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2 INTRODUCTION

Energy and transport sector have been officially categorized as important divisions of the critical infrastructure at European level with the need to improve their protection. Considering all the ongoing large- and megaprojects in the energy and transport sector in Europa, then this is an excellent progression. This has led to new approaches and developments, like for example the requirement to asses all the significant natural and man-made hazards that could occur.

From the year 2009 onwards, there has been fast and extensive development concerning the technological advancements for improving hazards evaluation and risk reduction. One of those excellent advancements is the European Union's Earth observation programme, with objective to achieve a global, continuous, high quality Earth observation capacity for providing information to improve the management of the environment, understand and mitigate the effects of climate change, and ensure civil security etc. Nevertheless, the scope of this work does not include services provided by the European Earth observation programme (Troon, 2018) for a wide range of applications in a variety of areas, even if it would be very interesting to compare todays technological situation against the situation in the years 2009/2010, when there was a need for fast, accurate, high quality remote sensing.

The work is covering a broad spectre of different natural and man-made disasters, attentionally without going into too much detail, because by every single described event, it is possible to carry out much more detailed research as it has been done until today.

3 MATERIALS AND METHODS

Information about events was extracted from media monitoring, NVE atlas-geographic metadata, earlier “landslide database” developed by NGU, eklima and from personal notes (Troon, M., 2010a). Experience shows that there is generally slightly underreporting of such events, and it can therefore be assumed that the number of landslides is somewhat larger. This is also important in order to better prepare assessments, because various landslide types are triggered under different conditions.

The study focuses on natural disasters, the physical-impacts in this case of nature and technology, involving different material and temporal damage. It is usually recommended not to manipulate neither the independent nor the dependent variables, so case study method was chosen for this study (Stake, 1995).

The scope of the Directive was limited to the energy and transport sectors. It constituted the first step in a step-by-step approach to identify and designate ECIs and assess the need to improve their protection. The Directive outlined the approach all Member States would be required to follow to identify, designate, and protect European Critical Infrastructures in the energy and transport sectors, while indicating the ICT sector as a priority for possible future expansion of its scope. ("SWD(2012) 190 final," 2012).

The EC Directive 114/08/EC ("DIRECTIVE 2008/114/EC," 2008) outlines the idea of critical infrastructure (CI) as follows "critical infrastructure’ means an asset, system or part […] which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in […] as a result of the failure to maintain those functions” ("DIRECTIVE 2008/114/EC," 2008).

Baltic Sea Regions economy is increasingly dependent on the functioning of international networks and logistics systems. The worst-case threat scenario is a situation where critical imported goods or services are temporarily unavailable. ("Threats to CI," n.d.).

There is no form of hazard which means more economically than natural hazards. A natural hazard can cause serious, or in some cases severe, damage to life, property and CI, and usually causes economic losses, which severity depends on the resilience or recovery capacity of the affected population as well as on the availability of existing infrastructure.

As far as security of supply and CI is concerned, it is more important to pay attention to the consequences of disturbances rather than to their root causes. At the same time, the root causes of disruptions are more important to CI owners and operators and infrastructure companies.

The CI can be destroyed or disrupted by natural disasters or technical failures and by some other threats outlined in the EC Directive 114/08/EC ("DIRECTIVE 2008/114/EC," 2008). Present work is concerned only with natural disasters and with technical failures to some extent.
Furthermore, the EC Directive 114/08/EC (“DIRECTIVE 2008/114/EC,” 2008) states the concept of European critical infrastructure as an “European critical infrastructure’ or ‘ECI’ means critical infrastructure [...] the disruption or destruction of which would have a significant impact on at least two [...] States. The significance of the impact shall be assessed in terms of cross-cutting criteria. This includes effects resulting from cross-sector dependencies on other types of infrastructure” (“DIRECTIVE 2008/114/EC,” 2008).

Concerns about the security of these systems resulted into a series of programmes for their protection, such as the EPCIP. The high-level objectives of such programmes are to increase the protection and lately the resilience of critical infrastructures against all hazards. The Commission sets out an overall policy approach and framework for critical infrastructure protection (CIP) activities (“COM/2006/0786,” 2006). In the endeavour of this high-level objective, several specific objectives must be achieved such as identifying systems’ vulnerabilities, interdependencies and evaluating impact. (Giannopoulos et al., 2013).

The EEA countries (Norway, Iceland, and Liechtenstein) are invited to all EPCIP-related meetings. To formalise this cooperation with the EEA, the Commission has recently presented a proposal for a Council Decision, which aims to expand the applicability of Directive 2008/114/EC to the EEA countries (“COM(2012) 97 final,” 2012).

Norway participates regularly in the Directive workshops and EPCIP points of contact meetings. Under the cooperation schemes of the Nordic countries, Sweden and Denmark have further specific contacts with Norway. With regard to sectoral CIP activities driven by the Commission, Norway is fully involved in the work on the protection of critical information (CIIP) as well as energy infrastructure (via membership in the pan-European energy operator associations) (“SWD(2012) 190 final,” 2012).

There are opinions that four of the five Nordic countries have a better starting point for the task of making their critical infrastructure resilient than most of the EU. Even before the resilience discourse emerged in the context of critical infrastructure, it was clear that the CIP terminology and definitions used by the Nordic countries adhered to their own longer-term traditions, and the solutions they had adopted to meet new circumstances. In other words, the Nordic CI concept was based on the traditional total defence or civil defence systems that were built up during the Cold War (Pursiainen, 2018).

Norway also chose to speak about critical or vital societal functions rather than just critical infrastructure. In the Norwegian approach – called “Protection of Critical Infrastructures and Critical Societal Functions in Norway” (NOU 2006: 6, 2006). Critical societal functions formed a more general level, being dependent on but also encompassing infrastructures (Pursiainen, 2018). The discussion about resilience is going on and the Council Directive on EPCIP (“DIRECTIVE 2008/114/EC,” 2008) defines protection as “all activities aimed at ensuring the functionality, continuity and integrity of critical infrastructures in order to deter, mitigate and neutralise a threat, risk or vulnerability”. A general
meaning appropriate to CI, is provided by the United Nation's International Strategy for Disaster
Reduction (UNISDR) (“Terminology - UNISDR,” n.d.) as follows “The ability of a system, community
or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard
in a timely and efficient manner, including through the preservation and restoration of its essential basic
structures and functions”.

One of the most enlightening in the present framework is the Commission document “Overview of
Natural and Manmade Disaster Risks in the EU” (“SWD/2014/0134,” 2014). The document is a
The Commissions (“SEC(2010) 1626 final,” 2010) procedures, are highlighting that member states
should consider all significant natural and man-made hazards that could occur “on average once or more
every 100 years (i.e. annual probability of 1% or more) and for which the consequences represent
significant potential impacts, i.e. number of affected people greater than 50, economic and
environmental costs above €100 million, and political/social impact considered significant or very
serious”. The document identifies the twelve most addressed hazards as follows: (Natural hazards:)
Floods, Severe weather, Wild/Forest fires, Earthquakes, Pandemics/epidemics, Livestock epidemics;
(Man-made hazards:) Industrial accidents, Nuclear/radiological accidents; Transport accidents; Loss of
critical infrastructure; Cyber attacks; and Terrorist attacks. The emerging risks in the document include
climate change-related hazards, space related hazards, and anti-microbial resistance (“SEC(2010) 1626

Norway's 2014 ‘National Risk Analysis’ (NRA, 2014) divides hazards into natural events, major
accidents and malicious events and each group is additionally divided into risk areas with related
scenarios.

While both civil protection and CI remain under the national authority, it is important to point out that
the macro-regional dimension of cooperation between the Nordic countries, and more widely within the
Baltic Sea Region, is producing tangible results. The Nordic Council of Ministers (NCM) and the
Council of the Baltic Sea States (CBSS) are crucial facilitators of this cooperation. Nevertheless, it
would be difficult to imagine this activity without strong EU support, especially where funding and the
supporting framework of the European Union Strategy for the Baltic Sea Region (EUSBSR) are
concerned (Pursiainen, 2018). Nevertheless, the problem how to organize CI resilience efforts remains,
because most of the CI is owned and operated by private actors and handling through regulations or
public-private partnership is sometimes not very effective.
5 WHERE DOES NATURAL DISASTER FIT IN?

The threat of worldwide climate change is a scenario that has received increased attention in the past years. The potential effects are worrying – melting of the polar ice caps to raise sea level and flooding of low-lying coastal areas; intensification of damaging storms; and alteration of regional weather patterns with disastrous implications.

Natural catastrophes, such as earthquakes, hurricanes, volcanic eruptions, landslides, rock falls, unstable rock slopes, debris avalanches, snow avalanches and submarine landslides etc. (*Terminologi for naturfare*, 2016) have always created a major problem in many developing and developed countries.


The winter of 2009–2010 in Europe and particularly in Scandinavia was remarkably cold (Rommetveit, 2010). Worldwide, rare weather patterns carried cold, humid air from the north. The cold wave occurred due to a cold weather phenomenon where a strong high pressure remained over Northern Europe, and brought in continuous cold air from the Arctic Ocean. The cold weather started on December 16, 2009 with light snowfall (Stranden and Grønsten, 2011) and persisted throughout January and out in February 2010. The weather phenomenon was due to high pressure over Greenland and Iceland, a phenomenon described by meteorologists as the Arctic Oscillation, which was negative compared to normal. The North Atlantic Oscillation in Winter 2009/10 was lower than during any winter in over a century and this resulted in more easterly winds bringing cold air into Northern Europe from the Arctic (Rommetveit, 2010) (Fereday et al., 2012). This led to widespread transport disruption and power failures etc.

5.2 EXTREME WEATHER ASK.

Extreme Weather Ask (“ekstremvær navn,” n.d.) swept 6. January 2010 over northern Norway. According to the Norwegian Meteorological Institute's (MET Norway) extreme weather warning (“Ask,” n.d.): Ask provided strong south-westerly winds throughout Northern Norway. In Nordland, Troms and Western Finnmark, full storm and strong storm have been reported in exposed places for shorter periods. This type of extreme weather warning is given out in Norway usually once or twice
every year. However, the name “Ask” of this extreme weather warning proved to be prophetic, because the English translation of “Ask” is “Ash”.

5.3 **Volcanic Eruptions from the Eyjafjallajökull.**

In April 2010, the volcanic eruptions from the Eyjafjallajökull glacier in Iceland literally “froze” all air traffic in the EU; more than 84,000 (“P7_CRE-REV(2010)04-20,” 2010) flights were cancelled. National solutions were not effective in dealing with these kind of problems, which affected airspace globally. As result three types of zones were included in the decision making at European level, based on the degree of contamination (“P7_CRE-REV(2010)04-20,” 2010, p. 4). The paralysis of European air transport caused by the cloud of volcanic ash gave rise to protests from hundreds of airlines. That figure was augmented by the impact on the tourist industry. In view of the chaos caused by this situation have been raised questions like: will the EU commission study and tackle the effects of this unusual phenomenon on the transport and tourist industries (“P7_QE(2010)2980,” 2010)? etc. The political fallout from the Eyjafjallajokull volcano in Iceland continued as people around Europe pondered whether the closure of so much of the continent’s airspace was the right thing. One of the solutions was seen at that time through more investment in railway infrastructure (“Eyjafjallajokull,” 2010).

The dispersion of volcanic ash led to closure of the Norwegian air space 15th of April 2010. There were two critical periods in the volcanic ash crisis, the 14th –28th of April and 3rd –23rd of May 2010. The restrictions in aviation created challenges in the health sector. The volcanic ash crisis had extensive economic consequences and implications (Maal et al., 2013). All this caused external pressure on the already from natural disasters suffering railway transport in Norway, as passenger had to choose other means of transportation.

5.4 **The Spring of 2010.**

Fast temperature rises and high temperature in northern Norway in March and mid May 2010, many places well above 20°C for several days, led to intense snow melting and water overflow throughout the region (Roald, 2013). By some weather stations in West Finnmark, Troms and northern parts of Nordland, the flood was the largest observed, and with today’s available data bases must be characterized
as 200-year flood or larger. The flood led to landslides, erosion and flooding in many places (Pettersson, 2010).

Figure 1 Precipitation and temperature along the Norland Line (between Steinkjer and Bodo) March 2010.

On the Figure 1 it is possible to see the data from different meteorological stations along Nordland line railway, between Steinkjer and Bodo. Available data reflects clearly, that there was a sharp temperature drop from 1-3. March, from about -5°C to -22°C and then the mean temperature started to rise very fast in the region from 3-7. March from daily mean temperatures -22°C to daily mean temperatures well above +5°C in some locations. That means the first mean temperature drop was about -17°C during a two days period and the mean temperature rise was about +17°C during a two days period. The days with higher precipitation are between 7-11. March. This kind of fluctuations in the temperature together with precipitation have caused fast snow melting and rapidly increasing water flow.

The reason for this kind of temperature fluctuation was a föhn, which is a type of dry, warm, downslope wind that arises in the downwind side of a mountain range. Föhn can begin when deep low-
pressure systems move into Norway. It is a rain shadow wind that results from the subsequent adiabatic warming of air that has released most of its moisture on windward slopes (Pettersson, 2010).

Appendix Figure 8 displays data from different meteorological stations along Nordland line railway, between Lønsdal and Bodø and on the figure, it is possible to see that it was low temperatures 11-12. May and then the weather started to get warmer. The hottest days were 16-18. May depend on where in the region one was, with daily mean temperatures above 15°C. By May 15, the maximum temperature was above 20°C in some places, and 17-18. May there have been many places in Troms and Finnmark, that had well above 20°C as maximum temperature. The heat led to very fast snow melting and rapidly increasing water overflow.

The snow melting that led to the rapid flooding, also led to many landslides over a large geographical area, from Helgeland to Alta. The landslides occurred often in a negligent terrain about 600-900 MASL.

The problems with floodwaters began already on May 15 in the smallest streams, one day or more before the flood culminated. There were the greatest damages along small and steep watercourses, and in addition there was extensive mass transport in low lying areas. Some places also experienced destruction caused by ice drift (Pettersson, 2010). Several roads and railways were closed, and settlements were isolated.

5.5 **GEOHAZARDS THROUGHOUT 2009/2010.**

In 2003 has a transport study analysed vulnerability in Norway’s national road, rail, air, and sea transport infrastructures. The transport system was found to be less vulnerable than the telecommunication and electrical power supply system, due to greater redundancy. But, even if the transport sector could be accused at the time of being conservative with respect to the use of modern information and communication technology (ICT), it was noted that this is likely to change in the future, and dependency on the information infrastructures will increase [14], [15]. However, it took six years until very serious situation arrived in 2009/2010 and the pressure on the development need was increased significantly.

Particularly intense rainfall and snowfall was a problem during the 2009/2010 season, because the railway ballast was very often washed out and as consequence the railway line was closed until the repair work was completed. In addition, many landslide incidents are associated with periods of intense or prolonged rainfall (Figure 1, Figure 2, Figure 7, Figure 8.) (Troon, 2016).
There was excessive awareness in the Norwegian National Rail Administration (Jernbaneverket) (JBV) that climate change can lead to further challenges on a railway that was already suffering from maintenance needs, but so far there have been few concrete strategies for how to consider the future climate. There has been an assumption, that if the maintenance and renewal rate increases, the railway will be well enough improved.

Furthermore, in the last years the JBV’s technical regulations ("Teknisk regelverk," n.d.) which describes the generic technical requirements for the subsystems within railway infrastructure, have been changed to better take into account mutually past and today's climate and future climate change (Frauenfelder et al., 2013). Nevertheless, this was not the case during the 2009/2010 season.

The railway network faces challenges related to the decades of maintenance setback, extreme weather events and climate change. Both winter 2009 and summer 2010 have been marked by challenging weather events. Excessive precipitation which caused repeated closures of several railway lines because of the damage. Following these events, JBV has expressed the need to take into account, that climate change can lead to more extreme weather in the future (Årsrapport 2010., 2010). Furthermore, climate change is likely to result in more precipitation as rainfall, because of higher temperatures and extreme weather conditions are expected to increase both in frequency intensity (Masson-Delmotte et al., 2018).

Figure 2: Overview of natural hazard incidents 2009/2010.

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2 Bane NOR, and the Norwegian Railway Directorate replaced the former agency the Norwegian National Rail Administration (Jernbaneverket) in 2017.
Geostatistics offers a way of describing the spatial continuity that is an essential feature of many natural phenomena and provides adaptations of classical regression techniques to take advantage of this continuity [37]. Figure 3 reflects main part of the natural hazards incidents by incident type, which occurred during the 2009/2010 winter season on the railway lines and caused disruption or closure of traffic. The most intensive periods regarding natural hazards have been March (over 50 incidents) and May (over 20 incidents). There is a very good correlation between natural hazards incidents as shown on the Figure 3, appendix Figure 7 and between meteorological data as shown on the Figure 1, appendix Figure 8. Most affected railway lines have been Nordland line (almost 50 incidents) and Bergen (over 40 incidents) line. On the other railway lines, the incidents have occurred evenly, except on the Ofoten line and Sorlands line, where was slightly higher incidents rate concerning natural hazards. There is one common landslide type occurring with highest incident rate on all the railway lines and this is rock fall Figure 7. A rockfall will be seen in this work as a fragment of rock (a block) detached by sliding, toppling, or falling, that falls along a vertical or sub-vertical cliff, proceeds down slope by bouncing and flying along ballistic trajectories or by rolling on talus or debris slopes (Varnes, Schuster, et al., 1978). On the season 2009/2010 most of the rock falls are related to the Bergen line. Next highest occurrence rates have ice falls and snow avalanches in relationship with Norland line. Third highest occurrence rate is connected to the debris flow or debris flood and geographically taking place mostly on the Norland line and Sorland line but affecting all the other railway lines as well to some degree. The results of this incidents have been, that in some cases the railway lines have been closed for days and in some cases the railway lines have been cleared and repaired within hours. However, they have complicated additionally a very complicated situation and made already dangerous situation even more dangerous.

\(^3\) (Based on data from NVE). Graphic reflects the general situation with some accuracy.
Figure 4 is reflecting that same situation where was JBV in relationship to road network in Norway in the 2009/2010 season. The figure has been added only to give slight comparison to natural hazards information related to the railway network. Norwegian National Public Roads Authority (NPRA) was facing same challenges as JBV, but in a more extensive area, as road network is much more widespread. At the same time there are some big differences about reporting of such events in the NPRA and JBV. In the NPRA is reporting of incidents related to natural hazards very well regulated and the procedure is well known to the people involved. In contrast JBV has no clear procedure for reporting such events in or around the railway network. Consequently, there can be a slight underreporting of such events.

Figure 4 Road traffic disruptions caused by geohazards in 2009/2010 monthly.

The disruption caused by natural hazards on the roads, mirrors the situation from the JBV in a much larger scale. Rock falls for example are occurring always and everywhere and have the highest occurrence rate. The Figure 4 is bringing even more indistinct out the period in 2010 from March to May where main part of the incidents related to natural hazards has happened.

While infrastructure owners/managers are responsible for the owning, maintaining, operating, developing and quality of the infrastructure, the consequences of the infrastructure problems are primarily laid on the railway operators. In addition, the operators of course have responsibility for deficiencies in their own equipment and crisis management.

The winter weather also contributed to the destruction of railroad tracks and track switches, damaged equipment and to the short-term solutions. In the next step, the operation had to be adapted to the reduced security level of the collapsed system. This means that problems which, in themselves, could be acute and delimited in time, had system effects that propagated during the winter period and contributed to lasting reduction of speed and axle pressure restrictions. Reduced number of freight trains in traffic and

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4 (Based on data from NVE). Graphic reflects the general situation with some accuracy.
cargo capacity that could not be fully exploited resulted in the regularity of freight transport, delivery
time and service quality was damaged until the late summer.

Reasons for railway traffic disruption in
2009/2010

Figure 5 Responsibilities and reasons for railway traffic disruption in 2009/2010 (Troon, 2018) (Øverli, 2011) (Troon, 2016)

Reasons for railway traffic disruptions have covered all the technical sphere and it is possible to divide
those disruptions based on disruption type and responsibilities, as shown on Figure 5. There have been
written great amount of reports, articles and analysis regarding those events in the 2009/2010 season,
but it is hard to find the term Critical Infrastructure Protection (EPCIP), critical infrastructure (CI) or
the Norwegian approach – called “Protection of Critical Infrastructures and Critical Societal Functions”
in those writings. Throughout the prism of practical work, it is possible to see the signs of Nordic CI
concept based on the traditional total defence or civil defence systems in operation during the 2009/2010
season. Figure 5 highlights in a compact way all the circumstances which have created the so called
“train chaos” in 2009/2010. This work is dealing only with external factors and particularly with this
part shown in the Figure 5 as landslide/landslide risk/notification. The incidents count number 84 is
reflecting only those incidents which occurred during the period what’s called “train chaos”.

13
The railway is particularly dependent on the infrastructure being comprehensive. Defilements that occur in one place in the supply chain propagates further.

As described above in addition, many landslide and avalanche incidents are associated with periods of intense or prolonged snowfall and rainfall periods. Railway has systematically a “winter problem”, because all periods of low punctuality occur during winter. Furthermore, there is good correlation between low punctuality and different weather events in terms of temperatures below minus 10 degrees or snow fall of more than 10 centimetres Figure 1. Analyses of delay data indicated that weather conditions accounted for 60 percent of all delays. (Olsson et al., 2010).

The spring time also offered special problems because of the frost heaving, freezing and thaw cycles with subsequent release of landslides and ice queuing or ice blocking the drainage systems. Particularly in relation to frost heaving, the lack of maintenance is a contributing factor to the problems. Older ballast with too much fine material has poor drainage properties and makes the track more vulnerable to frost heaving. This can be prevented with better substructure and ballast. The stabilizing properties of the substructure and the ballast are reduced over time if they are not maintained.

As a measure to tackle weather-related problems, JBV has established a step-by-step contingency plan already before 2009/2010. The levels in the emergency plan are colour coded and contain clear instructions, which measures shall be taken for each level. All track sections have on-call personnel who can be called out to make extras and report back to the line manager, who is responsible for the line or area.

Norwegian and foreign railway operators were unprepared for the extreme weather conditions that arose during the 2009/2010 season. Heavy precipitation [18], long periods of low temperature and fast variation in the temperature led to damage of the railway infrastructure and of the operator's equipment. The operators had to drive fewer and shorter trains, while the staffing at the terminals had to be increased to handle the situation(Frauenfelder et al., 2013). The response was characterized by improvisational measures rather than pre-established routines, and the experience shows that the subsequent disturbances in train traffic spread to other segments of the logistics chain and caused a shift in freight transport from rail to road.

6 WHERE DOES SLOPE TECTONICS FIT IN?

Hillslopes occupy most of the land surface with the exception of terraces and plains formed by river deposits. Because of their extent the study of slopes has always been close to the heart of geomorphology
although most geomorphological work on slopes, carried out before the middle of the twentieth century,
was related to the classical models of slope evolution since the 1950s has much attention been paid to
processes of hillslope denudation, and the study of slope material strength and resistance has been
brought into the subject only in the 1970s (Selby, 1982).

6.1 MAN-MADE DISASTERS AND ANTHROPOGENIC HAZARDS

Man-made disasters are events where an anthropogenic hazard has come to culmination. The difference
between natural and man-made disasters is the element of human action or inaction. They are often
mirrored with natural hazards. Anthropogenic hazards can seriously affect humans, ecosystems and
other life forms.

Risk assessment is indispensable in order to identify threats, assess vulnerabilities and evaluate the
impact on assets, infrastructures or systems taking into account the probability of the occurrence of these
threats. This is a critical element that differentiates a risk assessment from a typical impact assessment
methodology (Giannopoulos et al., 2012).

6.1.1 Slide in Løsberga.

Steinkjer is located at the top of Beitstadfjorden, the northern subdivision of the Trondheimsfjord system
in Trøndelag county (formerly known as Nord-Trøndelag county) in Norway. Located about 60
kilometres inland from the coast, Steinkjer is in point of fact still linked to the Atlantic Ocean through
the strait of Skarnsundet. About sixty kilometres from Steinkjer to the east is Sweden.

Working as geologist, geotechnician or emergency responder in the NPRA (Troon, 2018), requires
fulfilling of few general requirements, related to the assignment region and office location, for carrying
out the required tasks. One of those requirements is historical and present knowledge about the region
related to one's field of responsibility. Therefore, it is very important to obtain knowledge, as fast as
possible, about ongoing projects, historical natural disasters, historical man-made disasters, possible
danger zones and probable natural hazards areas.

North Trøndelag is in many ways an extraordinary region regarding nature, transportation planning,
road construction, geology, natural disasters (Troon, 2012a) (Troon, 2012b) and man-made disasters
(Bruland et al., 2009). There are few unusual and learning-rich examples about man-made disasters and
anthropogenic hazards in the region, as for example “Løsberga (Bruland et al., 2009)” slide in 2008,
“Kattmarka” slide in 2009 and “Rungstadvatnet (“Pressemelding,” n.d.)” slide in 2012. The reasons for all those events have been different. Nevertheless, in one or another way there is one common scientific discipline, connecting all those events and this is geology, more specifically engineering geology.

NPRA regulations and some manuals require to carry out so called maintenance work by road cuttings, if there is a reason to believe, that there is a risk for landslide or rock fall or there have been landslides or rock falls. In the year 2012 there have been carried out different long planned maintenance works by road cuttings around all the North-Trøndelag. One of those road cuttings maintained was “Løsberga”.

“Løsberga” itself is a housing estate and road cutting, about 107 meters high, 2 kilometers south of Steinkjer, along the European route E6 (E6), southeast of Beitstadfjorden. For carrying out such maintenance, it is forward-looking to be informed about all the different aspects of the projects as good as possible. The “Løsberga” project is an exceptional example about engineering geology and maintenance planning. During the maintenance preparation phase in 2011 and execution phase in 2012, have been carried out different site visits and light engineering geological mapping of the “Løsberga”.

“Løsberga” slide in 2008 and maintenance in 2012 is directly related to the slope tectonics and covers many aspects of critical infrastructure protection, transportation planning, road construction and engineering geology.

6.1.2 Geology and ground conditions

In The Geological Survey of Norway’s (NGU’s) reference databases, have been registered 168 different publications and maps that deal with geological issues specifically in Steinkjer municipality (Dahl, 1997). Steinkjer and Løsberga are part of the pre-Cambrian basement of the Caledonian orogenic zone (age roughly 400-600 million years) (Bruland et al., 2009) in northern Trøndelag. The basement complex forms an axial culmination in the Caledonides, represented by a "barrier" of land which has its direct continuation eastwards into the pre-Cambrian of Sweden (Ramberg et al., 2007). On the bedrock data from NGU at a scale 1: 50,000 (“BERGGRUNN N50 - Inneholder data under Norsk lisens for offentlige data (NLOD) tilgjengeliggjort av Norges geologiske undersøkelse (NGU),” 2016), which shows the prevalence of the different rocks on the earth's surface, the area south of Steinkjer, around E6 is stated to consist of metamorphic volcanic and sedimentary rocks, mainly amphibolite, greenschists and metamorphic shale and sandstone variants.

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5 Kattmarka, Namsos, 13th March 2009. Quick clay slide in Connection with road work. Large housing area slid out into the sea shore.
On the bedrock data (Figure 6), rock boundaries and plan structure are stated to have light to medium steep fall (20°-50°) towards NW (i.e. unfavourable in relation to road cuttings along "Løsberga").

6.1.3 Summary of the project history

Different geological and engineering geological reports and notes have been prepared about "Løsberga" and E6, during different phases of planning, construction and maintenance, starting as early as 1969 (Bruland et al., 2009).

Most of them describe the rock along the mountain rock slope in Løsberga as "massive to some amphibolite schists ". "the mountain is permeated by rue, smooth or rusty fractures in several directions". Among other descriptions are the sliding directions described and which, according to the description, gave considerable stability problems for the road construction in Løsberga, also for approx. 50 years ago, "fractures and fissures fall 60° -70° against the road" and "drop with a fall approx. 45° towards the road". The fractures which were likewise surveyed 50 years ago and have given extra problems to the road construction work 50 years ago, have been surveyed in 2004, 2006 and 2012 and they caused major problems relating to the ongoing expansion work for E6.

During the planning and construction phase used engineering geological reports/notes, describe the rock mass in the southern part of Løsberga as "amphibolite, meta-arkose and quartz gneiss". The southernmost part of the slope (i.e. including the area where the sliding of the “Monolith” occurred) is

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6 On the left map sheet: amphibolite, garnet-bearing, garnet-glitter shale and hornblend shale in exchange, in places with layers of sandstone and in some places also fayuixe / quartz kerosene; varying amounts of amphibolite and greenschists. In North part of Løsberga: schists, sandy to clayey, grey to greyish green, partly with amphibolite ribbons, usually garnet.
described as "massive and slightly fractured", and no cracks have been described there with particularly adverse direction. However, for the area a little further north (centre part, profile 4700-4800), it is described that "some marked cracks with approx. 50 ° grades out towards the road” and that „There may be a need for extensive securing with bolts to prevent larger slides of flake-shaped rock mass”. The main issue with the slope stability is not whether the geologic formation in Løsberga consists of amphibolite, greenschists, meta-sandstone (archose), quartzschists or quartzite. The stability of hard rocks as one generally sees in Scandinavia is largely determined by the orientation of marked fractures and joints, and of how the character (length / endurance and friction ratio) of these fractures is. If a high road cutting is undercut and replaced by unfavourably oriented slippery slope, there will be a risk of landslide or rock avalanche and no matter how strong the rock is and what kind of rock it is (Bruland et al., 2009).

6.1.4 Construction phase

A particularly serious incident occurred on May 9, 2007, approx. 30 meters from the southern end of the area, then approx. 1500 m³ slipped along a flat and smooth slipway with slope approx. 60 ° out to the road. The E6 was closed for 8 days and the railway for half a day after this incident. It was noted that the fracture plane observed earlier was far more unstable than previously thought. After the blasting on June 30, 2008, however, a large sliding along a fracture plane occurred with the direction approximately parallel to the road and with 45 ° inclination towards the road. The sliding included a massive of approx. 8000 m³, which later got the name „Monolith", limited by a marked transverse fracture plane in the north and a fracture plane in the south, which sat down approx. 3 meters vertically. Large blocks rushed out on the road, and the E6 and the Nordland Line railway were closed (NRK, 2013). The rock masses were named after the slide on June 30, 2008 based on form and condition. The «Monolith» was the large rock mass that had settled vertically, while the «Sinnataggen» was the rock mass, which hung again north of the Monolith, and which "threatened" to come down. On July 5, occurred another rock avalanche in the southern corner of the Monolith (about 1000m³) slipped out. After the slide on June 30, work was started immediately for the establishment of a new monitoring system entailing a theodolite for registration of movement and prisms have been mounted on supposedly unstable and assumed stable portions on the road cutting. On 3th of November small part (about 100m³) of the rock mass was blown on top of the cutting. About 1 hour later, the monitoring system showed that there were movements in the rock mass. The situation was assessed continuously, and 2.5 hours later, the railway was closed, because the movement in one of the prisms exceeded the alarm value. Only 10 minutes later a new rock avalanche occurred. Parts of the «Sinnataggen» loosened and slid down the slip plane. The largest part of the rock mass wedged against
the «Monolith». This was an event that was expected to occur. During the same event, however, parts of the «Monolith» also loosened (about 1000-1500 m³ in the south). Some of the rock mass rushed out on the road and to some degree also reached the railroad, which after this unfortunate incident was closed for several days (Bruland et al., 2009).

6.1.5 Summary of the construction phase

The reasons for the rock avalanche, that took place in Løsberga on June 30, 2008, and later problems, are marked and radiant, unfavourably oriented faults, which in the southern part subcutaneously cut the road cutting at full height. The fractures are flat with chlorite coatings and therefore have low friction. These fractures were not discovered until blasting at the bottom of the road cutting was carried out. The blasting of the lower part of the road cutting, which is later was called the «Monolith», and the rock avalanche occurred as a direct consequence of this. Marked fractures and faults of this type are not particularly common in greenschists and can be difficult to detect in advance.

For Løsberga, however, it is a fact that fractures / faults with an unfavourable direction for the stability of high road cuttings were mapped and reported during construction work in 1969. Fractures / faults with unfavourable direction have also been registered further north by the blasting work, that has been going on in Løsberga since 2005, but not with similar endurance / length and character / flatness as by the slide surface that led to the rock avalanche on June 30, 2008 (Bruland et al., 2009). Løsberga is in a very narrow area in the meaning of transportation and as a result of those incidents there have not been many alternative routes for bypassing the construction site. As result the traffic on the railway and on the main road E6 was interrupted for days between south and north in the middle of the country.

6.1.6 Maintenance phase

The preparation work for the maintenance work of the Løsberga road cutting started already in 2011 and included in the start, collecting and investigating of available historical material about the E6 Vist-Jevika-Selli road construction project. The reason why it was decided to include the Løsberga road cutting in the list of road cuttings with need for maintenance, was firstly, because of different reports about rock falls, secondly there is a requirement to control this type of road cuttings after a certain time and thirdly the monitoring of the rock mass movement in Løsberga road cutting was still going on and is continuing until today. Site visits started in the year 2012 and consisted of light engineering geological
mapping and general observations. The maintenance work itself was carried out during the summer 2012 and consisted mainly in extra bolting and anchoring and removal of loose material from the road cutting.

7 SUMMARY.

In the light of the EC Directive 114/08/EC (“DIRECTIVE 2008/114/EC,” 2008) and taking into account that Norway is not a member state of the EU, but a EFTA\(^7\) and EEA\(^8\) and participating in different working groups of the EC Directive, it is very interesting to compare the ideas and principles in the directive against reality in the field. As described above the incidents related to the railway in the year 2009/2010 paralysed partly and sometimes fully the railway traffic in Norway in addition 2010 the flight traffic was paralysed fully by Eyjafjallajökull eruption. Together with the incidents in North Trøndelag the picture about the importance of natural and man-made (as well relating to slope tectonics) disasters is becoming clearer. The scope of the Directive is defining transport sector as a critical infrastructure.

During a long span of time, three out of four transport modes have been heavily affected or totally disabled for certain period. For example, CargoNet, the successor of NSB Gods, has announced closure of train lines and terminals as a result of customer dissatisfaction and their economic losses in 2011 (NRK, 2011). Similar announcements can be found relating to the incidents in the years 2008, 2009, 2010. The first time that there is an effort to assess critical infrastructures using a combination of technological and economical models and when critical infrastructures will be considered as complex techno-economical systems, can be found in the “Risk Assessment Methodology for Critical Infrastructure Protection” (Giannopoulos et al., 2013) (Theocharidou et al., 2015). The methodology proposed in the work focuses on the impact and cascading effects of a disruptive event without performing detailed analysis on each infrastructure asset. It incorporates all the measures that must be applied to critical infrastructures in order to reassure that can withstand a shock, bounce back and recover in case of a disruptive event. It is pointed out that most of today’s models assume that economic recovery starts immediately after a disruption of an infrastructure occurs. However, it is likely that in the immediate aftermath of a disaster, industries are not able to start recovery activities because of several practical obstacles. For example, a repair workforce may not be able to reach damaged railway line after a man-made or natural disaster, because the roads are damaged as well, or air ambulances cannot take off because of volcanic eruption. Hopefully there will be soon a model or methodology considering immediate post disaster period in which there is no recovery.

\(^7\) European Free Trade Association (EFTA)
\(^8\) European Economic Area (EEA)
On local and regional level there are many regulation and manuals, for example provided by NPRA and JBV, which can be used in planning, construction and assessment processes in relationship to natural disasters, considering all the important factors. As stated above, then the EU directive(“DIRECTIVE 2008/114/EC,” 2008) does not perform detailed analysis on each infrastructure asset and therefore the philosophy’s, regulations and manuals at national level will be still very important and the directive could add value to them.


BERGGRUNN N50 - Inneholder data under Norsk lisens for offentlige data (NLOD) tilgjengeliggjort av Norges geologiske undersøkelse (NGU), 2016.


COMMISSION STAFF WORKING DOCUMENT Overview of natural and man-made disaster risks in the EU Accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions The post 2015 Hyogo Framework for Action: Managing risks to achieve resilience, 2014.


Figure 7 Railway traffic disruptions caused by geohazards in 2009/2010 monthly on the railway line\textsuperscript{9}.

\textsuperscript{9} (Based on data from NVE). Graphic reflects the general situation with some accuracy.
Figure 8 Precipitation and temperature along the Norland Line (between Lønndal and Bode) May 2010\(^{10}\). 

\(^{10}\) (Based on data from MET Norway).