ELGIP vision on reduction of geotechnical uncertainties for infrastructure


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Abstract

Transport infrastructure, including its connecting hubs that enable intermodal transport, are either built on or in the subsoil, and often use soil as construction material. Consequently, the subsoil plays a critical role in the complete life cycle of transport infrastructure. However, the natural formation and (sub)base materials that support the actual surface or structure are often very much overlooked as an important part of the infrastructure system, with occasionally disastrous consequences. This article summarizes the ELGIP vision on future transport infrastructure which aims at highly optimized, risk management-driven geotechnical (re)design, construction, maintenance and operation.

Introduction

Transport infrastructure, including connecting hubs that enable intermodal transport, are either built on or in the subsoil, and often use soil as construction material. Consequently, the subsoil plays a critical role in transport infrastructure design, construction, maintenance and demolition. However, the natural formation and (sub)base materials that support the actual surface or structure (e.g. tunnel) are often very much overlooked as an important part of the infrastructure system, as can be seen in figure 1. With occasionally disastrous consequences...

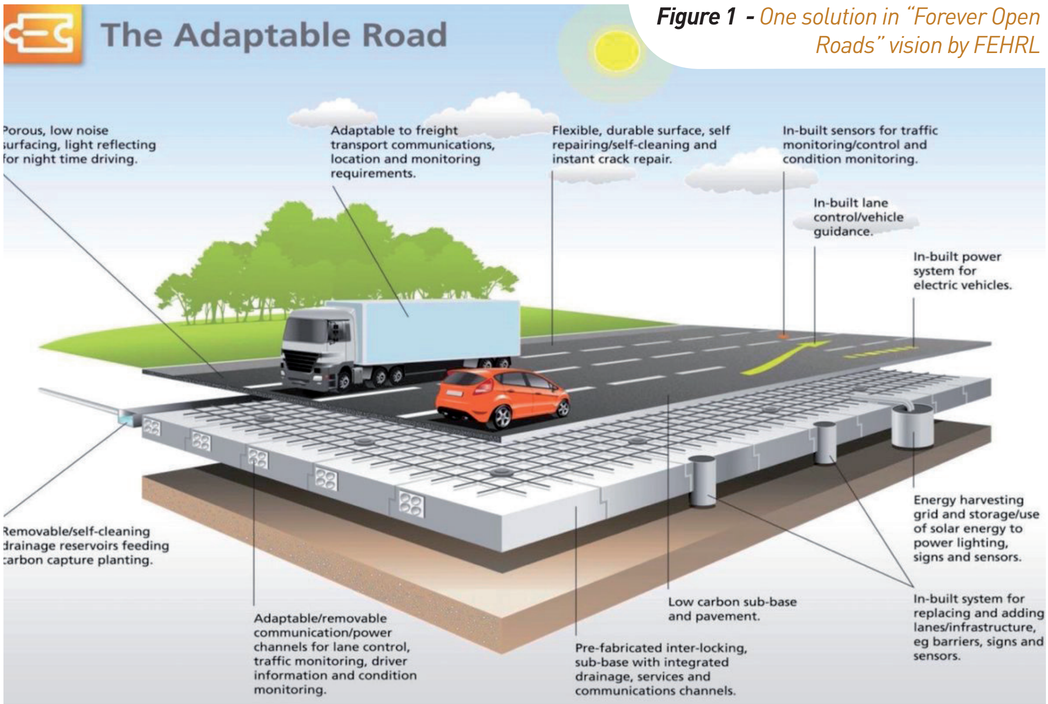


Figure 1 - One solution in "Forever Open Roads" vision by FEHRL

A strong group of 13 European research organisations in geotechnical engineering, the European Large Geotechnical Institutes Platform (ELGIP, see figure 2), aims to promote the profession internationally and has taken matters in its own hands. With over 2000 of professional staff, its members are committed to show that geotechnical engineering is essential in dealing with many pressing societal challenges associated with the built environment including transport infrastructure.

Figure 2 - ELGIP (www.elgip.net).

ELGIP members representing Norway (Norwegian Geotechnical Institute), Sweden (Swedish Geotechnical Institute), the Czech Republic (Technical University of Prague) and the Netherlands (Deltares) have formulated a vision document 'Reduction of geotechnical uncertainties for transport infrastructure'. This vision describes the challenges concerning the use and complete life cycle of transport infrastructure, and explains how geotechnical engineering plays a prominent role in solving these. The ELGIP vision on future transport infrastructure aims at highly optimized, risk management-driven geotechnical (re)design, maintenance and operation. This article will highlight the main components of this vision document.

The impact of geotechnical engineering

First, two examples of transport infrastructure disasters are given, to underpin the importance of the natural formation and supporting subsoil materials:

- On December 6th 2006, during the construction of a new part of road E6 in a quick clay area at Munkedal in Sweden, a landslide occurred affecting the old road (see figure 3). Several cars were drawn into the landslide. About 500m of road and 200m of the adjacent railway were destroyed. Fortunately, no one died. The costs for reconstruction alone were about €52 million. The landslide occurred due to incorrectly stored masses of subbase materials that triggered the slide [1].
- On March 20th 2012 a retaining structure along motorway A13 in Austria between Innsbruck and Brenner to Schönberg sud-

denly collapsed. This 40 year old concrete structure was designed according to the standards that had to be met at that time. It was regularly inspected, but failed only weeks after the last inspection (see figure 4). The retaining wall failed extremely rapid due to a combination of unexpected loading (by water accumulation behind the wall due to exceptionally high snow melt), structural problems and brittle behavior. As a result a truck driver was killed. Also potential risk led to the control of other similar retaining walls, and after the evaluation some parts were reconstructed.

To put this in perspective, in the years 2000-2006 the European Union (EU) invested €859 billion in its transport infrastructure [2], corresponding to €122 billion annually. Based on collected examples of similar disasters, it seems fair to assume that the failure costs equal at least 10% of the investment costs. Extrapolated to the EU, total failure costs may amount to €12.2 billion. And a conservative estimation of subsoil-related failures (about 1/3 of total failure costs) then amounts to about €4 billion annually for the EU.

Hence, geotechnical engineering plays an important role in one of the greatest challenges of modern society: continuing to provide a safe, secure, efficient and affordable transportation network for people and goods. The resulting (geo)technical challenge is twofold:

1. New transport infrastructure and hubs need to be built in a more resilient, more durable and more affordable manner;
2. Existing transport infrastructure need to be maintained, retrofitted and repurposed to meet societal demands.

Figure 3 *- Road damaged by landslide at E6, Munkedal, Sweden*

Source: SGI.

Policy challenges

As mentioned in policy documents from the European Commission (EC), transport is a key factor in modern economies [3]. Infrastructure is essential for the European quality of life, see figure 5, and vital for the EU's competitiveness [4]. The required infrastructure network enables links between the different stages of production chains and allows service industries to reach their clients. Moreover, mobility is a significant employer in its own right.

According to EC policy documents challenges for transport networks focus on the availability, affordability and sustainability of the infrastructure.

An infinitely available infrastructure network

The 2001 EU Transport White Paper [3] also addresses the permanent contradiction between society demanding ever more mobility, and public opinion becoming increasingly intolerant of chronic delays and poor quality transport services. When transport systems are efficient, they provide economic and social opportunities: e.g. better accessibility to markets, employment and additional investments. Conversely, when transport systems are deficient in terms of capacity or reliability (and thus not available), they can have an economic cost such as reduced or missed opportunities and lower quality of life.

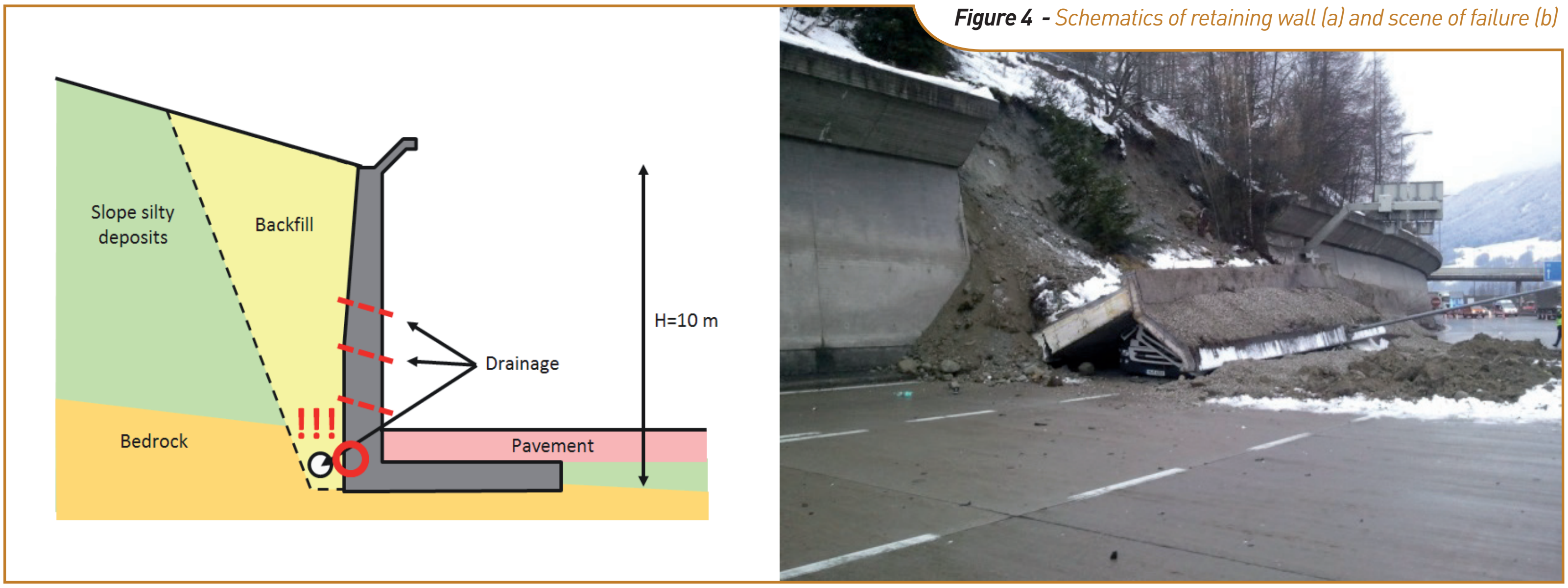


Figure 4 *- Schematics of retaining wall (a) and scene of failure (b)*

Figure 5 **-** *Infrastructure shapes mobility.*

Source: Chennai sustainable transportation network

Figure 6 **-** *Trans-European Transport Network (TEN-T).*

In that respect congestion is a major concern. Research has shown that in Utrecht, Manchester and Paris drivers spend more than 70 hours per year in road traffic jams [5]. And congestion costs Europe about 1% of gross domestic product (GDP) every year [6], which represented approximately €14.5 trillion in 2015 [7].

Unequal development of transport infrastructure between neighboring regions also has a negative influence on their interconnectivity. For example the Trans-European Transport Networks (TEN-T), which represent 800 km of key European corridors, have 9 north-south connections linking the continent, but only 4 east-west ones. And knowing that building a motorway, from planning to construction, can take up to 20 years, improvements of infrastructure networks have to be planned far ahead. With regard to infrastructure planning, in 2006 a list of EC policy actions [8] addressed the need to ensure a balanced approach to land-use planning.

By decreasing uncertainties in the natural formation and of subsoil materials through innovations in geotechnical engineering, significant gains may be achieved for infrastructure availability. Better understanding of local subsoil behavior and soil-structure interaction enable more efficient and timely maintenance strategies and less disruptive maintenance techniques. Moreover, improvements in geotechnical risk management and monitoring, also during the infrastructure's lifetime, will lead to less conservative observation-based design and construction.

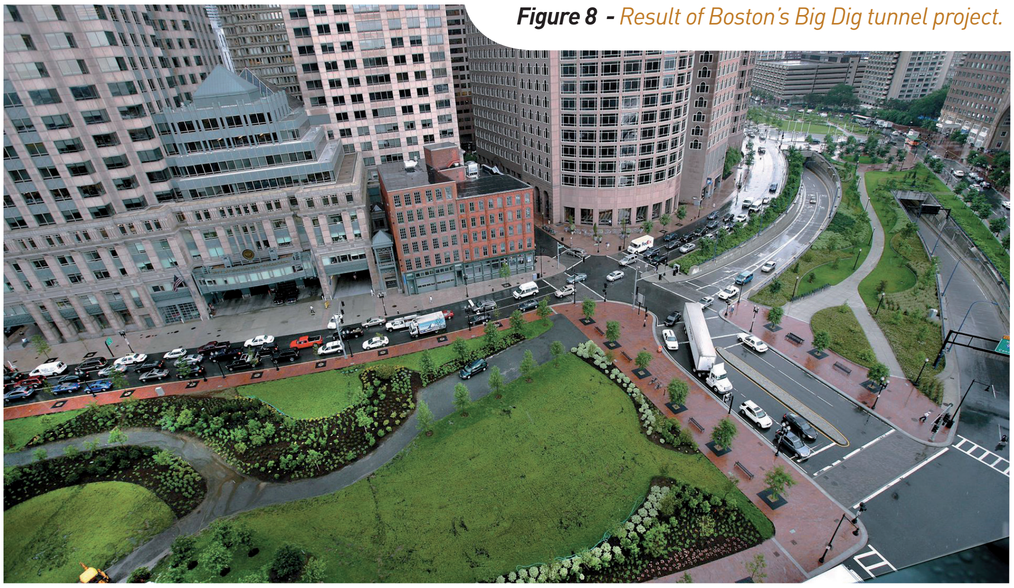
An affordable infrastructure network

A well-performing transport network requires substantial resources. In 2011 the cost of EU infrastructure development to match transport demand has been estimated [9] at over €1.5 trillion for 2010-2030. And the completion of the TEN-T network (see figure 6) would require about €550 billion by 2020. Obviously, there is an increased pressure on public resources for infrastructure funding.

User pay for the transport infrastructure network. However, not all costs related to the network are fully covered by the individual transport users (e.g. congestion, environmental damage and accidents). And the degree to which infrastructure costs are covered varies significantly both within and across modes. New approaches to funding and pricing of transport is required that reflect all costs of infrastructure. The affordability of transport infrastructure is clearly

Source: SGI

Figure 7 - *Wash-out of road and railway embankment at Ånn, Sweden.*



Source: Boston Globe

Figure 8 - *Result of Boston's Big Dig tunnel project.*

linked to a reduction of its life cycle costs. This includes extending the life span of existing infrastructure and increasing its resilience, see figure 7. Additionally, new infrastructure needs to be steadfast to maintain its long term functionality under changing conditions.

Knowing that at least one-third of infrastructure failure costs are subsoil-related, geotechnical innovations will have a significant impact on the affordability of infrastructure. These cover, amongst others, the development of reliable early warning systems for network parts vulnerable to hazards and methods to assess the condition of existing geotechnical structure (e.g. embankments, slopes).

A sustainable infrastructure network

Preferably, transport infrastructure investments are planned to maximize positive impact on economic growth and minimize negative impact on the environment, see figure 8. The importance of sustainability is emphasized in Europe2020, the EU's ten-year growth and jobs strategy launched in 2010. It addresses the shortcomings of our growth model and aims to create the conditions for smart, sustainable and inclusive growth.

The Europe2020 Resource-efficient Europe flagship initiative supports the shift towards a resource-efficient, low-carbon economy to achieve sustainable growth. And in alignment with this strategy, the 2011 Transport White Paper of the EC adopted a roadmap of 40 concrete initiatives for a competitive and resource efficient transport system (e.g. dramatically reducing GHG emissions in transport by 2050).

Innovations in geotechnical engineering boost sustainable infrastructure through capacity increasement of (existing) transport infrastructure, while at the same time a lower energy demand (during construction), lower raw material inputs and a smaller spatial footprint are required. It enables a sustainable transport infrastructure network that reduces health and safety risks during natural disasters, accidents and unwanted events and supplies (geothermal) energy.

What geotechnical engineering has to offer...

The ELGIP Vision Document illustrates that innovations in geotechnical engineering will have a significant positive impact on the availability, affordability and sustainability of transport infrastructure networks.

The main difference between subsoil materials (e.g. sand, gravel) and other building materials (i.e. steel, concrete, and to a lesser extent timber) is that subsoil materials are a natural material with much larger spatial variability, determined both by the environment at the time of deposition and the following geological history (see figure 9). This is accompanied by a much larger variability of subsoil characteristics. As a conservative estimate, earth structures may show uncertainties about 50% in the final required specifications whereas timber, concrete and steel structures show uncertainties in the range of 3-20%.

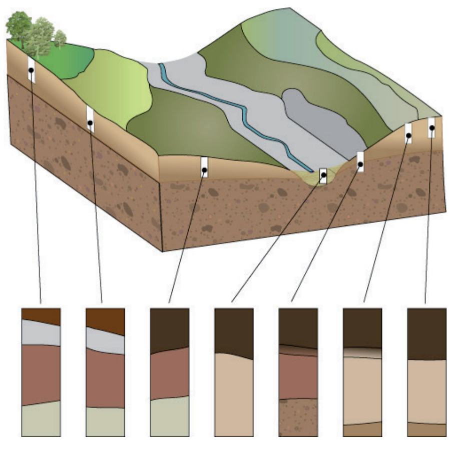
In addition, determination of soil parameters for geotechnical design is influenced by the type and extent of ground investigations, and the subsequent interpretation made by the geotechnical engineer. This results in a complex interaction that makes a reliable choice of geotechnical design parameters challenging. In this context, the geotechnical community currently handles inherent subsoil variability in two ways:

- By increasing the extent of ground investigations in an attempt to model the subsoil with more detail.
- By implementing an (over)-conservative design with the use of safety factors.

This may lead to unnecessarily expensive and less sustainable design of geotechnical structures that demand too many natural resources.

The ELGIP vision for sustainable, available and affordable transport infrastructure focusses, amongst others, on optimal observation-based geotechnical design. Leaner, less

Figuur 9 - *Variability of soil profiles over short distances.*



Source: Brady & Weil, 2002.

Figure 10 - *Betuweroute railway line*

conservative designs would result in substantial savings in construction costs and environmental impact, without affecting its stability and durability. In addition, the identification, assessment and prioritization of geotechnical risks for existing and newly built infrastructure will help to coordinate and economically apply the resources to minimize, monitor and control potential geotechnical hazards that could affect them. This is known as geotechnical risk management.

Example

The Waardse Alliance (the Netherlands) was related to the construction of part of the Betuweroute railway line, in which the subsoil-related risks were fully shared by client and contractor. The client asked for effective and cost-efficient solutions for building in challenging soft soil conditions. As part of the project, systematic instrumentation (based on risk management) was used for monitoring the construction process, aiming at achieving savings and increasing in the efficiency of it.

The sustainability impact of the project dealt with the optimization of land and resources (i.e. sand) used, resulting in minimized construction time and barriers for the surroundings. The availability impact of the project was reflected in the completion of the project within the expected time frame, enabling the operations to start on time. This directly links to the 'availability' ambitions. Due to the innovative approach, a positive financial project result of €25 million was achieved.

Conclusion

The ELGIP vision document shows that the application of risk management in geotechnical engineering in general, and monitoring or continuous control of subsoil conditions in particular, has great potential in leading to significant advantages for our society. Currently, the lack of sufficient research and innovation prevents us from using this potential, gaining the advantages for society.

Table 1 below shows the ELGIP objectives for the future of highly optimized, risk management-driven geotechnical (re)design, construction, maintenance and operation for infrastructure networks.

Tabel 1 - ELGIP objectives for future risk management-driven transport infrastructure (re) design, maintenance and operation

	Indicator	Guiding objective
Availability	Failure frequency, e.g. due to man-made and natural disasters	-25%
	Delay duration due to infrastructure repair, maintenance, reconstruction	-25%
	Fatalities and severe injuries due to man-made and natural disasters	-25%
Affordability	Travel time of persons / goods	-20%
	Total Cost of Ownership	-20%
Sustainability	Land use for infrastructure network	-30%
	Use of raw materials	-30%
	Use of secondary materials	+30%

Reference

[1] "Skadekostnader i byggprocessen– En litteratur genomgång", SGI Varia 642, Linkoping 2012;

[2] Steer Davies Gleave, 2009, "Ex Post Evaluation of Cohesion Policy Programmes 2000-2006, Work Package 5A: Transport", First Intermediate Report;

[3] COM(2001) 370 final, WHITE PAPER EU transport policy for 2010: time to decide, Brussels, 12.9.2001;

[4] COM(2008) 433 final, Greening Transport, Brussels, 8.7.2008;

[5] INRIX European National Traffic Scorecard 2010;

[6] Transport 2050: The major challenges, the key measures, EC memo/11/197, Brussels, 28.3.2011;

[7] see www.statista.com/statistics/279447/gross-domestic-product-gdp-in-the-european-union-eu/;

[8] COM(2006) 314 final, Keep Europe moving - Mid-term review of the European Commission's 2001 Transport White Paper, Brussels, 22.06.2006;

[9] EC calculations based on TENtec Information System and the Impact Assessment accompanying the White Paper, SEC(2011) 358;