Tunnelling and Underground Space Technology 58 (2016) 40–48

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Evaluation of two different drainage systems for rock tunnels

Håkan Stripple [a,*], Lars Boström [b], Tommy Ellison [c], Cathrine Ewertson [d], Peter Lund [e], Robert Melander [d]

[a] IVL Swedish Environmental Research Institute, Box 53021, SE 400 14 Gothenburg, Sweden
[b] SP Technical Research Institute of Sweden, Box 857, SE 501 15 Borås, Sweden
[c] BESAB, Tagenevägen 7, 422 59 Hisings Backa, Sweden
[d] Swedish Cement and Concrete Research Institute, SE 100 44 Stockholm, Sweden
[e] Swedish Transport Administration, SE 405 33 Gothenburg, Sweden

ARTICLE INFO

Article history:
Received 21 January 2015
Received in revised form 25 January 2016
Accepted 31 March 2016
Available online 29 April 2016

Keywords:
Tunnel drainage
Water
Rockdrain
Life Cycle Assessment (LCA)
Life Cycle Cost (LCC)

ABSTRACT

Water penetration and dripping in tunnels is almost always a significant problem which is usually solved with the help of a tunnel waterproofing drainage system mounted where drips and leaks are detected. Today's drainage systems are made of foamed polyethene (PE) mats which are covered with shotcrete. These are relatively expensive, complex to install, sensitive to mechanical impact, and often have a much shorter expected lifetime than the tunnel. In this study, a new type of drainage, Rockdrain, was studied and compared with the present drainage system. The systems were evaluated with respect to technical, environmental, and economic aspects. A field test was performed with the Rockdrain system and compared with installation of a traditional system. Laboratory tests were performed on especially the different shotcrete layers used in the Rockdrain system. The environmental evaluation was performed by Life Cycle Assessment (LCA) and the economic evaluation was performed by Life Cycle Cost (LCC) analysis. The results indicate that the Rockdrain system has a good drainage function, is significantly cheaper than the current system, has a longer expected lifetime, is easier to install, and is less sensitive to mechanical impact.

1. Introduction

Rock tunnels are very important components of a society's transport system. Road and rail tunnels shorten transport distances and many times also increase safety even if tunnel safety in itself can be an important aspect for example, from a fire safety perspective. Decreased transport distances and simplified routes, often provides faster transports, lower energy use in vehicles, improved environmental performance and lower transport costs. Rock tunnels and rock caverns also have other important functions in society such as storages, shelters and mines.

Rock tunnels and other excavated rock formations are often costly products that will be in operation for many years. Quality and technical function are important aspects as well as development of cost-effective production and construction processes that also meet the quality standards (Richards, 1998; Asakura and Kojima, 2003). Different rock tunnels contain many technical installations and activities which must be protected from leaking water from cracks in the rock. Although the rock is sealed with cement slurry by injection before and after blasting, almost always some leakage of water remains from the tunnel sides and roof. This water must regularly be pumped out of the tunnel. Leaking water can damage tunnel installations, form icicles that may cause danger to traffic, or other problems for the tunnels activities (Andrén and Dahlström, 2012; ITA Working Group on Maintenance and Repair of Underground Structures, 1991).

To divert leaking water in tunnels without lining, conventional drainage is today installed (Hargelius, 2006). Conventional drainage consists of foamed polyethene (PE) mats which are suspended on rock mounted threaded rods. The PE mats are assembled with different steel fittings and placed approximately 5–30 cm from the rock wall. The entire drainage structure is then covered with conventional reinforced shotcrete for mechanical protection and to reduce the fire risk of the polyethene mats. Conventional drainage is costly, requiring significant material resources and a labor intensive assembly. It is also subjected to mechanical stress by pressure fluctuations from passing trains and vehicles. This means that the lifetime and the technical function of the free-hanging design can greatly be shortened and

* Corresponding author.
E-mail addresses: Hakan.Stripple@IVL.se (H. Stripple), Lars.Bostrom@sp.se (L. Boström), Tommy.Ellison@besab.se (T. Ellison), Cathrine.Ewertson@cbi.se (C. Ewertson), Peter.Lund@trafikverket.se (P. Lund), Robert.Melander@cbi.se (R. Melander).

http://dx.doi.org/10.1016/j.tust.2016.03.015
0886-7798/

mechanically weakened. Much research has therefore been focused on the search for alternative solutions for tunnel drainage systems that will be better, cheaper, and with a longer lifetime (e.g. Lee et al., 2007; Butrón et al., 2010; Yuan et al., 2000; Grantz et al., 1997; Caputo and Huez, 1987).

In this study, a new alternative drainage method, which is designed to replace or supplement conventional drainage methods, has been analyzed and evaluated. The new drainage method is called Rockdrain and is further described below. Rockdrain is designed to be used in new installations as well as for maintenance and rehabilitation which is important since many tunnels are getting old and the need for renovation measures increase (Akçelik et al., 2002; Jung et al., 2013). This article is the result of these scientific studies and evaluations of the new Rockdrain drainage system. It is worth noting that this study only covers underground waterproofing drainage on the tunnel walls and roof. Additionally, there can be a drainage system with tubes and pumps in the bottom of the tunnel. This drainage system is not included in this comparative study since it can be considered equal for both the studied drainage systems (Gamisch and Girmscheid, 2005, 2009). A comprehensive technical report (Boström et al., 2013) and a report from the LCA and LCC evaluation (Stripple, 2013) of the system are also available.

2. Methodology in the study

In the study, a comparative analysis was made of two different drainage systems for rock tunnels. A standard technique is compared with a newly developed technique (Rockdrain) which is based on an entirely different drainage principle. A full scale test of the Rockdrain system was made in two tunnels in south Sweden - Kattleberg and Hallandsåsen. Different test sections of some hundred meters in length with water leakage have been installed with the Rockdrain system. Installation and production work were studied in detail concerning technical implementation and time studies were made of the work. The final product was analyzed using different material and function tests for several different technical properties such as water permeability and resistance to drop, mechanical strength, adhesion, fire resistance, thermal properties and salt tolerance, etc. The thickness of the various shotcrete layers was also measured by laser scanning.

The drainage system's environmental performance including energy characteristics was analyzed with Life Cycle Assessment (LCA) methodology according to the ISO standards (ISO 14040:2006, ISO 14044:2006) and other common practice such as the International Environmental Product Declaration system.[1] A reference group has been used for the review of the study. In a LCA analysis, a product's or a process's entire life cycle from raw material extraction via production, use, operation and maintenance to waste management and recycling is analyzed. In a LCA, the real processes are transferred into mathematical models. These are then used to analyze the environmental performance of each product or process. Computer models of the two drainage systems have therefore been developed in the study.

Similarly, a system analysis of the economic parts of a product or process can be performed. This is called LCC (Life Cycle Cost). In such an analysis, the different costs for the different parts of the system are calculated in the same way as in a LCA analysis. A comprehensive description of the methodology can be found in Fuller and Petersen (1995), Anon. (2005, 1999), Life Cycle Cost Handbook (2014). In this study, the LCC models are integrated with the LCA models into combined system models. Only internal costs have been included in the models. Thus, no external costs (externalities)[2] are taken into account. All costs have been included to the value they have as they arise during the lifetime and the society in the future is expected to be approximately equal to the society of today. This implies that a zero discount rate has been applied. All costs have been divided into labor costs, material costs, machine costs and transport costs. Data were collected as prices for different products, materials and services. The Rockdrain construction process was also studied and working time for the different processes was measured. Swedish price levels have been used. All rates are presented in Euro with a conversion factor of 9.1 Swedish kronor for 1 Euro. The labor cost used in the study was 60 Euro per hour. The life cycle cost was then calculated based on these data in the LCA/LCC models.

3. Technical description of the drainage systems

3.1. The technical function of the drainage systems

The two drainage systems differ significantly regarding technical function. Standard drainage today utilizes waterproof plastic mats that are set up to cover the leaking areas. The leaking water collects on the plastic mats and proceeds down to the bottom of the tunnel where drainage pipes lead the water out of the tunnel. The Rockdrain system works by channels formed in a shotcrete layer which then is covered with a less water permeable shotcrete layer called Solbruk T. Leaking water from the rock will spread in the shotcrete layer and finally reach a channel where it is drained off via the channel net to the bottom of the tunnel. Here, drainage pipes lead the water out of the tunnel. Physically there is a distinct difference between the two systems. In the standard system, the drains hangs freely off the rock wall, while the Rockdrain system is similar to a shotcrete layer directly attached on the tunnel rock, and thus becomes a part of the tunnel and not a separate installation in the tunnel. A free-hanging foamed polyethene mat construction is usually more sensitive to mechanical stress than shotcrete directly attached to the rock wall. This applies in particular to pressure fluctuation pulses from e.g. passing trains in tunnels which can produce adverse movements in the traditional drainage systems. This also affects the assessment of the lifetime of the two systems. Tunnel drains of various types have been installed since the 1960s and many of these have already been replaced for reasons of age. Newer drainage systems are expected to have a slightly longer lifetime and therefore, a life of 60 years has been assumed in the model calculations. The Rockdrain system forms the tunnel shotcrete layers and is thus expected to have the same lifetime as the tunnel's design lifetime and this is 120 years in Sweden.

3.2. Conventional drainage systems

The conventional or standard drainage systems used today is applied on the tunnel rock surface which is first covered with a layer of ordinary shotcrete. Holes are drilled in the rock and threaded 16 mm steel rods are mounted in the holes with cement paste. The diameter of the holes is approximately 40–60 mm and the depth of the holes is 1 m. The distance between the holes is 0.7–1 m. The holes are drilled with an electric driven drilling rig and the drilling capacity is estimated to be 20 holes per hour. The mounting rate of steel rods is approximately 20 rods per hour.

[1] The International Environmental Product Declaration (EPD) is a system designed for presentation of environmental performance and comparison of different products. For further information see www.environdec.com.

[2] External costs are costs that are not normally paid by the parties in a business deal, but by external parties. Examples of such costs are costs for pollution damage and health costs. The bearers of external costs can be either particular individuals or society at large.