RAIN – Risk Analysis of Infrastructure Networks in Response to Extreme Weather

Project Reference: 608166

FP7-SEC-2013-1 Impact of extreme weather on critical infrastructure

Project Duration: 1 May 2014 – 30 April 2017

RAIN PROJECT

Security Sensitivity Committee Deliverable Evaluation

Deliverable Reference	**D 7.4**
Deliverable Name	**Recommendation Summary**
Contributing Partners	**GDG**
Date of Submission	**January 2017**

The evaluation is:

- **The content is not related to general project management**
- **The content is not related to general project management**
- **The content is related to critical infrastructure vulnerability or sensitivity**
- **The content is not publicly available**
- **The content does not add new information that might be misused**
- **The content can cause no harm to the interests of EU or member states**
- **The content could not cause societal unrest**
- **There is no need to contact the National Security Authority**

Diagram path 1-2-3-4-6-7-8-9. Therefor the evaluation is Public.

Decision of Evaluation	**Public**	~~**Confidential**~~
	~~**Restricted**~~	

Evaluator Name	**P.L. Prak, MSSM**
Evaluator Signature	
Date of Evaluation	**2017-01-31**

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 608166

This project is funded by the European Union

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Date: 25/01/2017

Dissemination level: (PU, PP, RE, CO): PU

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 608166

This project is funded by the European Union

DOCUMENT HISTORY

Index	Date	Author(s)	Main modifications
0.0	Sept 2016	GM, HJ & KG	Initial draft for comment
0.1	January 25th 2017	GM & KG	Final draft
1.0			
2.0			
2.1			

Document Name: Recommendation Summary

Work Package: 7

Task: 7.4

Deliverable: 7.4

Deliverable scheduled date Month 36

Responsible Partner: GDG

Executive Summary

The RAIN project aims to provide an operational analysis framework to minimise the impact of extreme weather events on infrastructure in Europe. Work package 7 of this project considers remediation and mitigation strategies which aim to improve the resilience of existing infrastructure. This Deliverable, D7.4, offers a recommendation summary on techniques for mitigation of, adaptation to and coping with the potential impacts of extreme weather on infrastructure. This document will serve as a summary of the infrastructure protection guidelines as outlined in Deliverables D7.1 and D7.2. Due to climate change, various mitigation and remediation strategies should be considered. The RAIN approach is to provide a framework to consider advantages and disadvantages for a range of possible approaches and give a decision maker a logical framework with which to choose an optimum solution. Guidelines to future management protection plans are also proposed.

The report summarises the effects of climate hazards on European infrastructure and presents mitigation procedures, and adaptation and coping with potential impacts alleviate the impact on citizens. This report is divided into seven sections for the critical infrastructure assets previously outlined in Deliverables D7.1 and D7.2. These sections include bridges, pavements, cuttings and embankments, rail track, tunnels, electrical and telecommunications networks, and dams.

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1. Introduction

Climate change has become a global cause for concern, and infrastructure is particularly at threat from the consequences of changing climate. Extreme weather events are occurring all over the world at an increasing rate, for example, events such as heavy rainfall, drought, flooding, storms, freezing rain, snowstorms and lightning storms are becoming ever more commonplace. It is important to be prepared to adapt to the changing climate and in particular to extreme weather events. Such events pose a significant risk to infrastructure in Europe and can cause problems such as scour on bridge piers, disruption to telecommunication lines, flooded tunnels, landslides etc. The severity and frequency of these events is threatening components of infrastructure in Europe, and WP7 of the RAIN project aims to develop a methodology to assess the effectiveness of methods used to mitigate the effects of these extreme weather events.

As outlined in the Joint Research Centres report into the impacts of climate Change on transport (JCR, 2012):

- Weather-induced damage constitutes up to 50% of maintenance and repair costs to roads in Europe. This costs approximately €10 billion per year, on road infrastructure alone
- Extreme heat events resulting in track buckling and ballast failure are estimated to cost €25-48 million per year in Rail Delays and repair costs
- Rising river levels due to increased rainfall patterns across Europe can cause scour of bridge foundations, a hazard that has been identified as the primary cause of 60% of all bridge failures, and will increase as a threat to EU transport infrastructure
- Sea level rise expects to episodically or permanently inundate 4% of coastal transport infrastructure in Europe

This document describes some mitigation and adaptation measures for the infrastructure assets considered in the RAIN project. The effects of climate hazards and the ability of the mitigation and adaptation procedures to reduce the impact in the event of extreme weather events are considered. Mitigation measures are procedures/actions that can be put in place to reduce the impact of a hazard/event on the infrastructure. This can be achieved by adapting or modifying the infrastructure itself.

Current EU policies anticipate climate change and an increase in extreme weather events in the coming years and it will be necessary for EU member states to adopt infrastructure protection plans to protect their critical infrastructure components. This document serves as a non-technical summary of the findings of Deliverable D7.1 (Analysis of Practical Remediation Strategies for Discrete Infrastructure systems) and D7.2 (Technical Impact Matrices) and provides an outline of the recommendations contained in these reports to aid in policy formulation.

2 Infrastructure

2.1 Road and Rail Bridges

2.1.1 Climate Hazards and Effects

Bridges are vulnerable to extreme weather hazards such as floods, tornadoes and wind storms. In particular, scour during flood events, and excessive lateral loading during windstorms are significant causes of failure. In general, floods are identified as the leading cause of bridge failure. Flash floods and urban floods can occur in areas with steep slopes, excessive rainfall, or poor drainage. 60% of all bridge failures result from scour and other hydraulic causes. In addition, debris accumulation developed by floodwaters increases the risk of higher lateral loads being imposed on critical elements of the bridges.

2.1.2 Mitigation and Adaption procedures:

Several remediation measures were outlined in the project deliverable D7.1 to mitigate the effects of extreme weather events on bridges. These included: provision of scour protection and/or erosion protection, lifting the bridge deck, provision of additional stiffeners, wind deflection devices and vibration dampeners. The most effective common mitigation strategies of bridges are scour/erosion protection and lifting of bridge decks. Scour protection can come in the form of riprap, which involves placing large blocks at the base of piers and abutments. Riprap prevents the removal of sediment from components submerged under water, and is especially useful in rivers with high flow velocities.

As outlined in RAIN Deliverable D7.2, adaptation to climate change is a significant issue for bridge owners. It is important to improve the resilience of bridges to be able to adapt to changing climates and to cope with the associated extreme weather events that may occur. As a result of climate change, rainfall volumes in various regions across Europe can be expected to increase. This can lead to flooding, and rapidly moving water, which can cause excessive scour and erosion around bridge piers, wing walls and abutments. During the design phase, adaption and remediation measures must consider the change in frequency and intensity of extreme weather events when assessing design input parameters. Different regions in Europe will experience varying severity of rainfall and flooding, therefore the most effective mitigation approaches may be regionally different. Design and planning of adaption procedures should consider higher extremes of weather events in the future. And that the current capacity of any adaption measure may not be sufficient in the future.

2.2 Pavements

2.2.1 Climate Hazards and Effects

The leading causes of pavement failure are extreme weather events such as heavy rainfall, windstorms and flooding (including river floods and coastal floods). These lead to structural problems when the capacity of drainage systems are exceeded, resulting in bleeding, flushing, aging of surface course, rutting, cracking, potholing, spalling, faulting or ravelling, oxidation and collapse due to failure of lower layers. These distresses may be classified into three further subsets including; superficial damage, damage in deeper layers, or structural damage.

2.2.2 Mitigation and Adaption procedures

Several remediation and mitigation measures were outlined in D7.1. There are three main levels of techniques used to protect pavement outlined in D7.1. These are categorised as design, maintenance and rehabilitation methods. These methods include:

- Ensuring that the drainage system can cope with relevant design storms
- Careful consideration of material used in the construction of the system
- Prevention of moisture ingress
- Restoration of flexibility of the pavement by use of fog seals
- The use of chipseal and re-sheeting to prolong the life of roads
- Micro surfacing, crack/ break and seat, rubblization
- Additives and emulsifiers such as elastomers and plastomers in the asphalt mix

Regular cleaning and repair of drainage systems was identified as the best mitigation strategy for the prevention of superficial damage, damage in deeper layers and structural damage. At the design level, it should also be ensured that materials and compositions are adapted to extreme conditions, and that adequate drainage facilities are installed. This will prevent damage in deeper layers and structural damage.

Climate Change will impact on the adaption and remediation techniques used on road pavement design in a number of ways. The most effective remediation measure for pavements is identified as correct maintenance, including cleaning and repair of drainage systems. The design of drainage systems should consider the increased stress placed on the system due to more frequent and higher intensity rainfall events. Summer rainfall patterns may be very dry resulting in periods of drought with potential for cracking, whilst winter months may have excessively high rainfall volumes. Naturally, rainfall trends will vary between regions in Europe. Therefore maintenance, including cleaning and repair procedures will be temporal, for example periods of time where rainfall is extreme will require more extensive and frequent cleaning and repair.

2.3 Cuttings and Embankments

2.3.1 Climate Hazards and Effects

There are a number of different contributors to the occurrence of a landslide such as bedrock and soil properties, slope morphology, relief energy, land use and heavy/prolonged rainfall. After heavy rainfall, there is a change in hydrostatic pressure acting on the slope surface, this leads to changes in the total stresses and pore stresses in the soil. Other important trigger factors include earthquakes, snow melt, soil erosion by rivers or sea waves, volcanic eruption and anthropogenic activities such as excavation, loading and land use changes.

The leading causes of landslides as identified in Deliverable 7.1 are:

- High antecedent rainfall
- High intensity period rainfall
- Poor surface drainage

- Steep slope geometry
- Soil material instability

Flooding is also a major contributor to the occurrence of deep landslides and flows. This is an aspect that requires added consideration with the onset of climate change. It is also important to consider that heavy rainfall, tornados and snow and ice loading are the principle causes of rock falls.

2.3.2 Mitigation and Adaption procedures

Several remediation measures were outlined in D7.1 to mitigate the effects of landslides, these include:

- Analysis of the wetting front depth in soil masses
- Monitoring and mapping of landslide events, and prediction of rainfall events
- Surface drainage techniques such as buried drains
- The use of vegetation
- Slope re-grading, reduction of disturbing forces and soil improvements
- Structural inclusions, the use of gabions, geogrids, anchored beams etc.

As part of Deliverable 7.2, landslides types are considered as one of the following types: shallow landslide, deep landslide, flow or rock fall.

The most effective remediation strategy for shallow landslides and flows is generally considered to be drainage works. Drainage works can take the form of the installation of herringbone drains, or culverts etc. If systems are already in place, maintenance can be undertaken to restore effectiveness to the system. In either case, the capacity of the drainage system should be analysed, with consideration of potential rainfall events. The most effective strategy for deep landslides is the installation of piles and anchors. Slope anchoring involves driving an anchor into a slope face, and tensioning. The stability of the slope should first be analysed to determine the depth and number of anchors necessary. For rock falls, the best strategies have been identified as monitoring techniques and the installation of rock fall nets. Monitoring techniques involve early warning systems for the likelihood of rock falls. This can be identified in the form of scree at the base of a rock face. The unstable part of the slope can then be removed in a controlled manner. Rock fall nets are a passive form of landslide damage mitigation, as they catch falling debris from rock faces, and do not actually prevent them.

As previously stated, climate change is causing an increase in the severity and frequency of extreme weather events that have a detrimental effect to slope stability, such as rainfall, flooding, tornados, snow and ice loading, freezing rain and wildfires. When considering methods of adapting cuttings and embankments to increase resistance their resistance to failure, one should consider the long-term effects of climate change. If drainage techniques were to be applied to a slope, the adequacy of their capacity in the future should be analysed with respect to cost. The lifetime of an upgrade should be critically analysed against the expected potential for climatic and extreme weather events. Methods such as vegetation, drainage installation, structural inclusions and slope regrading will have different lifespans and their continued effectiveness will vary over time.

Climate change is anticipated to bring about higher extremes in rainfall patterns, which can result in riverine flooding and soil saturation in slopes. Rising sea levels, and extreme storm events will incur coastal flooding in many areas also. These events will pose a threat to cuttings and embankments, instigating shallow and deep landslides, rock falls and flows. The likelihood of these failures is expected to increase as climate change continues, and predicting and remediating these damages will be an important part of protecting infrastructure.

2.4 Rail Track including Switches and Crossings

2.4.1 Climate Hazards and Effects

Climate effects can result in component, e.g. rail, sleeper, ballast etc. failure and material failures e.g. fatigue cracks, rolling contact fatigue cracks, wear, material deformation and shear failure. Some of the leading causes of indirect failure as detailed in D7.1 are: freeze-thaw action, flooding leading to washout of ballast, build-up of vegetation waste such as fallen leaves, ice, snow, and excessive heat.

2.4.2 Mitigation and Adaption procedures

Several remediation measures were outlined in Deliverable 7.1 to mitigate the effects of extreme weather events on rail tracks, these include:

- Pre-stressing or stretching of rail track
- The provision of small gaps between track lengths to allow for thermal expansion
- Inspection of tracks to detect local weaknesses in Winter
- Replenishment of ballast around sleepers, and re-tensioning of welded rails
- At-risk rails are painted white so that they absorb less heat
- Regular measurement of rail temperatures

These measures were assessed based on a number of characteristics involving technical effectiveness, cost and environmental impact in Deliverable D7.2. Rather than modifying the asset it is often more effective to manage the hazards themselves. In this approach rather reducing the effects of the event, resources are concentrated on risk reduction e.g. by forming natural hazard maps, incorporating weather information system and provide technical training etc.

2.5 Tunnels

2.5.1 Climate Hazards and Effects

The following are some of the leading causes of tunnel failure as detailed in Deliverable 7.1:

- Weather hazards such as flooding from rainfall, sea water, rivers or groundwater
- Gravity falls and rock mass failures such as spalling
- Slabbing and major rock bursting, squeezing, swelling, running sand settlement and cratering.

As outlined in the Deliverable 7.2, the most common failure in tunnels are river flooding and coastal flooding, with the tunnel's relative position to sea and or river level being a critical factor. Heavy rainfall can also have an (indirect) impact on tunnels since it can cause landslides and rock slides at the tunnel portal and on ceilings and walls.

2.5.2 Mitigation and Adaption procedures

Several remediation measures were outlined in D7.1 to mitigate the effects of extreme weather events on tunnels. As flooding and other water induced loading are the prime cause of tunnel failures, the strengthening of the waterproofing capacity of these structures is paramount. Moreover, any other action that benefits water evacuation, such as pumping, will greatly reduce the risk of failure. These include: maintenance and upgrading of sewer networks, temporary overflow storage tanks, frequent checks to ensure structures can withstand high water pressures and wind forces in ventilation shafts, waterproofing barriers and doors and emergency reserve pumps.

Climate change will result in several threats to both immersed in water and non-immersed tunnels. For immersed tunnels that cross a watercourse there is a risk that water cannot flow quickly enough through the drainage systems and thereby increase the risk of erosion or flooding. In non-immersed tunnels there is a threat that flooding will occur due to rainfall exceeding the capacity of the drainage system. In addition, water can induce destabilization of slopes and rocks causing landslides. The onset of climate change may also raise sea water levels, and thus increase the threat of tidal flooding.

The occurrence of extreme weather events is increasing and this calls for the adaptation of tunnel maintenance and remediation strategies. Increasing the resilience of infrastructure such as tunnels is necessary with the onset of climate change. Therefore, the inclusion of infrastructure protection guidelines in EU policy is paramount to the efficient operation of transport networks in Europe.

2.6 Electrical and Telecommunications Networks

The findings of D7.2 identified several critical elements of Electrical and Telecommunications Networks including:

- Generators and their auxiliary power systems
- Transmission lines
- Transmission transformers
- Switches and breakers
- Protection relays
- SCADA and associated Telecoms
- Other Voltage-management devices

2.6.1 Climate Hazards and Effects

The leading causes of electrical and telecommunications network failures as detailed in Deliverable 7.1 are wind storms, ice/ wet snow storms, extreme heat, lightning, flash floods, wild fires and sand storms

2.6.2 Mitigation and Adaption procedures

Several remediation measures were outlined in D7.1 to mitigate the effects of extreme weather events on electrical and telecommunications networks, these include:

- Rights of way maintenance, such as vegetation management
- De-icing and anti-icing measures
- Prevention of line sagging
- Regular tower inspections and maintenance

Electrical and Telecommunications Networks are especially vulnerable due extreme weather events due to their extensive coverage across urban and rural countryside. Events such as ice/ snow storms, extreme heat, lightning etc. all pose a great threat to this component of infrastructure. The introduction of EU infrastructure protection guidelines would be beneficial to member states and would clarify a standard by which maintenance operation bodies can adhere to. The increasing threat of extreme weather events in Europe due to climate change also calls for a protection plan which allows for adaptation of design methods to allow for more extreme weather. The variability of weather events necessitates the ability to adapt and cope with mitigation and remediation techniques in design, construction and operational phases of infrastructure management.

2.7 Dams

2.7.1 Climate Hazards and Effects

Dams are also quite sensitive to extreme weather events that will significantly increase the retained water height such as rapidly accumulated large volumes water due to heavy rainfall and river floods. Some of the leading causes of dam failure, as detailed in Deliverable 7.1 are:

- Overtopping of a dam
- Inadequate spillway design
- Debris blocking spillways
- Settlement of dam crest

There is also a risk of damage to the foundation due to extreme weather events, including settlement and instability of the foundation or slope instability, piping, and internal erosion due to seepage. Furthermore, the possibility of structural failures due to the materials used in construction should be considered. These can be caused by static sliding, high rainfall and high temperature variance. It is also necessary to distinguish between non-erodible and erodible dams; which are more vulnerable to erosion generated by extreme events like heavy rain, windstorms, etc.

2.7.2 Mitigation and Adaption procedures

In Deliverable 7.1 it was outlined that the majority of the mitigation measures are related to maintenance and checking of all structural elements and pumping/water removal systems. The following are a small number of the remediation measures outlined in Deliverable 7.1 to mitigate the effects of extreme weather events on dams, these include:

- Monitoring of future meteorological conditions and their potential impact
- Correct design to meet the necessary design loads and standards

- Regular and frequent maintenance of valves and joints etc.
- Maintenance and removal of vegetation and waste build up, dredging etc.
- Correct operation of the dam and its components
- Raising the crest of the dam
- Regular monitoring of dam displacement

In the case of erodible dams, as described in deliverable 7.2, special attention should be paid to erosion protection measures to assist in protecting the structure. Generally, reducing the inflow water, increasing the dam capacity and reducing dam erosion are the primary mitigation procedures that should be considered to protect against extreme weather events.

The frequency of extreme rainfall events, riverine and coastal flooding, wind waves and surges are more likely to increase, which can induce high levels of stress on dams and can lead to complete failure. The overflow capacity of dams will need to be increased to allow for more extremes in water levels to cope with future demands. The effect of rising sea levels will also increase the threat of seawater ingress into river dams from downstream. The added stresses due to these situations need to be accounted for in effectively designing dam systems in the future.

3 Summary and Conclusions

Weather stresses due to climate change contribute to a large proportion of road and infrastructure costs in Europe. The EU recognises that failure of infrastructure components is a serious issue, and climate change and its associated extreme weather events is a major contributor to this. With the continued onset of climate change, the number of failures is expected to rise as extreme weather events worsen.

Engineering design standards must be revised and updated to anticipate the effects of climate change, and regional impacts will also require flexible standards and design approaches to be introduced. Currently, there is a high level of uncertainty in the existing climate models. Adapting infrastructure to cope with extreme weather events will aid in preventing disasters, delays and the need for more expensive remediation/repair strategies in the future.

To cope with the potential impacts of climate change, it is necessary to adapt infrastructure in Europe to future extreme weather events. This involves analysing the risk associated with critical infrastructure systems in Europe and mitigating the impacts of extreme weather. The adequacy of infrastructures needs to be assessed in response to climate change, and this Deliverable serves to briefly outline the how and why in the case of each infrastructure component. This document serves to summarise techniques for mitigation of and adaptation to the potential impacts of extreme weather on critical infrastructures in Europe. Mitigation and remediation techniques are necessary applications for the protection of infrastructure in Europe. The rate of climate change requires an adaptation strategy for the continued serviceability of mitigation measures and the operation of infrastructure.

This document outlines each of the main components of infrastructure in Europe in terms of associated climate hazards, mitigation procedures, and adaptation to potential future weather events. Adaptive characteristics are necessary for the design of mitigation and remediation strategies for components of EU infrastructure. And this document outlines a summarised recommendation.

4 References

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