kWh.

5.3 Studies (not realised)

In Switzerland a feasibility study called SERSO PLUST was carried out in the years 2001 to 2003. A final report was published in 2006 (TBA, 2006).

This study worked out an application of the SERSO idea to a Swiss highway section near Berne in strong cooperation with the local highway maintenance service.. The conceptual system design was slightly adapted to lower the overall costs. The feasibility study included several system simulations and optimisations, an overall cost estimation and a value benefit analysis.

The GeoVerSi-Study of the Ministeriums für Verkehr, Energie und Landesplanung of Nordrhein-Westfalen was carried out in the years 2004 and 2005. Aim of the study was to work out the actual experience of geothermal road heating all over the world and to show the limits and chances of such systems in Nordrhein-Westfalen (Germany). The costs of geothermal road heating systems have been summarized. A final report was prepared so far (NRW, 2005). The study recommended realising at least one pilot plant in cooperation with the road maintenance service. At the moment, the study is not continued.

6. CONCLUSION

Geothermal road, bridge or outside surface heating is a feasible and approved possibility to increase traffic and public safety. Several examples have shown, that geothermal road heating systems work without problems over years – complete renewable. A fully automatic operation allows reducing the number of night shifts of winter maintenance staff. Although the initial costs are high, such systems are not uneconomical. Social and macroeconomic benefits are given.

Figure 10: Geothermal road heating should keep traffic running.

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