Reduction of geotechnical uncertainties for infrastructure

An ELGIP VISION paper

Contents

1 General introduction

One of the greatest challenges for modern society is to continue to **provide a safe, secure, efficient, affordable transportation network for people and goods**. Economic growth and prosperity cannot be achieved without the interconnectivity and easy mobility afforded by infrastructure.
The resulting challenge is twofold: 1) new structures should be built in a more resilient, more durable, more affordable manner 2) exisisting structures need to be maintained, retrofitted and repurposed. **Geotechnical engineering plays an important role in this challenge**.

The goal of this paper is to show the relationship between the mentioned prominent pressing challenges concerning the field of design, building and maintenance of the built environment in general, and transport infrastructures in particular in Europe, and how geotechnical engineering plays a role in solving these challenges. **In essence this paper shows how geotechnical knowledge may boost international competitiveness**

Therefore this position paper is directed towards influencing the Horizon 2020 Research Agenda and other relevant European Commision policymaking actors, thus securing a more prominent place for geotechnical engineering within the EU and national research agenda.

However this paper also allows the geotechnical/ ELGIP community to select those research activities which have the most impact and require focus. Probably, these activities are the most suitable for putting forward in EU funding programmes (e.g. COST Actions, ERA-NET projects, Marie Curie Actions). Therefore, at a later stage, this paper may be the basis to formulate more focused communications (e.g. strategic research agenda) with certain liason officers in Brussels (DG MOVE, DG RESEARCH, DGD REGIO, DG CLIMATE).

The European challenges for infrastructure can be found in reports and papers by relevant European Commision policymaking actors, often reflected in calls. The relevant challenges have been noted in this paper and **it is shown how geotechnical expertise contributes to addressing these pressing problems in Europe with innovative solutions.**

1.1 Outline of paper

This paper starts with a 'top down' view on Europe's current objectives. Following is a chapter showing that the subsurface plays a major role in all phases of the lifecycle of infrastructure (design, build, maintain) and as such plays a major role in the affordability, sustainability and availability of infrastructure. Examples are given showing the impact if the subsurface is not sufficiently taken into account as well as examples showing the potential benefits of paying proper attention to the subsurface/ geotechnical engineering. The last part of this paper indicates how geotechnical engineering can result in significant advantages that are in line with major EU ambitions.

A shortened version of this vision document will be provided in a shorter 'position paper'.

Not mentioned in this paper is which research ELGIP expects would contribute most to reaching these ambitions. These are noted in a separate 'Research agenda' document.

2 The world around us - EU ambitions

As already mentioned in the 2001 Policy White Paper[1] by the EU, transport is a key factor in modern economies. And as the Greening transport package[2] mentions, mobility is essential for our quality of life and is vital for the EU's competitiveness. Mobility is the backbone of the economy making the links between the different stages of production chains and allowing service industries to reach their clients, as well as being a significant employer in its own right. As such it is of utmost importance for achieving the goals of the EU's growth and employment strategies.

The European transport industry directly employs more than 10 million people, accounting for 4.5% of total employment, and represents 4.6% of GDP [Eurostat].

The 2001 Policy White Paper[3] observes that there is a permanent contradiction between society, which demands ever more mobility, and public opinion, which is (still) becoming increasingly intolerant of chronic delays and the poor quality of some transport services. Congestion is a major concern and comprises accessibility. In addition, transport infrastructure is unequally developed in the eastern parts of the EU, compared to Western Europe. There is an increased pressure on public resources for infrastructure funding which requires a new approach to funding and pricing.

The EU has over 4.5 million km of paved roads and 212.500 km of railway lines, and has invested about €859 billion in its transport infrastructure in 2000-2006. The current impact of transport is significant: Congestion costs Europe about 1% of GDP every year [EU, 2011]. And transport is responsible for about a quarter of the EU's GHG emissions; 71.3% of the overall emissions are generated by road transport [EEA, 2008].

Therefore the 2011 White Paper concludes that the transport system needs to be optimised to meet the (economic and social) demands of enlargement and sustainable development, as set out in the conclusions of the Gothenburg European Council. As a modern transport system must be sustainable from an economic, social and environmental viewpoint.

Infrastructure shapes mobility. The EU recognizes that no major changes in transport will be possible without the support of an adequate infrastructure network and more intelligence in using it. Transport infrastructure investments have to be planned in a way that maximizes positive impact on economic growth and minimizes negative impact on the environment. Transport (infrastructure) has to be sustainable in the light of the challenges we face.

It can take up to 20 years to build a motorway, from planning to construction. The average cost per km varies depending on the location and complexity of the route. It can be as low as €7.1 million and as high as €26.8 million

[http://ec.europa.eu/transport/strategies/facts-and-figures]

[1] COM(2001) 370 final, WHITE PAPER European transport policy for 2010: time to decide, Brussels, 12.9.2001;
[2] COM(2008) 433 final, Greening Transport, Brussels, 8.7.2008;
[3] COM(2001) 370 final, WHITE PAPER European transport policy for 2010: time to decide, Brussels, 12.9.2001;

A short overview of policy and strategy documents and initiatives in a European context relevant to transport infrastructure is given in Appendix A:
2001 Policy White Paper
2006 Mid-term review of the EC's 2001 Transport White Paper
2008 Greening transport package
2009 A sustainable future for transport Policy Paper
2010 Europe 2020 strategy
2011 Transport White Paper
2014 Horizon 2020
2013 ECTP's reFINE Strategic Research Agenda
2013 Joint ETP Task Force on Infrastructure Strategic Research Agenda
FEHRL's Forever Open Roads concept

These sources confirm that transport infrastructure and mobility play a major role in the EU ambitions. Specifically, the challenges for transport infrastructure can be summarized as:

- sustainable infrastructure
- affordable infrastructure
- available infrastructure

3 How geotechnical engineering links to transport infrastructure

Infrastructures and transportation hubs are all either built on the subsurface or in the subsurface and often also use material from the subsurface as building material. Therefore it follows that the subsurface itself and materials from the subsurface (e.g. sand, gravel) plays a critical role both in the design and building phase as well as during the maintenance phase (i.e. all phases) of all transportation infrastructure modes.

However the subsurface itself and materials from the subsurface are often very much overlooked as an important part of the structure, with occasionally disastrous consequences leading to impact on availability, affordability and sustainability of the infrastructure. Often a lack of knowledge of a simplistic approach to the variability of the subsurface during the design and/ or construction phase may be the cause of these problems.

There are no readily available (to the authors) numbers on the impact/ cost of failures for infrastructure projects, with a geotechnical origin for Europe as a whole. Nevertheless to provide an indication of the significance of this impact/ cost first actual examples are given. Subsequently, an extrapolation will be made for Europe as a whole, for the costs (affordability) of subsurface/ geotechnical engineering related failures, based on Swedish and Norwegian figures. A similar argument may be made for sustainability and availability of infrastructure.

3.1 Failures where the subsurface/ geotechnical engineering played an important role

3.1.1 Landslides in soft clay; E6 Munkedal, Sweden and Mofjellbecken bridges, E18, Norway

Figure 3.1: Road damaged by landslide at E6, Munkedal, Sweden (Photo:SGI)

On December 6th 2006 during construction of a new part of road E6 at Munkedal in Sweden a landslide occurred affecting the old road. Several cars were drawn into the landslide. Fortunately no one died. About 500 meter of the road and 200 meter of the railway were destroyed. The social cost were about 52 M€ for rebuilding. The road was built in an area with quick clay. The landslide occurred due to incorrectly stored masses of subsurface materials and could have been avoided with geotechnical expertise involved at the time (Lind, 2012).

Similarily, on the 9th of February 2015, a 100 000 m^3 landslide in quick clay occurred close to the Mofjellbecken (Skjeggestad) bridges at road E18 in Norway. A part of the landslide occurred under the bridges and caused damage to them. One of the bridges had to be torn down by blasting and the other had to be reinforced (NVE, 2015). The cost for demolition and rebuilding of the bridges are expected to be around 11 M€. The landslide was caused by filling of soil masses i.e. loading of the subsurface in the vicinity to the bridges.

Figure 3.2: Bridge damaged by landslide at E18, Mofjellbecken, Norway (Photo: NGI)

3.1.2 Debris flow and wash-out of a road and railway embankment in Ånn, Sweden.

Figure 3.3: Wash-out of road and railway embankment, Ånn Sweden.

In July 30th 2006 an 8 meter high railway- and road embankment was washed out during heavy rain, close to Ånn in Sweden. A train had passed just minutes before the collapse, narrowly avoiding human disaster. No people were injured but the costs for repair and the consequences for the traffic were significant. The culverts under the embankments could not resist all the rain water and were probably clogged with soil, branches and trees before the collapse. One reason could also be a debris flow from the mountain. There is a need of more knowledge about the consequences of climate change on the transport infrastructure in order to avoid this kind of failure (Lundström and Persson, 2010)[4].

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[4] References: SGI (2013). Efficient underground construction. Draft Action Plan 2013 - 2016. Effektivare markbyggande. Förslag till Handlingsplan 2013 – 2016. Swedish Geotechnical Institute, SGI Dnr 1.1-1202-0116. (In Swedish).
Lind Bo (2012). Failure costs in the construction process - A review of the literature. Skadekostnader i byggprocessen– En litteratur genomgång. (In Swedish). SGI Varia 642, Linkoping 2012.
Lundström, K, Persson, H. (2010). The debris flow in Ånn, Sweden, 30th of July 2006. Documentation and analysis. Slamströmmen i Ånn 30 juli 2006. Dokumentation och analys. Swedish geotechnical Institute. Varia 614.
NVE (2015). The landslide at Mofjellbecken bridges. Investigation of technical causalities. Skredet ved Mofjellbekken bruer (Skjeggestadskredet). Utredning av teknisk årsakssammenheng (In Norwegian).

Figure 3.4 Photo: SGI

3.1.3 Example of failure - Motorway A13 Schönberg Austria

On 20th March 2012 a retaining structure along motorway A13 in Austria between Innsbruck and Brenner to Schönberg suddenly collapsed. The 40 year old structure was designed according to the standards current at the design time. It was regularly inspected but failed only weeks after the last inspection.

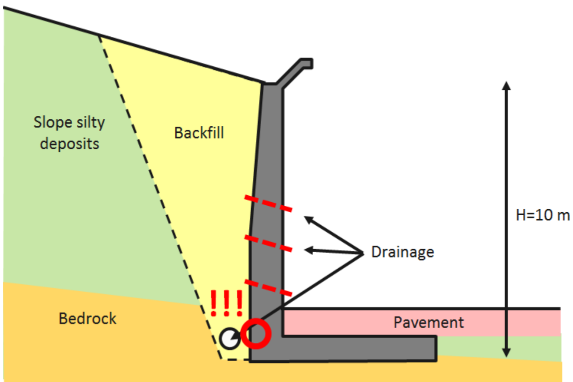

Figure 3.6: Schematics of retaining wall

Figure 3.5: Scene of failure

The concrete structure failed due to a combination of structural problems and (unexpected) loading of the retaining wall by water accumulation behind the wall due to exceptionally high snow melt.

The failure was extremely rapid due to brittle behaviour of the retaining wall.As a result the truck driver was killed. And the motorway closed for an unknown amount of time. Also potential risk led to the control of other similar retaining walls and after the evaluation some parts were reconstructed.

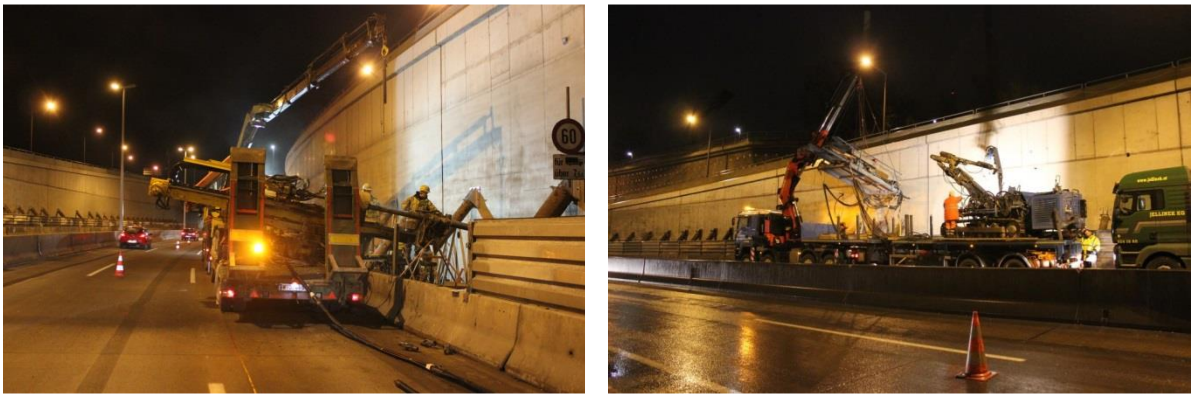

Figure 3.7 Example of reconstruction is shown for Motorway A23 Vienna - Graz

3.2 Estimated total impact of European geotechnically related failures

The outcome from studies on failure costs in building projects in general (i.e. not specifically for infrastructure) for Sweden and Norway is calculated to be about 10 % of the investment cost (Lind, 2012), which for Sweden amounts to approximately 2.7Bn€ annually (2011).
The failures are often human related. Uncertainties about the geological and geotechnical conditions are also important reasons for the failure costs. Of the total investment/ construction costs, approximately 20% are thought to be related to the subsurface/ geotechnical aspects.

About 1/3 of the total failure cost is estimated to be related to the subsurface/ geotechnical aspects i.e. for Sweden this would correspond to a total annual damage cost of close to 1/3 x 2.7Bn€ = 900M€ (SGI, 2013). In the Netherlands (Paul Cools, GeoImpuls programme, Ministry of Infrastructure and Environment, Rijkswaterstaat) even mentions 50%, as does Professor Katzenbach (TU Darmstadt, personal communicé)[5].For Sweden, a reduction of these failures with as little as 10% would mean an annual saving of 90M€, and a larger decrease, of course, additional savings.

Based solely on investments in facilities in Sweden (roads, railways, canals, electricity and telecommunications; approximately 7.5Bn€ per year) the failure costs are expected to be about 750M€ of which approximately 250M€ should be subsurface/ geotechnically related. A reduction of Geotechnical related failures with 10% gives savings of up to 25M€ per year.

The EU has invested about 859Bn€ in its transport infrastructure in 2000-2006 [EEA, 2008], corresponding to 122Bn€ annually. Assuming the figures for failure costs in Sweden and Norway may be extrapolated over the rest of the European countries, total failure costs will amount to 12.2Bn€ (10% of investment costs) and a conservative estimation of the geotechnical related failures then amounts to about 4Bn€ (1/3 of total failure costs) annually for Europe.

Both the examples as well as the extrapolation show that the subsurface/ geotechnical engineering have a significant impact on affordability, availability and sustainability of infrastructure. Even just

[5] In this document a conservative percentage of 10% will be used to give an estimation of the impact of the subsurface/ geotechnical engineering related to the total

marginal progress with improved Geotechnical knowledge will save a lot of money that could be used for example to maintenain existing infrastructure.

3.3 Difference between subsurface materials and other building materials

The main difference between subsurface materials (e.g. sand, gravel) and other building materials (i.e. steel, concrete, and to a lesser extent timber) is that subsurface materials are a natural material with spatial variability (i.e. location and depth, see Figure 3.8) determined both by the environment at the time of deposition and the following geological history. For example, river sediments may vary in particle size based on their location of deposition within the bend of a river. Coarse gravels which were deposited at the outside of the bend in a river may lie within a few metres (or ten's of metres) from fine grained silty sediments deposited at the inside of the bend.

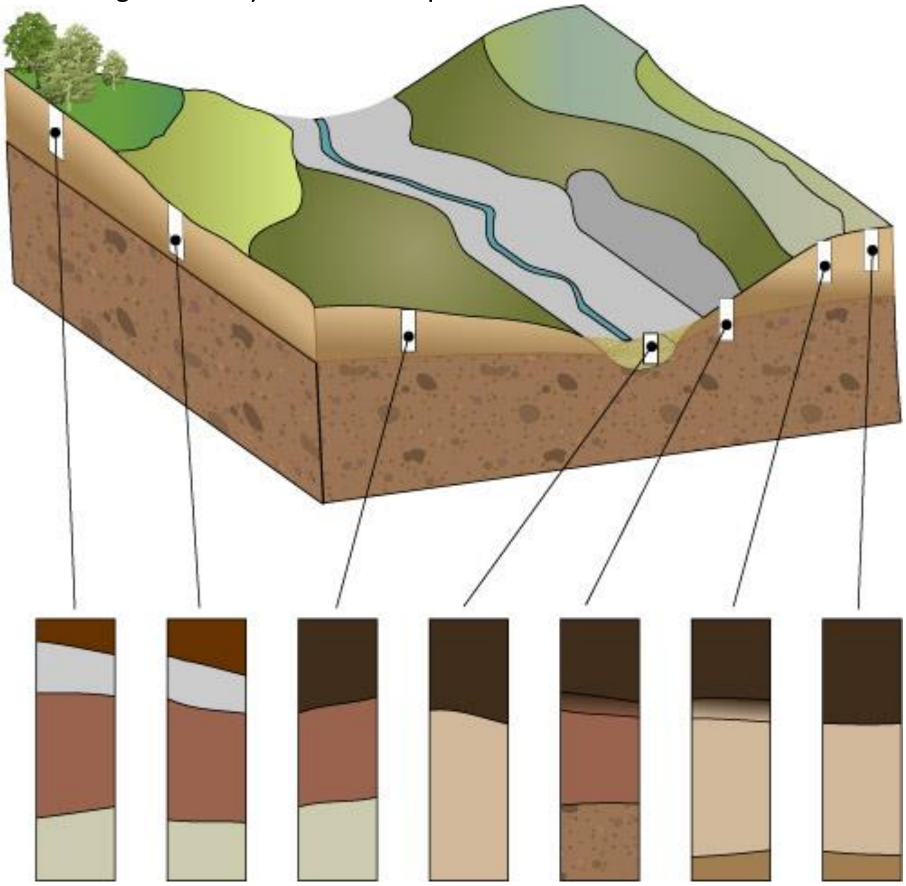

Figure 3.8 Variablity of soil profiles can occur over short distances (adapted from Brady & Weil, 2002). Brady, N.C. &Weil, R.R. 2002. The nature and properties of soils. Prentice Hall.

In addition to this, determination of soil parameters for geotechnical design is influenced by the type and extent of ground investigations, and the following interpretation made by the geotechnical engineer. This results in a complex interaction that makes a reliable choice of geotechnical design parameters challenging.

If used as building material, subsurface materials show a much larger variability than other materials. For example, as a conservative estimation, earth structures may show uncertainties about 50% in the final required specifications whereas timber structures, concrete structures and steel structures show uncertainties in the range of 3-20%.

3.4 Dealing with subsurface variability: current and future approaches

Subsurface characterization is a combination of actual data, knowledge about the quality of the data, knowledge on the geology, and most importantly engineering judgement. In this context, the geotechnical community handles inherent subsurface variability in two ways:

- By increasing the extent of ground investigations in an attempt to model the subsurface 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 the future should focus even more on optimal geotechnical design i.e. sustainable, available and affordable. Leaner, less conservative designs would result in substantial savings in construction costs, without affecting the stability and durability of the structure.

In addition, the identification, assessment and prioritization of geotechnical risks for already built and new structures 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.

Potential benefits of geotechnical risk management are: a) a systematic and explicit evaluation of uncertainties sources; b) consideration of the potential consequences; c) minimization of unforeseen situations, incidents and accidents; and d) integration of all activities related to infrastructure safety from feasibility studies, design, construction, operation and maintenance.

During the design, construction and operation phases of infrastructure, geotechnical risk management by means of monitoring or continuos control contributes to adapting the design to optimize the final design for new structures and to garantee its operability and maintenance during the life time. These last two aspects also apply for already existing structures.

In the following paragraphs, examples are provided showing the application of risk management, with special focus on monitoring or continuos control leading to significant advantages. The examples are from several countries represented in ELGIP; Norway, The Netherlands, Czech Republic, Italy and Belgium. They cover a variety of projects with special geotechnical focus like railway construction and maintanance, road construction, earth structures, bridge foundations and excavations.

3.4.1 Example #1: Mapping of natural hazards for the Norwegian National Rail Administration (Country: Norway, example from Norwegian Geotechnical Institute[6])

The objective of this project was the identification and prioritization of railway sections under geotechnical hazards; scouring / sliding of embankments, river erosion, earth slides (including quick clay) and rock falls. Identification of the risks along the railway was carried out for the client (The Norwegian National Rail Administration) so that the client could take precautionary measurements in the areas with compromised stability before an unwanted event (disaster) took place, and in this

[6] Personal communication with Guro Grøneng and Priscilla Paniagua, Norwegian Geotechnical Institute.

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way increase transportation safety and operational time. Figure 3.9 shows an example from a railway section in Norway where earth slide activity in the terrain above the railway was identified as a risk.

In this project, continuos monitoring is an alternative in prioritized sections were mitigation measures are challenging to take. In addition, the observational method has been used for hazards identification and prioritization of the railway sections.

Figure 3.9 Earth slide activity above a railway section in Norway (Photo: NGI).

The sustainability impact of the project is reached through the reduction of train shutdowns and delays caused by unexpected situations. These oblige the railway administration to provide alternative means of transport, as busses, lorrys and taxis; and cover the expenses this may cause. Estimations of the cost due to an increase in the travel time when the train stops or delays in goods transporation reaches 11€/person/hour or 10€/ton/hour in the case of goods transport[7].

The availability impact of the project is to give a more secure and competitive transport system, an adequate network preventing the breakdown of the existing railway infrastructure leading to congestion in other transport networks. The affordability impact of the project is shown as a reduction/no expenses in emergency maintenance (i.e. reparation and clean up after an event) and unexpected costs (due to train shutdowns) since the maintenance during the operational time is prioritized and preventive. It is estimated that the costs[8] for repairing damaged zones in the railway,

[7] Data taken from NGI (2013). Impact of extreme weater events on infrastructure in Norway (InfraRisk). Report 20091808-01-R. The values given are in 2005-euros.
[8] Data taken from NGI (2013). Impact of extreme weater events on infrastructure in Norway (InfraRisk). Report 20091808-01-R. The values given are in 2005-euros.

railway foundation, cables and connections reaches 4100€/m. Just the cost of clean up after an event may exceed 2600€/m.

The sustainability, availability and affordability impact of the project, due to geotechnical hazards identification and prioritization of the railway sections, is indicated as a more reliable, secure and competitive transport system and reduction of expenses in emergency maintenance which saves around 1,34 M€ on a linear section of 200m, not including costs for delay of people or goods.

3.4.2 Example #2: The logistic and distribution centre Point Park Prague (Country: Czech Republic, example from Czech Technical University[9])

The logistic and distribution centre Point Park is situated partly in cuts and partly on an embankment. To minimize the land consumption, the embankment around its perimeter is constructed from reinforced subsurface materials, close to 10 m high, wih nearly a vertical slope. Before the construction of the last hall of the centre, together with the access road, tensile cracks appeared behind the zone of reinforcement with visible tilting of the whole reinforced block and a tendency to the complete overturning. Then, the client asked for the reason causing the failure of the structure, the structure reconstruction and a way to guarantee the long term stability and functionality of this geotechnical structure, in particular with respect to the limit states of failure and serviceability.

The reinforced structured has been monitored in terms of vertical deformations, horizontal deformations and tilting. This has been done during the reconstruction process and during the operational part of the structure to guarantee long term functionality.

The sustainability impact of the project is shown by the reduction on land use (i.e. protection of greenfields) and natural aggregates since all the excavated material from the cuts is being used in the embankment, reducing with this the carriage of more subsurface material from external sources. The availability impact of the project is guaranteed in the long term by the new approach of soil reinforcement and its respective monitoring to keep operating the structure efficiently. The affordability impact of the project is indicated by the use of raw materials (subsurface materials) for the retaining wall construction, available at the site, instead for concrete or steel; reducing with this the final price, energy consumption and CO_2 footprint.

The sustainability, availability and affordability impact of the project, due to construction and monitoring of the reinforced earth embankment, is indicated as reduction on land use, long term stability and reutilization of excavated materials available at the site which reduces the final costs of the project, energy consumption and CO_2 footprint.

3.4.3 Example #3: The Dora Baltea Bridge – Strambino, Torino (Country: Italy, example from Politecnico di Torino[10])

Dynamic measurements of the traffic-induced vibrations on the Dora Baltea Bridge (see Figure 3.10) are used to asses scour of the foundations after erosion processes due to flooding or the normal river level. The client asked for solutions for early warning systems and assesments of the bridge safety during and after major flood events, in order to assist in decision making for keeping the

[9] Personal communication with Professor Ivan Vaníček, Faculty of Civil Engineering, Geotechnical Department, Czech Technical University Prague

[10] Foti, S. & Sabia, D. (2011). Influence of foundation scour on the dynamic response of an existin bridge. Journal of Bridge Engineering 116 (2): 295-304.
Personal communication with Assistant Professor Sebastiano Foti, Department of Structural and Geotechnical Engineering, Politecnico di Torino.

bridge in operation or not. In this way, real time measurements were applied to detect vertical displacements, the dynamic response and critical situations associated to scour of foundations.

Figure 3.10 Scour of the foundation for the Dora Baltea Bridge in Italy (Photo: POLITO).

The sustainability impact of the project is reflected in limited maintenance costs for bridges subjected to scour of foundation. The availability impact of the project is shown in more secure infrastructure and less downtime for crucial bridges during and after major flood events. Regarding the affordability impact of the project, this type of solutions can reduce the number of piers requiring retrofitting and implement real time monitoring on critical infrastructures.

The sustainability, availability and affordability impact of the project, due to dynamic measurements of the traffic-induced vibrations in the bridge, is indicated as reduction on maintenance costs, more secure and reliable infrastructure during and after major flood events.

3.4.4 Example #4: The Waardse Alliance (Country: The Netherlands, example from Deltares[11])

The Waardse Alliance is related to the construction of part of a new railway line (see Figure 3.11), in which the (subsurface-related) risks were fully shared by the client and the 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.

[11] Personal communication with Joost Breedeveld and Mike Woning, Deltares.

Figure 3.11 Construction work for the Betuweroute railway line in the Netherlands (Photo: Deltares).

The sustainability impact of the project deals with the optimization of land and resources (i.e. sand materials) used, resulting in minimized construction time and barriers for the surroundings. The availability impact of the project is reflected in the completion of the project within the expected time frame that made possible that operations started on time. The affordability impact of the project relates to a positive financial project result of 25M€.

The sustainability, availability and affordability impact of the project, due to systematic instrumentation during construction based on geotechnical risk management, is indicated by the land and material use optimization minimizing construction time and barriers which results in savings up to 25M€.

3.4.5 Example #5: Bypass Mechelen (Country: Belgium, example from the Belgian Research Institute[12])

This project consists of the construction of a railway bypass on a steep reinforced earth embankment, as shown in Figure 3.12. This posed a challenge due to the limited space available to construct the railway extension and a lack of experience and confidence in this construction technique under a railway. The client wanted to reduce costs with the designed solution. Therefore, measurements and monitoring were done to convince the client in gaining confidence and to apply this cost-effective and sustainable construction technique.

Figure 3.12 Reinforced earth embankment at Bypass Mechelen in Belgium (Photo: BBRI).

The sustainability impact of the project is positive in comparison with alternative construction technique (building with subsurface materials vs. a retaining wall system). The availability impact of the project is shown in the reduction, in a significant way, of the travel time between Brussels and Amsterdam, and an improved flow and connections of the railway traffic around and towards Brussels.

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[12] Personal communication with Noël Huybrechts, Head of the Geotechnical Division, Belgian Building Research Institute (BBRI).

The sustainability, affordability and availability impact of the project, due to measurements and monitoring of the reinforced earth embankment, is indicated by reutilization of the excavated material, reduction of travel time and an improved flow and connection of the railway traffic around Brussels.

3.4.6 Example #6: Oosterweel Link Antwerp (Country: Belgium, example from the Belgian Research Institute[13])

This project looked for closing the ring road surrounding the city of Antwerp and decreasing in a significant way traffic jams caused a.o. by the harbor traffic (see Figure 3.13). For the client, the original solution (sunken tunnel) was out of budget. In addition, a lot of uncertainty existed with regard to a more cost-effective solution (cofferdam and stapled cut and cover tunnel). Therefore, a 3.5 M€ preliminary test program with intensive monitoring was set-up. Monitoring and back-analysis allowed to decide on the buildability of the project, to quantify and optimize geotechnical design parameters and to identify possible construction risks.

Figure 3.13 Reinforced earth embankment at Bypass Mechelen in Belgium (Photo: Noriant, NP-BRIDGING).

The sustainability impact of the project is reflected in a design with optimized design parameters that lead to less use of raw materials. The availability impact is indicated by the solution given to major traffic problems in the Antwerp area. The affordability impact of the project is reflected in the cost reduction which in fact it was a requirement to go on with the project. The cost reduction on the project is estimated to 400M€.

[13] Personal communication with Noël Huybrechts, Head of the Geotechnical Division, Belgian Building Research Institute (BBRI).

The sustainability, affordability and availability impact of the project, due to the pre-project geotechnical monitoring and back analysis test program, is indicated by a design with optimized parameters, use of less raw material, a solution to the traffic problems around Antwerp and in a cost reduction up to 40M€.

4 How can geotechnical engineering contribute to EU ambitions

4.1 What is reaction of ELGIP on EU ambitions

The above chapters show that if insufficient attention is given to geotechnical engineering, great losses may be expected in relation to availability, affordability and sustainability for infrastructures, not to mention safety issues. Conversely, significant gains may be made if geotechnical engineering is given the proper attention and time/ place in the design-, build- and maintenance process. ELGIP expects that geotechnical engineering may significantly aid the EU ambitions of sustainability, availability and affordability as is indicated below.

4.2 Sustainability

Our economy and society requires transport since it enables market interaction and allows mobility of citizens. This helps to economic growth and job creation. Transport requires sustainable infrastructure in the light of the new challenges that the society faces. It demands less congestion, less travel time, less delays, less downtime of vital structures (i.e. bridges, tunnels, and railways), alternative construction materials, lower CO_2 emissions, and minimal environmental impact, among others. Our transport infrastructure should respond to the needs of the present without compromising the capacity of future generations to respond to their needs.

Geostructures like embankments, slopes, road- and bridge foundations are important components of critical infrastructures like transportation networks. Geotechnical engineering may aid transport infrastructure to be more sustainable in the design, build and maintenance phases by providing an economically competitive construction. This means a construction with higher utility value and at the same time with lower energy demands, lower raw material inputs and lower need of new plots of land. In addition, a construction where the risk of the danger for human health and life during natural disasters, accidents and unwanted events is reduced.

Seven categories where geotechnical engineering can contribute to improve the sustainability of the societal system include (i) waste management, (ii) infrastructure development and rehabilitation, (iii) construction efficiency and innovation, (iv) national security, (v) resource discovery and recovery, (vi) mitigation of natural hazards, and (vii) frontier exploration and development.[14]

In particular, some areas that combine sustainability and geotechnical engineering are for example:

- Innovative and energy efficient ground improvement techniques that lead to less use of greenfields and/ or have less impact on groundwater, flora and fauna etc. and/ or may reduce the amount of natural raw materials needed e.g. soil reinforcement, *in-situ* enhancement of the subsurface (soil), as shown in Figure 4.1.

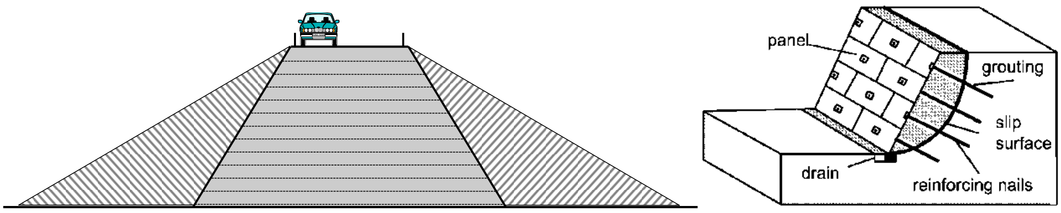

Figure 4.1 Diagram explaining how to reinforce a earth embankment (to the left) and in-situ soil enhancement (to the right (personal communication with Vanicek).

[14] Basu, D-, Misra, A. & Puppala, A.J. (2015). Sustainability and geotechnical engineering: perspectives and review. Canadian Geotechnical Journal 52: 96-113.

- The use of alternate, environment friendly materials in geotechnical constructions, and reuse of waste materials (Figure 4.2). The use of non-standard construction materials (and thus saving natural raw materials e.g. sand, gravel), such as ash, slag, mining waste, construction and demolition waste, excavated subsurface materials and rock.

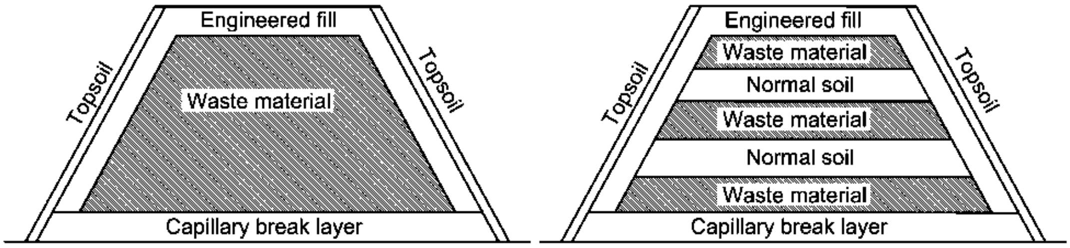

Figure 4.2 Diagram explaining the use of waste material in a earth embankment (personal communication with Vanicek.

- Geohazards mitigation (Figure 4.3) including studies on the effects of global climate change and of multihazards on geo-structures. Sustainable geotechnical engineering should focus on minimization of ecological footprints and in making geo-structures reliable. In this way, the effects of hazards can be minimized. Reliability and resilience is particularly important for critical infrastructures (e.g., lifeline systems like transportation and power supply network without which other systems like cities cannot function) of which geostructures like dams, embankments, slopes and bridge foundations are important components[15].

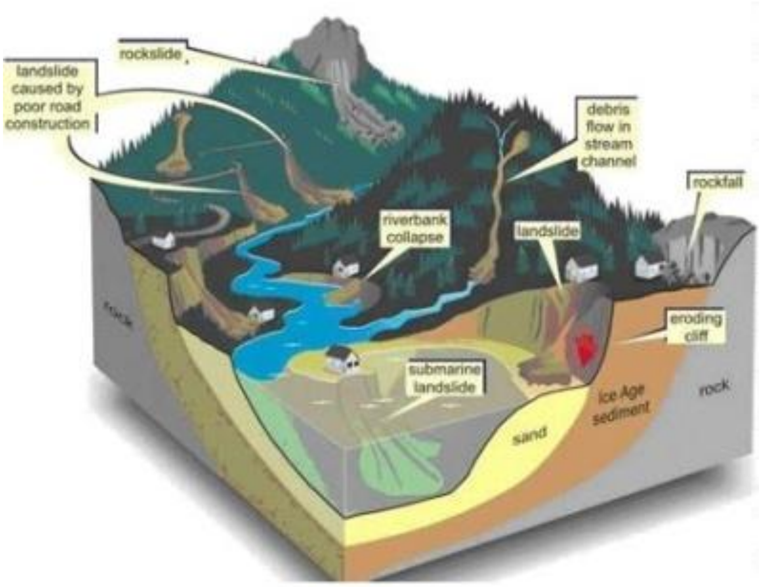

Figure 4.3 Some geohazards examples. (Taken from http://www.mining-technology.com)

Other potential areas where geotechnical engineering may concentrate its efforts from the sustainability point of view are: bio-slope engineering; efficient use of geosysnthetics; sustainable foundation engineering that includes retrofitting and reuse of foundations, and foundations for energy extraction; use of underground space for beneficial purposes including storage of energy;

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[15] Basú, D., Misra, A., Puppala, A.J. & Chittoori, C.S. (2013). Sustainability in Geotechnical Engineering. Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris 2013

mining of shallow and deep geothermal energy; preservation of geodiversity and incorporation of geoethics in practice[16].

4.3 Availability

Because of its intensive use of infrastructures, the transport sector is an important component of the economy and a common tool used for development. This is even more so in a global economy where economic opportunities are increasingly related to the mobility of people, goods and information.

When transport systems are efficient, they provide economic and social opportunities and benefits that result in positive multipliers effects such as better accessibility to markets, employment and additional investments. 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.[17]

By decreasing uncertainties of subsurface and of natural materials, significant gains may be achieved for the availability of infrastructures. Specifically decreasing these uncertainties may lead to:

- More robust design and construction techniques that lead to less breakdowns of the infrastructure

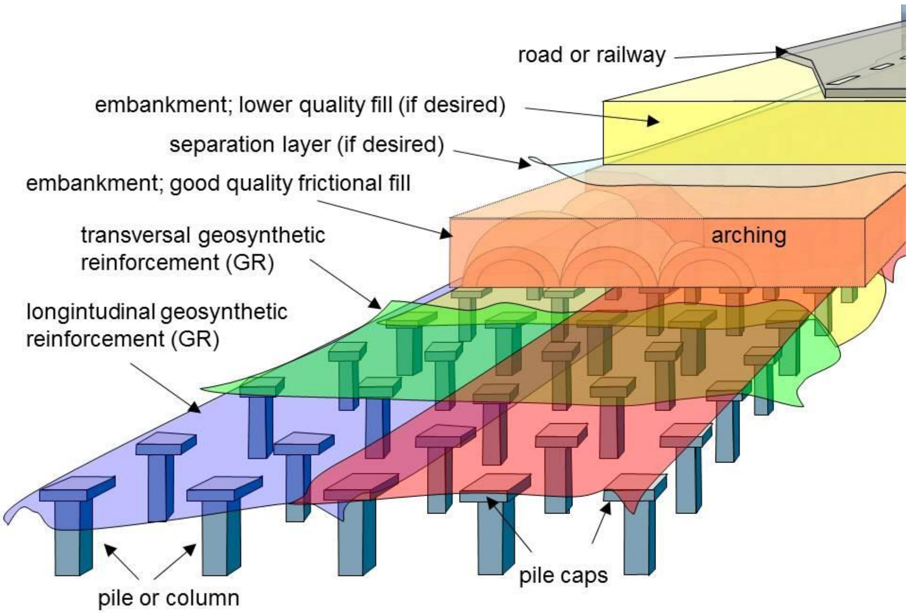

Figure 4.4 A basal reinforced piled embankment. No post-construction settlements are expected for this construction type. Therefore, the only maintenance will be pavement replacement of the surface after 10 years. For a traditional sand and drain method, some post-construction differential settlements are expected, leading to additional and more invasive maintenance requirements.

- more efficient and timely maintenance by understanding sooner where measures are required
- and maintenance techniques that are less disruptive to infrastructure use

Tools that are expected to be required to achieve this goal are amongst others geotechnical risk management and monitoring.

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[16] Basú, D., Misra, A., Puppala, A.J. & Chittoori, C.S. (2013). Sustainability in Geotechnical Engineering. Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering, Paris 2013

[17] https://people.hofstra.edu/geotrans/eng/ch7en/conc7en/ch7c1en.html

During the design & construction phase, observational based design (that greatly relies on both geotechnical risk management and monitoring) may lead to alternative construction techniques and/ or designs that are less conservative and more geared towards local conditions. During exploitation of the structure, monitoring may lead to a better understanding of the behaviour of the subsurface and the interaction between the subsurface and the structure.

4.4 Affordability

Europe today is faced with the need to adapt its infrastructure to climate change, growing mobility needs, higher traffic loads and to reduce impact on the environment. Affordability of this infrastructure is linked to a reduction of its life cycle costs. This includes extending the life span of existing infrastructure and to make the infrastructure more resilient. New infrastructure needs to be more robust to maintain its long term functionality for these changing conditions.

The previous examples have shown that the ground plays an important role in the infrastructures resistance to failures and that the failure costs are about 1/3 geotechnical related. This implies a need for identification of spots along the infrastructure network that are geotechnical vulnerable to external risks as climate change and other hazards.

It highlights the need for example for geotechnical monitoring, early warning systems and prediction tools, as well as methods to assess the condition of existing geotechnical structures as embankments and slopes.

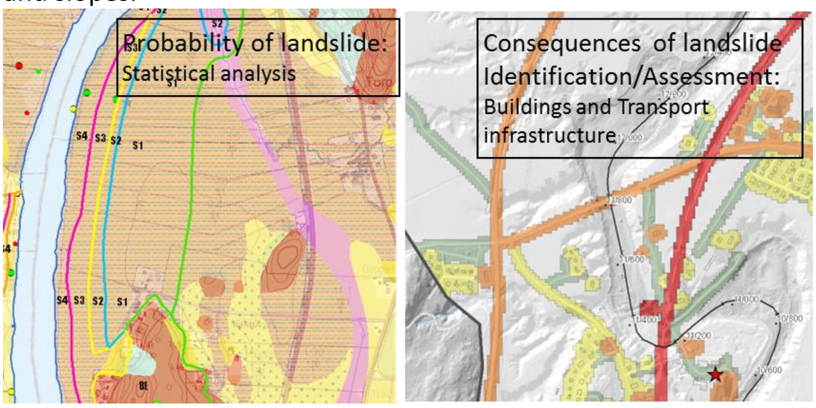

Figure 4.5: Maps of probability respectively consequences of landslides (from SGI)

Other examples include new or improved methods for optimizing earth structures like reuse of excavated subsurface materials, reinforcement of embankments, mitigation of unstable slopes and adaptation of infrastructure to increased precipitation and sea level rise.


Figure 4.6: Reinforcement of unstable slope/embankment, Sollefteå, Sweden. (Photo: SGI)

4.5 Overview of possible impact

The examples of failure in section 3.1 and the examples in section 3.4 on how to correctly deal with the variability and large uncertainties in subsurface conditions prove that this significantly influences the availability, affordability and sustainability of Europe's transport infrastructure network. As mentioned, about 25% to over 33% of the total failure costs in construction is assumed to be related to the subsurface conditions and/or subsurface materials[18].

It has been shown that the application of risk management in geotechnical engineering in general, and monitoring or continuos control of subsurface conditions in particular, has great potential in leading to significant advantages for our society. Currently, the lack of effective and widely acceptated risk management tools prevent us from using this potential.

The table below shows the objectives that will be set for the future of highly optimized, risk management-driven geotechnical (re)design and operation for European infrastructure network.

[18] GeoIpuls, interview Wim Anemaat (Fugro) and Paul Cools (RWS) in Fugro Opinie (juli 2013), on the basis of analyses of SBR/TNO/NVAF

	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%
Affordability	Fatalities and severe injuries due to man-made and natural disasters	-25%
	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%

Figure 4-4 ELGIP objectives for future risk management-driven transport infrastructure (re)design and operation

Meeting these objectives will require international engagement and collaboration of transport infrastructure stakeholders in both the public and private sector, and stimulation of research across the member states with expertise in geotechnical engineering, risk management, road design and operation, sensor technology, data visualization, environmental engineering and economics.

5 How to achieve the possible impact?

In the previous chapters show that geotechnical engineering has great potential in leading to significant advantages for our society in terms of availability, affordability and sustainability of the European transport infrastructure network. That requires international engagement and collaboration of stakeholders to develop effective and widely accepted risk management tools in a multi-disciplinary context.

It is desireable to structure the multi-disciplinary collaboration in research required, for creating the most impact in the shortest amount of time possible. From an geotechnical engineering point of ELGIP has used to the following structure in it's Transport infrastructure Strategic Research Agenda in which required adavancements in geotechnical engineering are llinked to the societal context.

		SUSTAINABILITY decrease of raw material's use increase of secondary material's use decrease of land use [%]	AVAILABILITY decrease of failure frequency decrease of delay duration decrease of fatalities and injuries [%]	AFFORDABILITY decrease of fatalities and injuries decrease of travel time of persons / goods decrease Total Cost of Ownership [%]
ECO-MANAGEMENT	"Infrastructure built on enhanced materials"	§3.4.5		
	"Low impact infrastructure"	§3.4.2		
ASSET MANAGEMENT	"Infinitly available infrastructure"			
	"Affordable infrastructure maintenance"		§3.4.3	
RISK MANAGEMENT	"Observation-based infrastructure design"	§3.4.6		§3.4.4
	"Steadfast infrastructure in changing conditions"		§3.4.1	

Figure 5.1 Structure of ELGIP transport infrastructure Strategic Research Agenda

The examples mentioned in section 3.4 of this document have been placed within this matrix, based on the focus of the solution required by the client. ELGIP's Transport Infrastructure Strategic Research Agenda consists of many more concrete short-, medium- and long-term research topics for the field of geotechnical engineering. The structure enables partners from other fields of expertise to connect there contributions to the societal context.

6 In conclusion

Infrastructures are of vital importance to Europe's goals for economic growth and prosperity. The specific current challenge for infrastructures in Europe is twofold:

1. new structures should be built in a more resilient, more durable, more affordable manner
2. exisisting structures need to be maintained, retrofitted and repurposed.

Geotechnical engineering plays an very important role for this challenge.

Failure costs related to geotechnical engineering add up to a very significant amount compared to the total (building) investment costs. Based on conservative estimations, subsurface/ geotechnically related failures costs may exceed 4Bn€ annually i.e the **affordability** of infrastructure is strongly influenced by the subsurface. Similar arguments may be made for sustainability and availability of infrastructure.

On the other hand significant advantages compared to regular current practive may be reached if sufficient attention is given to innovative approaches within geotechnical engineering. Main focal areas are: 1) long term monitoring programmes during design, build and maintain phases. These allow for 2) better application of geotechnical risk management, specifically Observational based design methods. Such an approach is thought to allow also for 3) more application of new and enhanced materials that are currently not widely used.

How significant these advantages may be are provided in 4.5. Generally speaking improvements in various areas of 20 – 30% or more may be achieved. With reference to the mentioned geotechnical component of failure costs, small (percentage) gains lead to significant (absolute) savings.

7 APPENDICES

A. Appendix The world around us – EU transport ambitions

European view on transport (infrastructure)

As already mentioned in the 2001 Policy White Paper[19] by the EU, transport is a key factor in modern economies. And as the Greening transport package[20] mentions, mobility is essential for our quality of life and is vital for the EU's competitiveness. It is the backbone of the economy making the links between the different stages of production chains and allowing service industries to reach their clients, as well as being a significant employer in its own right. As such it is key to achieving the goals of the EU's growth and employment strategies.

The European transport industry directly employs more than 10 million people, accounting for 4.5% of total employment, and represents 4.6% of GDP [Eurostat].

The 2001 Policy White Paper observes that there is a permanent contradiction between society, which demands ever more mobility, and public opinion, which is (still) becoming increasingly intolerant of chronic delays and the poor quality of some transport services. Congestion is a major concern and comprises accessibility. In addition, transport infrastructure is unequally developed in the eastern and western parts of the EU. There is an increased pressure on public resources for infrastructure funcing and a new approach to funding and pricing is needed.

The EU has over 4.5 million km of paved roads and 212.500 km of railway lines, and has invested about €859 billion in its transport infrastructure in 2000-2006. The current impact of transport is significant: Congestion costs Europe about 1% of GDP every year [EU, 2011]. And transport is responsible for about a quarter of the EU's GHG emissions; 71.3% of the overall emissions are generated by road transport [EEA, 2008].

Therefore the 2011 White Paper concludes that the transport system needs to be optimised to meet the (economic and social) demands of enlargement and sustainable development, as set out in the conclusions of the Gothenburg European Council. As a modern transport system must be sustainable from an economic, social and environmental viewpoint.

Infrastructure shapes mobility. The EU recognizes that no major changes in transport will be possible without the support of an adequate infrastructure network and more intelligence

[19] COM(2001) 370 final, WHITE PAPER European transport policy for 2010: time to decide, Brussels, 12.9.2001;
[20] COM(2008) 433 final, Greening Transport, Brussels, 8.7.2008;

in using it. Transport infrastructure investments have to be planned in a way that maximizes positive impact on economic growth and minimizes negative impact on the environment. Transport (infrastructure) has to be sustainable in the light of the challenges we face.

> *It can take up to 20 years to build a motorway, from planning to construction. The average cost per km varies depending on the location and complexity of the route. It can be as low as €7.1 million and as high as €26.8 million*
>
> *[http://ec.europa.eu/transport/strategies/facts-and-figures]*

A short overview of relevant documents in a European context.

EU policy on transport infrastructure 2000-2010

Already in June 2001, the sustainable development strategy was adopted by the European Council in Gothenburg. In alignment, the 2001 Policy White Paper was published. With regard to infrastructure, it addresses the bottlenecks in the required (intermodal) trans-European network and the fact that the cost for using transport generally fail to reflect all the costs of infrastructure, congestion, environmental damage and accidents.

In 2006[21] the EC argued for a more comprehensive, holistic approach to transport policy, as a result of monitoring the White Paper actions. Annex I of this mid-term review summarized a list of main actions to be taken. With regard to infrastructure, this list addressed the need to ensure a balanced approach to land-use planning. Moreover, it already emphasized that the availability and affordability of infrastructure was at stake. Smart charging schemes for the use of infrastructure were foreseen as a solution to this challenge. The Greening transport package, published by the EC in 2008, elaborated on this externalization of transport costs, while moving the transport further towards sustainability at the same time.

In 2009 the EC defined a new vision[22] for the future of transport, to end the 10-year period covered by the 2001 White Paper. It gives an overview of (global) trends and challenges (e.g. climate change adaptation, urbanisation). With regard to sustainable transport policies, the (funding of) maintenance, development and integration of modal infrastructure networks is explicitely covered.

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[21] COM(2006) 314 final, Keep Europe moving - Mid-term review of the European Commission's 2001 Transport White Paper, Brussels, 22.06.2006;
[22] COM(2009) 279 final, A sustainable future for transport - Towards an integrated, technology-led and user-friendly system, Brussels, 17.6.2009;

European growth and jobs strategy 2010-2020

Europe 2020[23] is the European Union's ten-year growth and jobs strategy that was launched in 2010. It is about more than just overcoming the crisis from which our economies are now gradually recovering. It is also about addressing the shortcomings of our growth model and creating the conditions for a smart, sustainable and inclusive growth (see figure 1).

Five headline targets have been set for the EU to achieve by the end of 2020. These cover employment; research and development; climate/energy; education; social inclusion and poverty reduction. Every European member state has translated these EU targets to national targets[24]. The Europe 2020 strategy objectives are supported by seven 'flagship initiatives' providing a framework through which the EU and national authorities mutually reinforce their efforts in areas supporting the Europe 2020 priorities.

ANNEX 1 - EUROPE 2020: AN OVERVIEW

<table>
<tr><th colspan="3">HEADLINE TARGETS</th></tr>
<tr><td colspan="3">– Raise the employment rate of the population aged 20-64 from the current 69% to at least 75%.
– Achieve the target of investing 3% of GDP in R&D in particular by improving the conditions for R&D investment by the private sector, and develop a new indicator to track innovation.
– Reduce greenhouse gas emissions by at least 20% compared to 1990 levels or by 30% if the conditions are right, increase the share of renewable energy in our final energy consumption to 20%, and achieve a 20% increase in energy efficiency.
– Reduce the share of early school leavers to 10% from the current 15% and increase the share of the population aged 30-34 having completed tertiary education from 31% to at least 40%.
– Reduce the number of Europeans living below national poverty lines by 25%, lifting 20 million people out of poverty.</td></tr>
<tr><th>SMART GROWTH</th><th>SUSTAINABLE GROWTH</th><th>INCLUSIVE GROWTH</th></tr>
<tr><td>INNOVATION
EU flagship initiative "Innovation Union" to improve framework conditions and access to finance for research and innovation so as to strengthen the innovation chain and boost levels of investment throughout the Union.
EDUCATION
EU flagship initiative "Youth on the move" to enhance the performance of education systems and to reinforce the international attractiveness of Europe's higher education.
DIGITAL SOCIETY
EU flagship initiative "A digital agenda for Europe" to speed up the roll-out of high-speed internet and reap the benefits of a digital single market for households and firms.</td><td>CLIMATE, ENERGY AND MOBILITY
EU flagship initiative "Resource efficient Europe" to help decouple economic growth from the use of resources, by decarbonising our economy, increasing the use of renewable sources, modernising our transport sector and promoting energy efficiency.
COMPETITIVENESS
EU flagship initiative "An industrial policy for the globalisation era" to improve the business environment, especially for SMEs, and to support the development of a strong and sustainable industrial base able to compete globally.</td><td>EMPLOYMENT AND SKILLS
EU flagship initiative "An agenda for new skills and jobs" to modernise labour markets by facilitating labour mobility and the development of skills throughout the lifecycle with a view to increase labour participation and better match labour supply and demand.
FIGHTING POVERTY
EU flagship initiative "European platform against poverty" to ensure social and territorial cohesion such that the benefits of growth and jobs are widely shared and people experiencing poverty and social exclusion are enabled to live in dignity and take an active part in society.</td></tr>
</table>

Figure 1: Summary of Horizon 2020 strategy for smart, sustainable and sustainable growth

ELGIPs ambitions on significantly contributing to an improved and sustainable mobility of Europe's society relate to many challenges that the EU aims to meet through its 2020 strategy, the headline targets and the national translation.

[23] COM(2010) 2020 final, EUROPE 2020 - A strategy for smart, sustainable and inclusive growth, Brussels, Brussels, 3.3.2010;

[24] see http://ec.europa.eu/europe2020/pdf/annexii_en.pdf

Europe 2020; Innovation Union flagship initiative

The “Innovation Union” flagship initiative[25] is a crucial investment for the future of Europe. For example, for achieving the Europe 2020 headline target of **investing 3% of EU GDP in Research & Innovation** by 2020, through which 3.7 million jobs and an increase of the annual GDP by €795 billion could be created by 2025.

Horizon 2020 is the financial instrument implementing the Innovation Union, with nearly €80 billion of funding available over 7 years – in addition to the private investment that this money will attract. Transport infrastructure-related research funding in Horizon 2020 is most likely to appear in the Societal Challenge of “Smart, Green and Integrated Transport”.

Europe 2020; Resource-efficient Europe

The “Resource-efficient Europe” flagship initiative [26] supports the shift towards a **resource-efficient**, **low-carbon** economy to achieve **sustainable growth**. Natural resources underpin our economy and our quality of life. Continuing our current patterns of resource use is not an option. Increasing resource efficiency is key to securing growth and jobs for Europe. It will bring major economic opportunities, improve productivity, **drive down costs** and boost competitiveness. It provides a long-term framework for actions in many policy areas, supporting policy agendas for e.g. climate change, energy, transport, industry, raw materials, biodiversity and regional development.

In the 2011 White Paper[27], infrastructure-related key components in this framework are (1) **cutting GHG emissions** by 80- 95% and (2) a **sustainable**, secure and competitive transport system that removes all obstacles to the internal market for transport, promotes clean technologies and modernises transport networks.

Europe 2020; Industrial Policy for the Globailization Era

Transport enables economic growth and job creation. In the context of the “Industrial policy for the globalization era” flagship initiative[28] a new partnership between the EU, Member States and industry has been launched. With regard to the focus on investments in innovation, several transport-related priority areas with great potential (key enabling technologies; **bio-based products**; sustainable industrial and construction policy and **raw materials**; clean vehicles and vessels; smart grids) underpin this partnership.

[25] http://ec.europa.eu/research/innovation-union/index_en.cfm

[26] http://ec.europa.eu/resource-efficient-europe/

[27] COM(2011) 144 final, Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, Brussels, Brussels, 28.3.2011

[28] http://ec.europa.eu/enterprise/policies/industrial-competitiveness/industrial-policy/index_en.htm

European policy on transport infrastructure 2010-2020

In the context of the Europe 2020 strategy, the 2011 White Paper the EC adopted a roadmap of 40 concrete initiatives for a competitive and resource efficient transport system. For example, through dramatically reducing GHG emissions in transport by 2050. The foreseen Single European Transport Area requires better connecting the eastern and western parts of the EU. Moreover, the 2011 White Paper emphasizes the need for infrastructure that minimises the impact on the environment, that is resilient to the possible impact of climate change and that improves the safety and security of users is emphasized.

As part of the 2011 White Paper, ten goals for a competitive and resource efficient transport system were formulates, aiming at achieving the 60% GHG emission reduction target. With regard to the physical infrastructure network, the following is included:

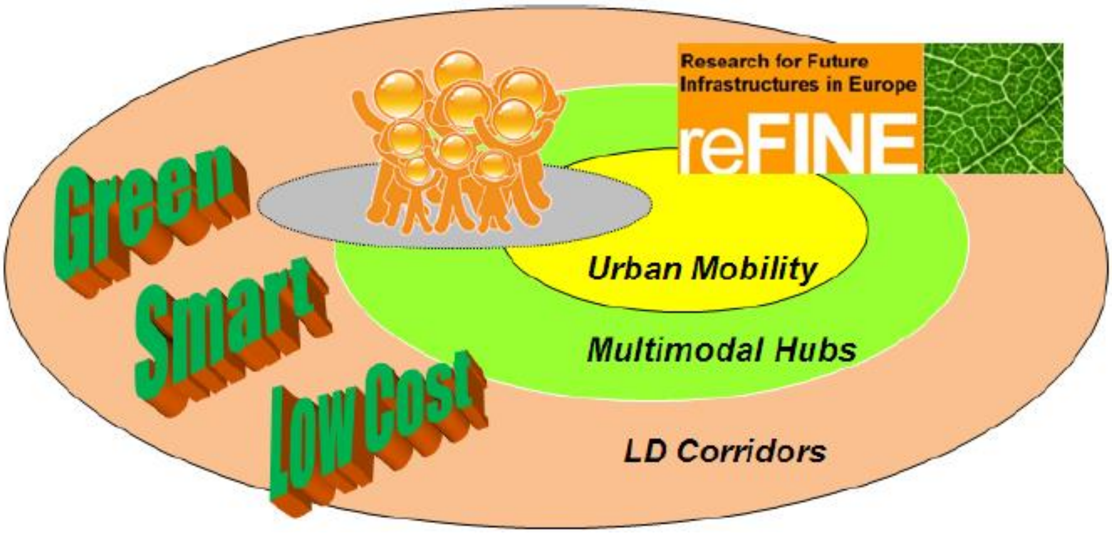
- 30% of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50% by 2050, facilitated by efficient and green freight corridors. To meet this goal will also require appropriate infrastructure to be developed.
- By 2050, complete a European high-speed rail network. Triple the length of the existing high-speed rail network by 2030 and maintain a dense railway network in all Member States. By 2050 the majority of medium-distance passenger transport should go by rail.
- A fully functional and EU-wide multimodal TEN-T core network by 2030, with a high quality and capacity network by 2050 and a corresponding set of information services.
- By 2050, connect all core network airports to the rail network, preferably high-speed; ensure that all core seaports are sufficiently connected to the rail freight and, where possible, inland waterway system.

Other European strategic documents on transport RDI

Research for Future Infrastructure Networks in Europe (reFINE)

The Construction Sector ETP (ECTP) aims through the reFINE[29] initiative at developing a RDI programme dedicated to infrastructure topics. Since 2012 this European-wide infrastructure initiative is the networking forum within the ECTP for all stakeholders that see the need to comprehensively tackle the infrastructure's challenges. It has produced several strategic documents aiming to influence Horizon 2020: a Vision document[30], a Strategic Targets and Expected Impacts document[31] and a Roadmap document[32].

[29] Research for Future Infrastructure Networks in Europe, http://www.ectp.org/TFI.asp;
[30] Building Up Infrastructure Networks of a Sustainable Europe, ECTP-reFINE, January 12, 2012 (draft);
[31] Building Up Infrastructure Networks of a Sustainable Europe - Strategic Targets and Expected Impacts, ECTP-reFINE, Octobre 2012;
[32] Building Up Infrastructure Networks of a Sustainable Europe - The reFINE Roadmap, ECTP-reFINE, May 2013;



The vision relies on the concept of High Service Level Infrastructures with minimum environmental impact (green), that ensure resilient services (smart) and can be affordably maintained and upgraded (low cost). Main expected impact is to achieve by 2030 the following “3x30” impact – thanks to appropriate RDI on infrastructure:

- GREEN: -30% of CO2 emissions, mainly thanks to an improved organisation of transport relying on this new generation of intermodal networks and multimodal hubs;
- SMART: +30% performance in terms ofinfrastructure capacity and infrastructure safety with respect to reduction of accidents;
- LOW-COST: -30% of costs in the development of new infrastructure and networks and refurbishment of old ones as well as in the operating, maintenance and administrative costs of all infrastructure (preventive maintenance becoming the standard).

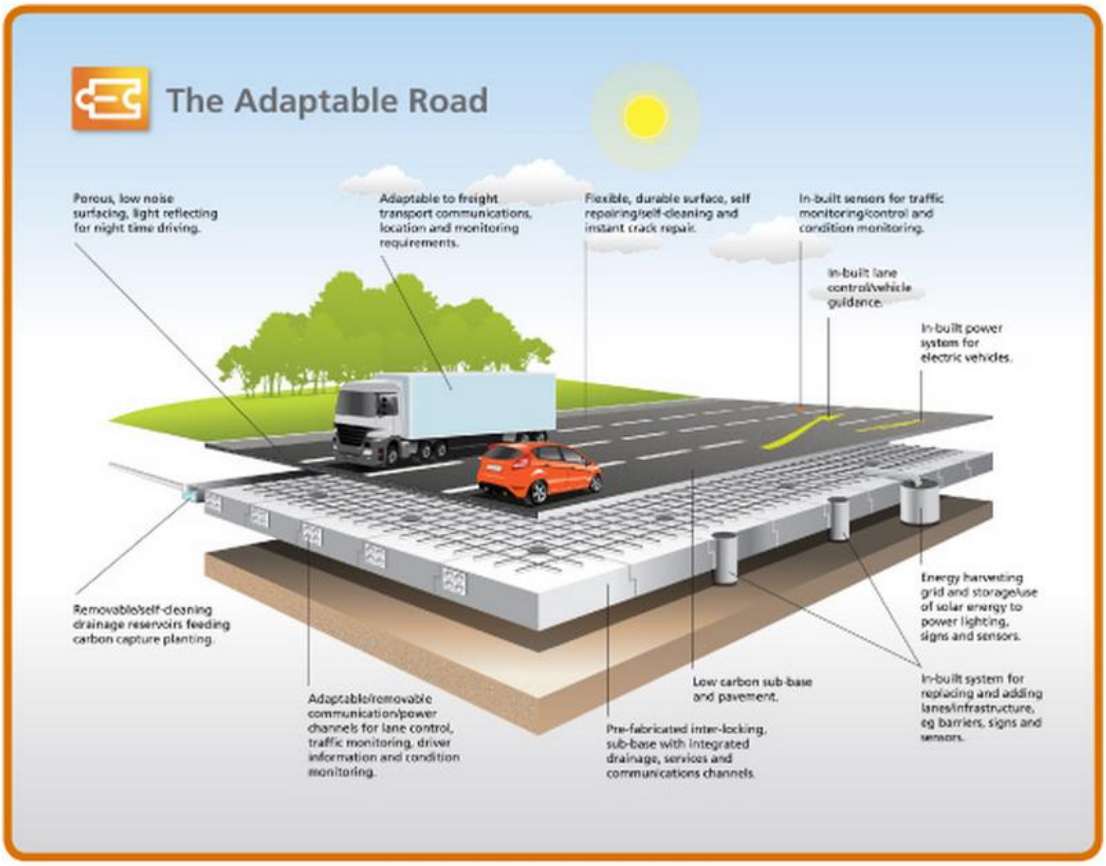
Joint ETP Task Force on Infrastructure

Bearing in mind that many journeys by transport users involve multiple modes, there is an added value in broadening a mode-specific orientation into a cross-modal perspective. In June 2012 the ETPs for road (ERTRAC), rail (ERRAC), water (Waterborne) and air transport (ACARE) as well as for construction (ECTP) agreed to create a joint roadmap on cross-modal transport infrastructure innovation[33]. Also with the aim to influence Horizon 2020. The guiding goal of this cross-modal roadmap is that by 2030 RDI should enable an improvement of 50% in infrastructure performance, risk and cost (versus a 2010 baseline) as well as enable seamless door-to-door services for passengers and freight.

[33] Roadmap for cross-modal transport infrastructure innovation - Towards a performing infrastructure, Joint ETP Task Force on Transport Infrastructure Innovation, Brussels, summer 2013;

FEHRL's Forever Open Roads concept

The Forum of European Highway Research Laboratories (FEHRL) set itself the challenge of developing a truly inspiring vision for how roads will be built, operated and maintained in the 21st century. The result: the Forever Open Road. A revolutionary concept that is developing a new generation of advanced and affordable roads that can be adopted both for maintaining the existing network and building new roads. The overall aim is to facilitate future mobility needs of our 21st century society.



The next generation of roads will require high levels of adaptation, automation and resilience. These three elements will define the next generation of road as follows:

- The Adaptable Road: focusing on ways to allow road operators to respond in a flexible manner to changes in road users demands and constraints
- The Automated Road: focusing on the full integration of intelligent communication technology (ICT) applications between the user, the vehicle, traffic management services and the road operation
- The Resilient Road: focusing on ensuring service levels are maintained under extreme weather conditions.

The table below shows the objectives that are set for the next generation of roads to meet, once the Forever Open Road concept is fully implemented on the European road network.

Societal Challenge	Indicator	Guiding Objective
Decarbonisation	Energy-efficiency of passenger and freight transport (pkm/kWh resp. tkm/kWh)	+10-20%*
	Energy consumed by road operations	Net zero
	Energy enclosed in materials	-25%*
Reliability	Failure frequency and duration	-35%*
	Time lost to maintenance, repair, reconstruction, and incidents	-50%*
Safety & Security	Fatalities and severe injuries	-35%*
	Cargo lost to theft and damage	-40%*
Liveability	Air quality, Noise, Natural Habitat	Policy compliance
Cost	Total Cost of Ownership	-30% *

*= vs. 2010 best practices baseline

Horizon 2020 "Smart, green and integrated transport"

The specific objective of Horizon 20202 Societal Challenge 'Smart, green and integrated transport' is to achieve a European transport system that is resource-efficient, climate- and environmentally-friendly, safe and seamless for the benefit of all citizens, the economy and society. This Specific Programme is structured in 4 broad lines of activities aiming at:

a) Resource efficient transport that respects the environment.
b) Better mobility, less congestion, more safety and security.
c) Global leadership for the European transport industry.
d) Socio-economic and behavioural research and forward looking activities for policy making.

In the first two Work Programmes of this Societal Challenge (for the periods of 2014-2015 and 2016-2017), these activities were addressed by three Calls for proposals, of which the Mobility for Growth calls are most relevant. Within the transport integration area of these calls, the topic of infrastructure has been explicitely addressed.

In both Work Programmes, this part of the 'Smart, green and integrated transport' challenge addresses besides the missing links in the European transport network, in particular at cross-border sections, a considerable disparity in the quality and availability of infrastructure persists within Europe. Furthermore, it mentiones a growing need to make infrastructure more resilient/ Although many elements of the existing surface transport infrastructure are in a deteriorating condition, and public resources available to maintain and upgrade transport infrastructure have been declining.

To summarize

Based on the above mentioned sources it is concluded that infrastructure plays a major role in the EU ambitions. Specifically, the challenges for infrastructure can be summarized as:

- sustainable infrastructure
- affordable infrastructure
- available infrastructure