AllTraIn

All-Hazard Guide for Transport Infrastructure

www.alltrain-project.eu

WP3 Report

Preventive and Mitigation Measures

The following report summarizes the results of Preventive and Mitigation Measures of the EU CIPS Project *AllTraIn*.

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Project Information

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1. Introduction

This chapter has the goal of identifying and defining possible measures capable of mitigate or prevent the impacts of the hazards defined in WP2 for every type of transport infrastructure studied in WP3.

The hazards defined in WP2 are divided into two major groups according to their origin: man-made and natural. The man-made hazards can either be intentional or unintentional. Intentional man-made hazards are criminal acts against the traffic infrastructure or its environment while the unintentional hazards comprises technical failures, human errors or other uncalculated external causes. The natural hazards are the ones related with the natural events that most affects transport infrastructures like extreme weather calamities and geo-hazards.

The transport modes studied in WP3 are road and rail networks individualized by four different types of infrastructures: bridge, tunnel, embankment and cut. Each one of these infrastructures is different having specific particularities and therefore WP3 establishes a different set of factors for each. Nevertheless, there are some factors, characterizing the transport mode (road/rail), common to the four types defined.

The measures presented can either be structural, operational or organizational and their goal is exclusively to prevent or mitigate the hazards or its impacts from the point of view of the local consequences considered in this project: damage of the infrastructure and disruption of the service. Therefore this approach disregards the global consequences as well as any potential human losses.

Also, the methodology proposed in the AllTrain project considers that the potential mitigation and prevention measures introduced, whether at the time of construction and/or existent at the time of the analysis, are characteristics of the infrastructure. Thus, the hazard trees include a query about measures right after the establishment of the hazard and before the characterization of the asset (infrastructure). The next figure illustrates the placement of this query. This has the goal of allowing the user to interrupt the assessment in case he considers having been implemented the appropriate and effective measures. Additionally, the measures presented and compiled in this document, can also provide a starting point for the transport owners and operators wishing to define a plan to cope with any studied hazard.

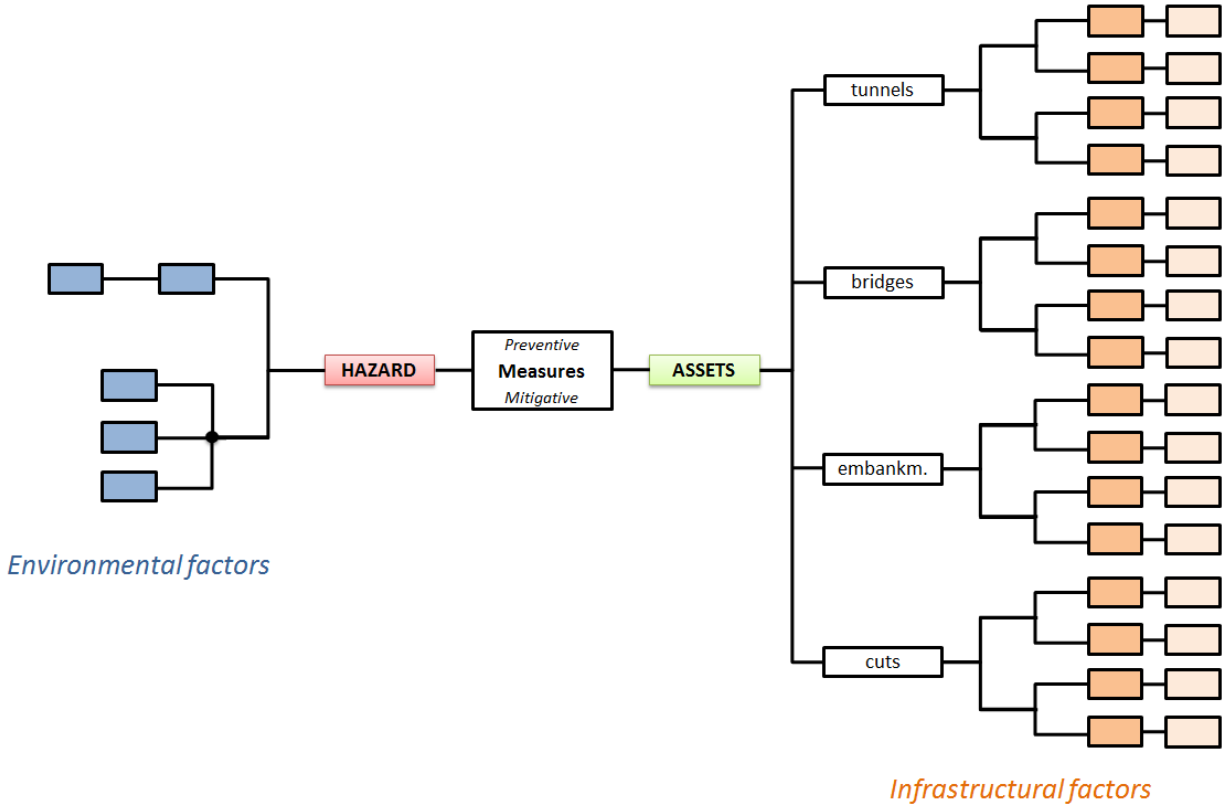

Figure 1 – Measures consideration in the AllTrain assessment methodology

2. General Measures

There is a group of preventive and mitigation measures that can be applied to all types of infrastructures regardless of the hazard considered. These measures can be regarded as general good practices of broad-spectrum use in the transport infrastructure asset management area.

Traffic redundancy

Redundancy of traffic is the capacity of a given infrastructure to maintain the service, even if providing a lower service level. The redundancy is provided by a parallel way, within the same transport infrastructure.

This measure can minimize the impact of one of the local consequences considered in AllTrain project: the disruption of the service.

Installation of (automatic) monitoring systems – CCTV

CCTV (closed circuit television) relies on strategic placement of cameras, and private observation and recording of the camera's input, in order to maintain perimeter security and monitor traffic and human activity within the transport infrastructure. The four main operational objectives are: monitor, detect, recognise and identify.

The implementation of CCTV in transport infrastructure provides an effective tool against several man-made hazards, but it also has the purpose of increasing the general security of mass passenger transport. This measure can also be implemented even if the concern relies only on the natural hazards in addition to the adoption of weather information systems.

Land-use planning

Land use plans are public policies which attempt to regulate the use of land in an efficient and ethical way. Based on the projected needs for accommodating population and economic growth during the planning period, a plan is created to provide necessary public facilities and services where they are needed, to designate ample and suitable areas for potential development, and to protect environmental resources. Risk conscious land use plans designate specific hazard areas, guide concentrated development away from these identified areas, and encourage open-space or low density development. Additionally, plans can contain evacuation routes, emergency shelters, and post-disaster reconstruction.

While land use plans include the various developmental needs of a specific area or community, hazard mitigation plans are long term measures taken to reduce the loss of life and property as a result of a disaster (1).

Maintenance procedures

Maintenance and repair works are activities that owners and transport operators are obliged to undertake periodically in order to extend infrastructure's operation over their expected service life. These works do not change the fixed asset or its performance, but maintain it in a good condition or restore it in the event of a breakdown.

Weather information systems

In general, weather information systems comprise automatic weather stations installed along the transport infrastructures, connect with a central system. The stations can measure real-time atmospheric, pavement, sub-ground, water level conditions and visibility. These systems can provide forecasts and warnings for the infrastructures user but they are also useful for owners and operators to manage and support real-time decisions.

3. Preventive and mitigation measures for natural hazards

3.1 Introduction

The natural hazards considered are the ones presented in the chapter 2 (*Hazards and security threats to road and rail infrastructure*) of the All-Hazard Guide for Transport Infrastructure, and that are listed in the next table.

Natural Initial Event	Hazard
Extreme Earthquake	Extreme earthquake
	Liquefaction
	Landslide (slide/fall)
	Intense water front
	Ground deformation/displacement
Extreme Rainfall	Extreme rainfall
	Flood
	Blackout
	Landslide (slide/fall)
	Landslide (flow)
Extreme snowfall	Extreme snowfall
	Avanlanche
	Snow drift
	Toggled trees
Extreme hot weather	Extreme hot weather
	Blackout
	Bush fire
Extreme wind, storm	Extreme wind, storm
	Storm surge
	Sand storm
	Toggled trees
Thunderstorm	Lightning
Volcanic eruption	Lava flow
	Ash cloud
	Landslide (slide/fall)
	Landlside (flow)
Extreme cold	Extreme cold
	Ice storm
Hail	Hail
Various continous processes	Landslide (slide/fall)

Various continous processes	Ground subsidence
Animals crossings	Animals crossings

3.2 Extreme Earthquakes

The most usual measures for preventing or mitigate the effects of extreme earthquakes are the following:

Vibro-compaction

Vibro compaction is a ground improvement technique used for densification of a cohesionless granular soil by means of a downhole vibrator. The use of clean sand backfill during vibro-compaction allows settletment and seismic liquefaction potential to be reduced.

Deep Mixing Method (DMM)

The deep-mixing method is a ground improvement thecnique that improves the characteristics of weak soils by mechanically mixing them with cementitious binder slurry. The grid pattern soil/cement mixture provides additional shear strenght for site to withstand strong ground motion.

Jet Grouting

Jet grouting is a technique that uses high pressure fluid jets to erode and mix/replace soil with grout thus forming columns or panels. This method strenghens liquefiable soils.

Earthquake Drain

An earthquake drain consists of high flow capacity prefabricated vertical drain wrapped with a geotextile fabric. These elements allow free access of pore water into the drain while preventing the piping of fines from adjacent soils. Both mechanisms provide liquefaction mitigation.

Wick Drains

Wick drains are a ground improvement technique that provides drainage paths for pore water in soft compressible soil, using prefabricated geotextile filter strips. It provides liquefaction mitigation and accelerates the consolidation process.

Rigid Inclusions

This ground improvement technique transfers loads through weak material to a rigid stratum using high-modulus, controlled stiffness columns, thus decreasing settlement.

Continuous Flight Auger (CFA) Piles

These deep foundation elements are cast-in-place, using a hollow stern auger with continuous flight. When the auger is extracted, the removed material is replaced by concrete or grout that is pumped through the hollow stern.

Seismic isolation

This measure consists in the principle of isolating the infrastructure from the earthquake vibration thus protecting its horizontal components from decoupling by the ground motion effect. The isolation is obtained by the installation of rubber bearings between the infrastructure and its foundation.

Infrastructure	Vibro-compaction	DMM	Jet-Grouting	Earthquake Drains	Wick Drains	Rigid Inclusions	CFA Piles	Seismic isolation
Tunnel	✓	✓	✓	✓	✓	✓	✓	
Bridge	✓	✓	✓	✓	✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓	✓	
Cut	✓	✓	✓	✓	✓	✓		

3.1.1 Liquefaction

The most usual measures for preventing or mitigate the effects of liquefaction are the following:

Vibro-compaction

Vibro compaction is a ground improvement technique used for densification of a cohesionless granular soil by means of a downhole vibrator. The use of clean sand backfill during vibro-compaction allows settletment and seismic liquefaction potential to be reduced.

Deep Mixing Method (DMM)

The deep-mixing method is a ground improvement thecnique that improves the characteristics of weak soils by mechanically mixing them with cementitious binder slurry. The grid pattern soil/cement mixture provides additional shear strenght for site to withstand strong ground motion.

Jet Grouting

Jet grouting is a technique that uses high pressure fluid jets to erode and mix/replace soil with grout thus forming columns or panels. This method strenghens liquefiable soils.

Earthquake Drains

Earthquake drains consist of high flow capacity prefabricated vertical drain wrapped with a geotextile fabric. These elements allow free access of pore water into the drain while preventing the piping of fines from adjacent soils. Both mechanisms provide liquefaction mitigation.

Wick Drains

Wick drains are a ground improvement technique that provides drainage paths for pore water in soft compressible soil, using prefabricated geotextile filter strips. It provides liquefaction mitigation and accelerates the consolidation process.

Rigid Inclusions

This ground improvement technique transfers loads through weak material to a rigid stratum using high-modulus, controlled stiffness columns, this decreasing settlement.

Continuous Flight Auger (CFA) Piles

These deep foundation elements are cast-in-place, using a hollow stern auger with continuous flight. When the auger is extracted, the removed material is replaced by concrete or grout that is pumped through the hollow stern.

Infrastructure	Vibro-compaction	DMM	Jet-Grouting	Earthquake Drains	Wick Drains	Rigid Inclusions	CFA Piles
Tunnel	✓	✓	✓	✓	✓	✓	✓
Bridge	✓	✓	✓	✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓	✓	✓	✓	✓

3.1.2 Landslide (slide/fall)

The most usual measures for preventing or mitigate the effects of landslides and rockfall phenomenon are the following:

Seismic flexible joints

Seismic flexible joints are joints especially designed to absorb large deformations due to the earthquake's forces. These elements have large movement capacity as to axial direction and rotation at joint parts.

Deep Mixing Method (DMM)

The deep-mixing method is a ground improvement thecnique that improves the characteristics of weak soils by mechanically mixing them with cementitious binder slurry. The grid pattern soil/cement mixture provides additional shear strenght for site to withstand strong ground motion.

Jet Grouting

Jet grouting is a technique that uses high pressure fluid jets to erode and mix/replace soil with grout thus forming columns or panels. This method strenghens unstable soils.

Soil nailing

Soil nailing is an earth retention technique using grouted tension-resisting steel elements, nails, which can be used to stabilize slopes and landslides.

Anchors

Anchors are stabilization and support elements that transfer tension loads using high-strength steel bars. These elements can be used to provide support and stabilization to slopes and landslides.

Diaphragm wall

Diaphragm walls are a method of creating a cast in-situ reinforced retaining wall. It is constructed in the ground using under slurry technique.

Reinforced concrete bridge piers

The reinforcement of bridge piers prevent shear failure and allows the structure (bridges) to maintain sufficient ductility.

Geotextile reinforcement

A geotextile geogrid is used to reinforce the base of an embankment since these elements are able to reach very high tensile strength. This allows the soil particles to interlock, thus providing an optimal lateral confinement to the granular soil, therefore limiting the related movements and increasing the shear resistance.

Metallic mesh draping and netting

The installation of metallic rockfall protection mesh provides a safety net where rocks can fall without hitting the infrastructure. These structures may be anchored at the top and/or at the bottom of slopes.

High Energy absorption (HEA) panels

The high energy absorption panels are structures that provide high tensile resistance while exhibiting low elongation thus ensuring that the debris accumulation will not impact directly the infrastructure.

Earthen barriers

These barriers are constructed of natural soil and rocks or mechanically stabilized earth are placed at the end of a catchment area having the capacity to absorb large impacts.

Controlled blasting

The blasting of unstable sections of rock in a controlled manner may prevent the consequences of hazardous rockfall.

Ditches and berms

The construction of a catch ditch or a berm at the toe of the slope provides an area for receiving and restraining the rockfall material. These elements reduce the energy of the falling projectile by trapping or slowing rockfalls. They should be covered by a layer of gravel in order to absorb the energy and a sturdy barrier to protect the infrastructure.

Rock bolts

The rock bolts are steel rods that are installed into holes drilled into the rock and are usually grouted and can be tensioned or not. This measure provides support to the outer surface of the slope.

Rock shed (avalanche shelter)

Rock sheds are structures installed over the infrastructure to withstand rockfalls. It provides the complete reduction in rockfall hazards over the length of the infrastructure encompassed by the rock shed.

Infrastructure	Seismic flexible joints	DMM	Jet-Grouting	Soil nailing	Anchors	Diaphragm wall	Reinforced concrete bridge piers	Geotextile reinforcement
Tunnel	✓	✓	✓	✓	✓	✓		
Bridge	✓	✓	✓	✓	✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓		
Cut	✓	✓	✓	✓	✓	✓		

Infrastructure	Metallic mesh and netting	HEA panels	Earthen barriers	Controlled blasting	Ditches berms	Rock bolts	Rock shed
Tunnel (*)							
Bridge	✓	✓	✓	✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓	✓	✓	✓	✓

(*) – Only the portals of tunnels are affected by rockfall hazards, therefore are considered to be either embankments or cut section of the road/rail ways.

3.1.3 Intense water front

The most usual measures for preventing or mitigate the effects of intense waterfront phenomenon are the following:

Flood barrier

A flood barrier is a specific floodgate designed to prevent extreme flooding from occurring in the protected infrastructure.

Protective fenders for bridge piers

A fender is a protection system that can be developed to prevent, redirect or reduce the impact loads on bridge elements to non-destructive elements.

Flow deflectors

The installation of a "V" shaped flow deflector on or immediately upstream the piers and abutments can redirect the flow velocities thus protecting footings and pillars from scouring.

Deep foundations

An infrastructure has deep foundations when they are installed at a deeper depth below ground surface. This renders the infrastructure less vulnerable to the potential effects of scour.

Seawalls

A seawall is a coastal defense construction to protect the infrastructure from the direct impact of the sea. They may be made from a variety of materials and the three main types are vertical, curved and mound.

Riprap protection

Riprap material is made from a variety of rock types, commonly granite or limestone and its use around the pillars and abutments of a bridge can prevent scour, and its application on embankments construction may defend the infrastructure from water erosion.

Geosynthetic reinforcement

Geosynthetic materials are manufactured from polyester or polypropylene and have high-strength and durability being commonly used to reinforce earth structures. This reinforcement can reduce the impact of water erosion in embankments.

Coastal Vegetation

The existence of coastal vegetation works as a natural barrier and can effectively prevent the spread of tsunamis as well as mitigate the flood and surge of water.

Infrastructure	Flood barrier	Protective fender	Flow deflector	Deep foundations	Seawalls	Riprap protection	Geosynthetic reinforcement	Coastal vegetation
Tunnel					✓			✓
Bridge	✓	✓	✓	✓	✓	✓		✓
Embankment	✓	✓	✓	✓	✓	✓	✓	✓

Cut	✓	✓	✓		✓	✓		✓

3.1.4 Ground deformations/displacements

The most usual measures for preventing or mitigate the effects of ground deformations/displacements phenomenon are the following:

Seismic flexible joints

Seismic flexible joints are joints especially designed to absorb large deformations due to the earthquake's forces. These elements have large movement capacity as to axial direction and rotation at joint parts.

Deep Mixing Method (DMM)

The deep-mixing method is a ground improvement thecnique that improves the characteristics of weak soils by mechanically mixing them with cementitious binder slurry. The grid pattern soil/cement mixture provides additional shear strenght for site to withstand strong ground motion.

Jet Grouting

Jet grouting is a technique that uses high pressure fluid jets to erode and mix/replace soil with grout thus forming columns or panels. This method strenghens unstable soils.

Vibro-compaction

Vibro compaction is a ground improvement technique used for densification of a cohesionless granular soil by means of a downhole vibrator. The use of clean sand backfill during vibro-compaction allows settletment and seismic liquefaction potential to be reduced.

Rigid Inclusions

This ground improvement technique transfers loads through weak material to a rigid stratum using high-modulus, controlled stiffness columns, this decreasing settlement.

Deep foundations

An infrastructure has deep foundations when they are installed at a deeper depth below ground surface. This allows the infrastructure to be founded at a ground level that may be less vulnerable to ground deformations impact.

Flexible pavements

Flexible pavements reflect the deformation of subgrade and the subsequent layers to the surface thus allowing the pavement to sustain higher stresses due to the ground displacement without structural damage.

Seismic isolation

This measure consists in the principle of isolating the infrastructure from the earthquake vibration thus protecting its horizontal components from decoupling by the ground motion effect. The isolation is obtained by the installation of rubber bearings between the infrastructure and its foundation.

Infrastructure	Seismic flexible joints	DMM	Jet-Grouting	Vibro-compaction	Rigid inclusions	Deep foundations	Flexible pavements
Tunnel	✓	✓	✓	✓	✓		✓
Bridge	✓	✓	✓	✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓	✓	✓		✓

3.2 Extreme Rainfall

The most usual measures for preventing or mitigate the effects of extreme rainfall are the following:

Road Surface

The use of porous asphalt as the road surface allows rainwater to drain away quicker than in normal asphalt road surfaces. This measure reduces road ruttings and improves road traffic safety.

Drainage system

A drainage system may comprise several different types of components such as gutters, inlet boxes, pipes, spillways, energy dissipaters, and its main purpose is to collect water and dispose it in the most appropriate points therefore preventing the impacts that the free water flow would sustain to the infrastructure and/or its traffic.

Secondary lining

In tunnels with no secondary lining the best protection against water-related hazards, like water percolation due to an increase in the water table, is the installation of a secondary lining that will completely waterproof the structure.

Secondary lining injection

The injection of the secondary lining in tunnels has the goal to avoid groundwater percolation by improving the coating and waterproofing system. The injection can be made with grout, sprayed concrete or specific products like resin.

3.2.1 Flood

The most usual measures for preventing or mitigate the effects of flooding are the following:

Flood barrier

A flood barrier is a specific floodgate designed to prevent extreme flooding from occurring in the protected infrastructure.

Flow deflector

The installation of a "V" shaped flow deflector on or immediately upstream the piers and abutments can redirect the flow velocities thus protecting footings and pillars from scouring.

Drainage system

A drainage system may comprise several different types of components such as gutters, inlet boxes, pipes, spillways, energy dissipaters, and its main purpose is to collect water and dispose it in the most appropriate points therefore preventing the impacts that the free water flow would sustain to the infrastructure and/or its traffic.

Riprap protection

Riprap material is made from a variety of rock types, commonly granite or limestone and its use around the pillars and abutments of a bridge can prevent scour, and its application on embankments construction may defend the infrastructure from water erosion.

Vegetation

The use of deep-rooting vegetation in slopes promotes the removal of water and prevents surface erosion by limiting the processes of sheet wash and overland flow.

Protective Wall

A protective wall (constructed with rock, gabions, concrete, piles, etc) can prevent slopes from suffering surface erosion due to flooding events.

Levee

Levees are a method of river flood control that consists of earthen embankments built between the river and the protected infrastructure.

Floodway

Floodways are dedicated pathways to divert floodwaters into topographical depressions near the river and are controlled by hydraulic structures that capture the overbank floodwaters.

Dyke

Dykes are protective structures, usually with a trapezoidal cross-section, erected from earthen material along a watercourse to prevent overflow of high waters.

Secondary lining

In tunnels with no secondary lining the best protection against water-related hazards, like flood due to an increase in the water table originated from an extreme rainfall, is the installation of a secondary lining that will completely waterproof the structure.

Secondary lining injection

The injection of the secondary lining in tunnels has the goal to avoid groundwater percolation by improving the coating and waterproofing system. The injection can be made with grout or sprayed concrete.

Infrastructure	Flood barrier	Flow deflector	Drainage system	Riprap protection	Vegetation	Protective wall	Levee
Tunnel	✓		✓				✓
Bridge	✓	✓	✓	✓			✓
Embankment	✓		✓	✓	✓	✓	✓
Cut	✓		✓		✓	✓	✓

Infrastructure	Floodway	Dyke	Secondary lining	Secondary lining injection
Tunnel	✓	✓	✓	✓
Bridge	✓	✓		
Embankment	✓	✓		
Cut	✓	✓		

3.2.2 Blackout

The prevention of blackouts affecting transport infrastructure is a subject of national management and therefore there is not any direct preventive measure any transport infrastructure owner or operator could undertake. Nevertheless, the most usual measure for mitigate the effects of blackout phenomenon is the following:

Power supply redundancy

This measure can be done by resorting to the redundancy of all the critical power systems of the infrastructure, namely centralized systems, with an alternative power source.

Infrastructure	Power supply redundancy
Tunnel	✓
Bridge	✓
Embankment	✓
Cut	✓

3.2.3 Landslide (slide)

The most usual measures for preventing or mitigate the effects of landslides phenomenon are the following:

Seismic flexible joints

Seismic flexible joints are joints especially designed to absorb large deformations due to the earthquake's forces. These elements have large movement capacity as to axial direction and rotation at joint parts.

Deep Mixing Method (DMM)

The deep-mixing method is a ground improvement thecnique that improves the characteristics of weak soils by mechanically mixing them with cementitious binder slurry. The grid pattern soil/cement mixture provides additional shear strenght for site to withstand strong ground motion.

Jet Grouting

Jet grouting is a technique that uses high pressure fluid jets to erode and mix/replace soil with grout thus forming columns or panels. This method strenghens unstable soils.

Soil nailing

Soil nailing is an earth retention technique using grouted tension-resisting steel elements, nails, which can be used to stabilize slopes and landslides.

Anchors

Anchors are stabilization and support elements that transfer tension loads using high-strength steel bars. These elements can be used to provide support and stabilization to slopes and landslides.

Diaphragm wall

Diaphragm walls are a method of creating a cast in-situ reinforced retaining wall. It is constructed in the ground using under slurry technique.

Reinforced concrete bridge piers

The reinforcement of bridge piers prevent shear failure and allows the structure (bridges) to maintain sufficient ductility.

Geotextile reinforcement

A geotextile geogrid is used to reinforce the base of an embankment since these elements are able to reach very high tensile strength. This allows the soil particles to interlock, thus providing an optimal lateral confinement to the granular soil, therefore limiting the related movements and increasing the shear resistance.

Infrastructure	Seismic flexible joints	DMM	Jet-Grouting	Soil nailing	Anchors	Diaphragm wall	Reinforced concrete bridge piers	Geotextile reinforcement
Tunnel	✓	✓	✓					
Bridge	✓	✓	✓	✓	✓	✓	✓	
Embankment	✓	✓	✓	✓	✓	✓		✓
Cut	✓	✓	✓	✓	✓	✓		

3.2.4 Landslide (flow)

The most usual measures for preventing or mitigate the effects of landslides – debris flow phenomenon are the following:

Check dams

A check dam is a small dam constructed in slopes to counteract erosion by reducing the debris flow velocity. Typically they integrate a system consisting of several check dams situated at regular intervals.

Channels

A channel structure can confine the debris flow material and direct it away from the protected infrastructure.

Deflecting dyke

This type of dyke have oblique or curving walls in order to force the debris flow material to deposit in a predetermined area.

Debris flow barrier

This type of barriers are constituted by flexible ring net barriers and stop debris flow surge, strain and retain coarse debris, allowing only water and fine-grained sediment to continue downstream.

Log erosion barrier

Log erosion barrier is a log placed in a shallow trench on the contour to intercept water running down a slope and trap the sediment. This type of barrier is used in sites with high erosion rates due to wildfires and reduces the debris flow velocity for low intensity rain events.

Debris flow shelter

A debris flow shelter is a structure similar to an avalanche shelter, constructed from reinforced concrete, which constitutes a canopy over the road/rail section intended to be protected. It dissipates the energy through the granular material placed on the shelter's roof where the debris flow lands.

Debris flow bridge

This structure provides a passageway for the debris material thus preventing blockage of the flow channel and directing the material away from the infrastructure. It is used when the estimated energy from the debris flow is too high for the resource to debris flow shelter.

Infrastructure	Check dams	Channels	Deflecting dyke	Debris flow barrier	Log erosion barrier	Debris flow shelter	Debris flow bridge
Tunnel	✓	✓	✓				
Bridge	✓	✓	✓				
Embankment	✓	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓	✓	✓	✓	✓

3.3 Extreme Snowfall

The most usual measures for preventing or mitigate the effects of extreme snowfall phenomenon are the following:

Protection of switches

The protection of rail switches can be done by the installation of snow and ice covers. These type of structures protect the rail equipment that is most sensitive to cold weather and snow, like points and switches. They keep snow out and prevent any damage by ice falling from passing trains. They can also include a heating system.

Multi-purpose vehicle

The use of this type of vehicles is common in the rail infrastructure with the purpose of de-icing the infrastructure. This type of vehicles are fitted with snow ploughs, hot-air blowers, steam jets, brushes, etc.

Snow fence

A snow fence is a type of fence used to accumulate windblown and drifting snow in a desired place. This can mitigate the effect of snow accumulation and blowing on to the infrastructure.

Drainage system

A drainage system may comprise several different types of components such as gutters, inlet boxes, pipes, spillways, energy dissipaters, and its main purpose is to collect water and dispose it in the most appropriate points therefore preventing the impacts that the free water flow would sustain to the infrastructure and/or its traffic.

Secondary lining injection

The injection of the secondary lining in tunnels has the goal to avoid groundwater percolation by improving the coating and waterproofing system. The injection can be made with grout or sprayed concrete. This procedure can also reduce the risk of icicles formation above the overhead line equipment (for the rail transport mode).

Welded joints

In the rail infrastructure the use of welded joints instead of bolted joints reduces the vulnerability of rail tracks to break during cold conditions, since these elements are more strong and capable of sustaining higher steel tensions.

Track signaling

The improvement of the resilience of rail track signaling equipment to snow promotes the availability of the infrastructure operation.

Anti-icing/deicing chemicals

The use of anti-icing/deicing chemicals on road pavements prevents snow and ice from bonding to the pavement surface. This practice is implemented before the hazard impact and can improve service levels as well as reduces the infrastructure maintenance costs.

Infrastructure	Protection of switches	Multi-purpose vehicle	Snow fence	Drainage system	Secondary lining injection	Welded joints	Track signaling	Anti-icing/deicing chemicals
Tunnel	✓	✓		✓	✓	✓		✓
Bridge	✓	✓	✓	✓		✓	✓	✓
Embankment	✓	✓	✓	✓		✓	✓	✓
Cut	✓	✓	✓	✓		✓	✓	✓

3.3.1 Avalanche

The most usual measures for preventing or mitigate the effects of avalanche phenomenon are the following:

Controlled blasting

The blasting involves the artificial triggering of smaller less destructive avalanches by detonating charges either above or on the snow surface.

Snow shed

A snow shed or avalanche gallery is a type of rigid-support structure for snow defense that promotes the passage in areas susceptible to avalanche hazards. This structure can either be fully closed, as an artificial tunnel, or consisting of framework elements.

Avalanche barrier (snow net)

This barrier is constituted by a high tensile strength steel wire mesh that extends across the slope preventing possible creeping within the snow cover and also the sliding of the snow cover on the terrain surface.

Braking mound

Braking mounds are used to retard the avalanche by breaking up the flow and increasing the dissipation of energy.

Snow fence

A snow fence is a type of fence used to accumulate windblown and drifting snow in a desired place. This can mitigate the effect of avalanche hazard by collecting snow that would otherwise be carried away thus decreasing the volume and the impact of the avalanche.

Snow deflection structures

A snow deflection structure is used to deflect and confine the moving snow within the avalanche track. It can either be earth fill structures or made by reinforced concrete and re-direct avalanches from the paths affecting the protected infrastructures.

Avalanche protection dam

An avalanche protection dam can either be a deflecting dam, used to divert avalanches away from the infrastructure at risk, or catching dam, intended to stop the avalanche completely before it reaches the infrastructure. Usually both these structures are used in combination.

Afforestation

The preservation and protection of forests can mitigate the impact of avalanches since forests fulfil all the functions of artificial avalanche defenses: retention, redistribution, retardation and catchment.

Infrastructure	Controlled blasting	Snow shed	Avalanche barrier	Braking mounds	Snow fence	Snow deflection structure	Avalanche protection dam	Afforestation
Tunnel	✓		✓	✓			✓	✓
Bridge	✓	✓	✓	✓	✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓	✓	✓	✓	✓	✓

3.3.2 Snowdrift

The most usual measures for preventing or mitigate the effects of snowdrift phenomenon are the following:

Snow fence

A snow fence is a type of fence used to accumulate windblown and drifting snow in a desired place. This is primarily employed to minimize the amount of snowdrift on roadways and railways. This type of fence usually consists of poles with horizontal planks across its section. They are installed linearly and have the ability to influence the wind flow in such a way that snow is accumulated downstream of the fence.

Wind baffle

A wind baffle is a structure consisting of one or two cross-shaped boards with one or two posts and that is used to break up large continuous cornices or to separate avalanche starting zones. These structures form a discontinuity in the snow distribution by increasing the snow erosion around them.

Anti-icing/deicing chemicals

The use of anti-icing/deicing chemicals on road pavements prevents snow and ice from bonding to the pavement surface. This practice is implemented before the hazard impact and can improve service levels as well as reduces the infrastructure maintenance costs.

Infrastructure	Snow fence	Wind baffle
Tunnel		
Bridge	✓	✓
Embankment	✓	✓
Cut	✓	✓

3.3.3 Toggled trees

The most usual measures for preventing or mitigate the effects of toggled trees phenomenon are the following:

Vegetation management plan

The implementation of a vegetation management plan allows the planting of the most suitable vegetation and trees in accordance with the region. The removal of trees classified as “highly vulnerable” or diseased is the most effective measure for toggled trees hazard.

Avalanche barrier (snow net)

This barrier is constituted by a high tensile strength steel wire mesh that extends across the slope preventing possible creeping within the snow cover and also the sliding of the snow cover on the terrain surface. This net can also sustain the impact from toggled trees.

Infrastructure	Tree removal	Avalanche barrier
Tunnel		
Bridge		
Embankment	✓	✓
Cut	✓	✓

3.4 Extreme Hot Weather

The most usual measures for preventing or mitigate the effects of extreme hot weather phenomenon are the following:

Operation procedures

Some rail operation procedures can minimise the effect of hot temperatures in the infrastructure. A common example of these procedures is reducing to the lowest minimum possible the number of movements of points or to reduce the speed limit. This measure is taken in combination with monitoring.

Track monitoring

The installation of probes along the rail tracks allows the infrastructure operator to measure and monitor the temperature thus enabling the fixation of thresholds for alerts.

Cooling systems

The installation of cooling systems along the rail track infrastructure can actively maintain the temperature within acceptable limits. Some examples are: the installation of a sprinkler system activated

by the passing of a temperature threshold can prevent the increase of the rail temperature to unacceptable limits; or the cooling of the operation signals and other electronic equipment by the installation of fans.

Painting rails

Painting rails white reduces the amount of heat these elements can absorb thus reducing its expansion. The rail temperature of painted white rails is 5 to 10 ºC lower than an equivalent rail that has not been painted.

Slab track

The installation of the rail track on a reinforced concrete slab rather than on sleepers and ballast prevents the buckling phenomenon since tracks can sustain much higher forces.

Composite surface

The use of composite surface for road pavement can mitigate the effect of hot weather as this type of pavement does not become smooth and slick with the increasing of the temperature as the asphalt do.

Infrastructure	Operation procedures	Track monitoring	Cooling systems	Painting rails	Slab track	Composite surface
Tunnel	✓	✓	✓	✓	✓	✓
Bridge	✓	✓	✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓	✓	✓	✓

3.4.1 Bush Fire

The most usual measures for preventing or mitigate the effects of bush fire phenomenon are the following:

Vegetation management plan

The implementation of a vegetation management plan allows the planting of the most suitable vegetation and trees in accordance with the region. The existent vegetation in the vicinity of the transport infrastructure needs to be looked after, cleaned and removed if necessary since it is the primary fuel for bushfire.

Infrastructure	Vegetation management plan
Tunnel	
Bridge	✓
Embankment	✓
Cut	✓

3.4.2 Blackout

The prevention of blackouts affecting transport infrastructure is a subject of national management and therefore there is not any direct preventive measure any transport infrastructure owner or operator could undertake. Nevertheless, the most usual measure for mitigate the effects of blackout phenomenon is the following:

Power supply redundancy

This measure can be done by resorting to the redundancy of all the critical power systems of the infrastructure, namely centralized systems, with an alternative power source.

Infrastructure	Power supply redundancy
Tunnel	✓
Bridge	✓
Embankment	✓
Cut	✓

3.5 Extreme Wind and Storm

The most usual measures for preventing or mitigate the effects of extreme wind and storm phenomenon are the following:

Reinforcement of supports for OLE

The reducing of the distance between supports of the overhead line equipment increase the ability of these rail components to withstand high winds.

Vegetation management plan

The implementation of a vegetation management plan allows the planting of the most suitable vegetation and trees in accordance with the region. The removal of trees classified as “highly vulnerable” or diseased is the most effective measure for avoiding falling trees in the infrastructure or the OLE.

Track signaling

The improvement of the resilience of rail track signaling equipment to storms promotes the availability of the infrastructure operation.

Seawalls

A seawall is a coastal defense construction to protect the infrastructure from the direct impact of the sea. They may be made from a variety of materials and the three main types are vertical, curved and mound.

Steel coating

The protection of steel infrastructures from corrosion can be improved by steel coating of structural or systems elements. This procedure is especially important for infrastructures exposed to salt-water in storm risk areas.

Wind barrier

A wind barrier is a specific wall designed to prevent extreme winds from impacting the protected infrastructure and thus affecting the traffic or the ole (in the case of rails).

Infrastructure	Reinforcement of supports for OLE	Vegetation management plan	Track signaling	seawalls	Steel coating	Wind barrier
Tunnel						
Bridge	✓	✓	✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓	✓	✓	✓

3.5.1 Storm Surge

The most usual measures for preventing or mitigate the effects of storm surge phenomenon are the following:

Flood barrier

A flood barrier is a specific floodgate designed to prevent extreme flooding from occurring in the protected infrastructure.

Seawalls

A seawall is a coastal defense construction to protect the infrastructure from the direct impact of the sea. They may be made from a variety of materials and the three main types are vertical, curved and mound.

Riprap protection

Riprap material is made from a variety of rock types, commonly granite or limestone and its use around the pillars and abutments of a bridge can prevent scour, and its application on embankments construction may defend the infrastructure from water erosion.

Wind barrier

A wind barrier is a specific wall designed to prevent extreme winds from impacting the protected infrastructure and thus affecting the traffic or the ole (in the case of rails).

Infrastructure	Flood barrier	Seawalls	Riprap protection	Wind barrier
Tunnel				
Bridge	✓	✓	✓	✓
Embankment	✓	✓	✓	✓
Cut	✓	✓		✓

3.5.2 Sand storm

The most usual measures for preventing or mitigate the effects of sand storm phenomenon are the following:

Wind barrier

A wind barrier is a specific wall designed to prevent extreme winds from impacting the protected infrastructure and thus affecting the traffic or the ole (in the case of rails).

Irrigation

The irrigation of the surroundings of the infrastructure may prevent the occurrence of sand/dust storms, since this phenomenon is triggered by the lack of rain.

Infrastructure	Wind barrier	Irrigation
Tunnel		
Bridge	✓	✓
Embankment	✓	✓
Cut	✓	✓

3.5.3 Toggled trees

The most usual measures for preventing or mitigate the effects of toggled trees phenomenon are the following:

Vegetation management plan

The implementation of a vegetation management plan allows the planting of the most suitable vegetation and trees in accordance with the region. The removal of trees classified as “highly vulnerable” or diseased is the most effective measure for toggled trees hazard.

Avalanche barrier (snow net)

This barrier is constituted by a high tensile strength steel wire mesh that extends across the slope preventing possible creeping within the snow cover and also the sliding of the snow cover on the terrain surface. This net can also sustain the impact from toggled trees.

Infrastructure	Tree removal	Avalanche barrier
Tunnel		
Bridge		
Embankment	✓	✓
Cut	✓	✓

3.6 Thunderstorm

3.6.1 Lightning

The most usual measures for preventing or mitigate the effects of lighting phenomenon are the following:

Reinforcement of supports for OLE

The reducing of the distance between supports of the overhead line equipment increase the ability of these rail components to withstand high winds.

Vegetation management plan

The implementation of a vegetation management plan allows the planting of the most suitable vegetation and trees in accordance with the region. The removal of trees classified as “highly vulnerable” or diseased is the most effective measure for avoiding falling trees in the infrastructure or the OLE.

Track signaling

The improvement of the resilience of rail track signaling equipment to storms promotes the availability of the infrastructure operation.

Wind barrier

A wind barrier is a specific wall designed to prevent extreme winds from impacting the protected infrastructure and thus affecting the traffic or the ole (in the case of rails).

Lightning rod

A lightening rod is a metal rod attached to the desired protected infrastructure constituted by a copper wire connected by a conductive grid to the ground. This system conducts the electrical current of a lightning safely to the ground. This can be installed in important transport infrastructure components, such as electronic equipment, centralized systems or critical traffic signaling.

Surge protector and arrestor

The impact of a lightning strike can origin overvoltage power surge of the rail network and its varied equipment sensitive to electric damage, such as electronic switching equipment, electric traction systems and telecommunications. A surge protector or a surge arrester are systems designed to prevent the occurrence of overvoltage in the electric equipment.

Infrastructure	Reinforcement of supports for OLE	Vegetation management plan	Track signaling	Wind barrier	Lightning rod	Surge protector and arrestor
Tunnel						
Bridge	✓	✓	✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓	✓	✓	✓

3.7 Vulcanic Eruption

A vulcanic eruption is a catasthropic event that is practically impossible to mitigate effectively with the technology and knowledge at our disposal today. Therefore the hazard management emphasis is put on the monitoring and study of the active volcanoes. Nevertheless there are some bibliographical mitigation measures adopted ocasionaly for the major events derived from a vulcanic eruption like the lava flow and the ash cloud. In what concerns the other two impacts (landslide/rockfall and debris flow) one could adopt the same mitigation measures already proposed for these impacts. However the effectiveness of these measures is surely affected by the magnitude of the initial event, the vulcanic eruption.

3.7.1 Lava flow

The most usual measures for preventing or mitigate the effects of lava flow phenomenon are the following:

Lava cooling

An operation of cooling a lava flow with sea water was first attempted in 1973, in Iceland. This 3-day operation consisted in pumping sea water into the lava flow thus successful attaining the flow halt.

Channels

A channel structure can confine at least some of the lava flow material and direct it away from the protected infrastructure as well as increasing the dissipation of energy.

Earth mounds

Earth mounds are used to retard the lava by breaking up the flow and increasing the dissipation of energy.

Infrastructure	Lava cooling	Channels	Earth mounds
Tunnel	✓	✓	✓
Bridge	✓	✓	✓
Embankment	✓	✓	✓
Cut	✓	✓	✓

3.7.2 Ash cloud

The most usual measures for preventing or mitigate the effects of ash cloud phenomenon are the following:

Signaling

The improvement of the resilience of rail track or road signaling equipment to low visibility conditions promotes the availability of the infrastructure operation.

Protection of switches

The protection of rail switches can be done by the installation of concrete covers. These type of structures protect the rail equipment that is most sensitive, like points and switches. They keep the falling ash out.

Infrastructure	Signaling	Protection of switches
Tunnel	✓	✓
Bridge	✓	✓
Embankment	✓	✓
Cut	✓	✓

3.7.3 Landslide (slide/fall)

The most usual measures for preventing or mitigate the effects of landslides and rockfall phenomenon are the following:

Seismic flexible joints

Seismic flexible joints are joints especially designed to absorb large deformations due to the earthquake's forces. These elements have large movement capacity as to axial direction and rotation at joint parts.

Deep Mixing Method (DMM)

The deep-mixing method is a ground improvement thecnique that improves the characteristics of weak soils by mechanically mixing them with cementitious binder slurry. The grid pattern soil/cement mixture provides additional shear strenght for site to withstand strong ground motion.

Jet Grouting

Jet grouting is a technique that uses high pressure fluid jets to erode and mix/replace soil with grout thus forming columns or panels. This method strenghens unstable soils.

Soil nailing

Soil nailing is an earth retention technique using grouted tension-resisting steel elements, nails, which can be used to stabilize slopes and landslides.

Anchors

Anchors are stabilization and support elements that transfer tension loads using high-strength steel bars. These elements can be used to provide support and stabilization to slopes and landslides.

Diaphragm wall

Diaphragm walls are a method of creating a cast in-situ reinforced retaining wall. It is constructed in the ground using under slurry technique.

Reinforced concrete bridge piers

The reinforcement of bridge piers prevent shear failure and allows the structure (bridges) to maintain sufficient ductility.

Geotextile reinforcement

A geotextile geogrid is used to reinforce the base of an embankment since these elements are able to reach very high tensile strength. This allows the soil particles to interlock, thus providing an optimal lateral confinement to the granular soil, therefore limiting the related movements and increasing the shear resistance.

Metallic mesh draping and netting

The installation of metallic rockfall protection mesh provides a safety net where rocks can fall without hitting the infrastructure. These structures may be anchored at the top and/or at the bottom of slopes.

High Energy absorption (HEA) panels

The high energy absorption panels are structures that provide high tensile resistance while exhibiting low elongation thus ensuring that the debris accumulation will not impact directly the infrastructure.

Earthen barriers

These barriers are constructed of natural soil and rocks or mechanically stabilized earth are placed at the end of a catchment area having the capacity to absorb large impacts.

Controlled blasting

The blasting of unstable sections of rock in a controlled manner may prevent the consequences of hazardous rockfall.

Ditches and berms

The construction of a catch ditch or a berm at the toe of the slope provides an area for receiving and restraining the rockfall material. These elements reduce the energy of the falling projectile by trapping or slowing rockfalls. They should be covered by a layer of gravel in order to absorb the energy and a sturdy barrier to protect the infrastructure.

Rock bolts

The rock bolts are steel rods that are installed into holes drilled into the rock and are usually grouted and can be tensioned or not. This measure provides support to the outer surface of the slope.

Rock shed (avalanche shelter)

Rock sheds are structures installed over the infrastructure to withstand rockfalls. It provides the complete reduction in rockfall hazards over the length of the infrastructure encompassed by the rock shed.

Infrastructure	Seismic flexible joints	DMM	Jet-Grouting	Soil nailing	Anchors	Diaphragm wall	Reinforced concrete bridge piers	Geotextile reinforcement
Tunnel	✓	✓	✓	✓	✓	✓		
Bridge	✓	✓	✓	✓	✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓		
Cut	✓	✓	✓	✓	✓	✓		

Infrastructure	Metallic mesh and netting	HEA panels	Earthen barriers	Controlled blasting	Ditches berms	Rock bolts	Rock shed
Tunnel (*)							
Bridge	✓	✓	✓	✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓	✓	✓	✓	✓

(*) – Only the portals of tunnels are affected by rockfall hazards, therefore are considered to be either embankments or cut section of the road/rail ways.

3.7.3 Landslide (flow)

The most usual measures for preventing or mitigate the effects of landslides – debris flow phenomenon are the following:

Check dams

A check dam is a small dam constructed in slopes to counteract erosion by reducing the debris flow velocity. Typically they integrate a system consisting of several check dams situated at regular intervals.

Channels

A channel structure can confine the debris flow material and direct it away from the protected infrastructure.

Deflecting dyke

This type of dyke have oblique or curving walls in order to force the debris flow material to deposit in a predetermined area.

Debris flow barrier

This type of barriers are constituted by flexible ring net barriers and stop debris flow surge, strain and retain coarse debris, allowing only water and fine-grained sediment to continue downstream.

Log erosion barrier

Log erosion barrier is a log placed in a shallow trench on the contour to intercept water running down a slope and trap the sediment. This type of barrier is used in sites with high erosion rates due to wildfires and reduces the debris flow velocity for low intensity rain events.

Debris flow shelter

A debris flow shelter is a structure similar to an avalanche shelter, constructed from reinforced concrete, which constitutes a canopy over the road/rail section intended to be protected. It dissipates the energy through the granular material placed on the shelter's roof where the debris flow lands.

Debris flow bridge

This structure provides a passageway for the debris material thus preventing blockage of the flow channel and directing the material away from the infrastructure. It is used when the estimated energy from the debris flow is too high for the resource to debris flow shelter.

Infrastructure	Check dams	Channels	Deflecting dyke	Debris flow barrier	Log erosion barrier	Debris flow shelter	Debris flow bridge
Tunnel	✓	✓	✓				
Bridge	✓	✓	✓				
Embankment	✓	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓	✓	✓	✓	✓

3.8 Extreme Cold

Besides the common and obvious consequences of low temperatures there are not so perceptible impacts of this hazard. One is the freeze-thaw actions that affect rock slopes particularly those with heavily jointed configurations, thus requiring stabilization works. Additionally, extreme cold has a significant impact on road pavements. In zones where freeze-thaw cycles occur regularly, the thawing process of susceptible subgrade decreases the surface resistance modulus of the pavement structure. Moreover, water leakage and freezing temperatures can cause ice to form along the tunnel contour in the form of icicles and pillars that can damage the tunnel structure, instalations and drainage system.

The most usual measures for preventing or mitigate the effects of extreme cold phenomenon are the following:

Protection of switches

The protection of rail switches can be done by the installation of snow and ice covers. These type of structures protect the rail equipment that is most sensitive to cold weather and snow, like points and switches. They keep snow out and prevent any damage by ice falling from passing trains. They can also include a heating system.

Anchors

Anchors are stabilization and support elements that transfer tension loads using high-strength steel bars. These elements can be used to provide support and stabilization to slopes and landslides.

Rock bolts

The rock bolts are steel rods that are installed into holes drilled into the rock and are usually grouted and can be tensioned or not. This measure provides support to the outer surface of the slope.

Reinforcement of supports for OLE

The reducing of the distance between supports of the overhead line equipment increase the ability of these rail components to withstand high winds.

Vegetation management plan

The implementation of a vegetation management plan allows the planting of the most suitable vegetation and trees in accordance with the region. The removal of trees classified as “highly vulnerable” or diseased can mitigate the effect if low adhesion associated with cold days and fallen leaves.

Subgrade materials of road pavements

The improvement of resilience of the subgrade materials to the thawing process reduces its negative impacts that may vary from cracking to the pavement structural failure.

Secondary lining

In tunnels with no secondary lining the best protection against water-related hazards, like icicles formation due to extreme cold, is the installation of a secondary lining that will completely waterproof the structure.

Secondary lining injection

The injection of the secondary lining in tunnels has the goal to avoid groundwater percolation by improving the coating and waterproofing system. The injection can be made with grout, sprayed concrete or specific products like resin.

Infrastructure	Protection of switches	Anchors	Rock bolts	Reinforcement of supports for OLE	Vegetation management plan	Subgrade materials of road pavements	Secondary lining	Secondary lining injection
Tunnel	✓					✓	✓	✓
Bridge	✓			✓	✓	✓		
Embankment	✓	✓	✓	✓	✓	✓		
Cut	✓	✓	✓	✓	✓	✓		

3.8.1 Ice storm

The most usual measures for preventing or mitigate the effects of ice storm phenomenon are the following:

Protection of switches

The protection of rail switches can be done by the installation of snow and ice covers. These type of structures protect the rail equipment that is most sensitive to cold weather and snow, like points and switches. They keep snow out and prevent any damage by ice falling from passing trains. They can also include a heating system.

Reinforcement of supports for OLE

The reducing of the distance between supports of the overhead line equipment increase the ability of these rail components to withstand high winds.

Multi-purpose vehicle

The use of this type of vehicles is common in the rail infrastructure with the purpose of de-icing the infrastructure. This type of vehicles are fitted with snow ploughs, hot-air blowers, steam jets, brushes, etc.

Vegetation management plan

The implementation of a vegetation management plan allows the planting of the most suitable vegetation and trees in accordance with the region. The removal of trees classified as “highly vulnerable” or diseased can mitigate the effect if low adhesion associated with cold days and fallen leaves.

Secondary lining

In tunnels with no secondary lining the best protection against water-related hazards, like icicles formation due to extreme cold, is the installation of a secondary lining that will completely waterproof the structure.

Anti-icing/deicing chemicals

The use of anti-icing/deicing chemicals on road pavements prevents snow and ice from bonding to the pavement surface. This practice is implemented before the hazard impact and can improve service levels as well as reduces the infrastructure maintenance costs.

Infrastructure	Protection of switches	Reinforcement of supports for OLE	Multi-purpose vehicle	Vegetation management plan	Secondary lining	Anti-icing/deicing chemicals
Tunnel	✓		✓		✓	✓
Bridge	✓	✓	✓	✓		✓
Embankment	✓	✓	✓	✓		✓
Cut	✓	✓	✓	✓		✓

3.9 Hail

The most usual measures for preventing or mitigate the effects of hail phenomenon are the following:

Pavement protection

The durability of road pavement can be improved by the use of steel coating process thus preventing the infrastructure failure.

Drainage system

A drainage system may comprise several different types of components such as gutters, inlet boxes, pipes, spillways, energy dissipaters, and its main purpose is to collect water and dispose it in the most appropriate points therefore preventing the impacts that the free water flow would sustain to the infrastructure and/or its traffic.

Protection of switches

The protection of rail switches can be done by the installation of snow and ice covers. These type of structures protect the rail equipment that is most sensitive to cold weather and snow, like points and switches. They keep ice and hail out.

Infrastructure	Pavement protection	Drainage system	Protection of switches
Tunnel			
Bridge	✓	✓	✓
Embankment	✓	✓	✓
Cut	✓	✓	✓

3.10 Various continous processes

3.10.1 Landslide (slide/fall)

The most usual measures for preventing or mitigate the effects of landslides and rockfall phenomenon are the following:

Seismic flexible joints

Seismic flexible joints are joints especially designed to absorb large deformations due to the earthquake's forces. These elements have large movement capacity as to axial direction and rotation at joint parts.

Deep Mixing Method (DMM)

The deep-mixing method is a ground improvement thecnique that improves the characteristics of weak soils by mechanically mixing them with cementitious binder slurry. The grid pattern soil/cement mixture provides additional shear strenght for site to withstand strong ground motion.

Jet Grouting

Jet grouting is a technique that uses high pressure fluid jets to erode and mix/replace soil with grout thus forming columns or panels. This method strenghens unstable soils.

Soil nailing

Soil nailing is an earth retention technique using grouted tension-resisting steel elements, nails, which can be used to stabilize slopes and landslides.

Anchors

Anchors are stabilization and support elements that transfer tension loads using high-strength steel bars. These elements can be used to provide support and stabilization to slopes and landslides.

Diaphragm wall

Diaphragm walls are a method of creating a cast in-situ reinforced retaining wall. It is constructed in the ground using under slurry technique.

Reinforced concrete bridge piers

The reinforcement of bridge piers prevent shear failure and allows the structure (bridges) to maintain sufficient ductility.

Geotextile reinforcement

A geotextile geogrid is used to reinforce the base of an embankment since these elements are able to reach very high tensile strength. This allows the soil particles to interlock, thus providing an optimal lateral confinement to the granular soil, therefore limiting the related movements and increasing the shear resistance.

Metallic mesh draping and netting

The installation of metallic rockfall protection mesh provides a safety net where rocks can fall without hitting the infrastructure. These structures may be anchored at the top and/or at the bottom of slopes.

High Energy absorption (HEA) panels

The high energy absorption panels are structures that provide high tensile resistance while exhibiting low elongation thus ensuring that the debris accumulation will not impact directly the infrastructure.

Earthen barriers

These barriers are constructed of natural soil and rocks or mechanically stabilized earth are placed at the end of a catchment area having the capacity to absorb large impacts.

Controlled blasting

The blasting of unstable sections of rock in a controlled manner may prevent the consequences of hazardous rockfall.

Ditches and berms

The construction of a catch ditch or a berm at the toe of the slope provides an area for receiving and restraining the rockfall material. These elements reduce the energy of the falling projectile by trapping or slowing rockfalls. They should be covered by a layer of gravel in order to absorb the energy and a sturdy barrier to protect the infrastructure.

Rock bolts

The rock bolts are steel rods that are installed into holes drilled into the rock and are usually grouted and can be tensioned or not. This measure provides support to the outer surface of the slope.

Rock shed (avalanche shelter)

Rock sheds are structures installed over the infrastructure to withstand rockfalls. It provides the complete reduction in rockfall hazards over the length of the infrastructure encompassed by the rock shed.

Infrastructure	Seismic flexible joints	DMM	Jet-Grouting	Soil nailing	Anchors	Diaphragm wall	Reinforced concrete bridge piers	Geotextile reinforcement
Tunnel	✓	✓	✓	✓	✓	✓		
Bridge	✓	✓	✓	✓	✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓		
Cut	✓	✓	✓	✓	✓	✓		

Infrastructure	Metallic mesh and netting	HEA panels	Earthen barriers	Controlled blasting	Ditches berms	Rock bolts	Rock shed
Tunnel (*)							
Bridge	✓	✓	✓	✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓	✓	✓	✓	✓

(*) – Only the portals of tunnels are affected by rockfall hazards, therefore are considered to be either embankments or cut section of the road/rail ways.

3.10.2 Ground subsidence

The most usual measures for preventing or mitigate the effects of ground subsidence phenomenon are the following:

Flood barrier

A flood barrier is a specific floodgate designed to prevent extreme flooding from occurring in the protected infrastructure.

Drainage system

A drainage system may comprise several different types of components such as gutters, inlet boxes, pipes, spillways, energy dissipaters, and its main purpose is to collect water and dispose it in the most appropriate points therefore preventing the impacts that the free water flow would sustain to the infrastructure and/or its traffic.

Vegetation

The use of deep-rooting vegetation in slopes promotes the removal of water and prevents surface erosion by limiting the processes of sheet wash and overland flow.

Protective Wall

A protective wall (constructed with rock, gabions, concrete, piles, etc) can prevent slopes from suffering surface erosion due to flooding events.

Levee

Levees are a method of river flood control that consists of earthen embankments built between the river and the protected infrastructure.

Floodway

Floodways are dedicated pathways to divert floodwaters into topographical depressions near the river and are controlled by hydraulic structures that capture the overbank floodwaters.

Dyke

Dykes are protective structures, usually with a trapezoidal cross-section, erected from earthen material along a watercourse to prevent overflow of high waters.

Seawalls

A seawall is a coastal defense construction to protect the infrastructure from the direct impact of the sea. They may be made from a variety of materials and the three main types are vertical, curved and mound.

Infrastructure	Flood barrier	Drainage system	Vegetation	Protective wall	Levee	Floodway	Dyke	Seawall
Tunnel	✓	✓			✓	✓	✓	✓
Bridge	✓	✓			✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓	✓	✓	✓	✓	✓

3.11 Animals crossings

The most usual measures for preventing or mitigate the effects of animals crossing phenomenon are the following:

Wildlife crossing

A wildlife crossing is a structure that allows animals to cross transport infrastructures safely for them and for the traffic. These structures can be underpass tunnels, viaducts and overpasses and are usually closed by channeling fences.

Infrastructure	Wildlife crossing
Tunnel	
Bridge	✓
Embankment	✓
Cut	✓

4. Preventive and mitigation measures for man-made hazards

4.1 Introduction

The man-made hazards considered are the ones presented in the chapter 2 (*Hazards and security threats to road and rail infrastructure*) of the All-Hazard Guide for Transport Infrastructure, and that are listed in the next table.

Man-made Initial Event	Hazard
Various intentional actions	Blockade
	Theft
	Sabotage
Various intentional/unintentional actions	Ramming
	Explosion
	Landslide (slide/fall)
	Avalanche
	Fire
	Flood
	Intense water front
	Hazardous release
	Blackout
	Ground subsidence
	Excessive vehicle weight/height

4.1 Blockade

The most usual measures for preventing or mitigate the effects of blockade phenomenon are the following:

Police and Security Services

This measure consists on control and monitoring by police or security services, done with patrols, helicopter observations, presence, or other type of intervention.

Infrastructure	Police and Security Services
Tunnel	✓
Bridge	✓
Embankment	✓
Cut	✓

4.2. Theft

The most usual measures for preventing or mitigate the effects of theft phenomenon are the following:

Police and Security Services

This measure consists on control and monitoring by police or security services, done with patrols, helicopter observations, presence, or other type of intervention.

Architectural Measures

This measure consists on avoiding the existence of hiding places, corners or other shapes where objects or persons can be placed or hidden (such as shelves, windows gratings, etc.).

Access and approach restriction

Access and approach restriction are measures intending access restriction and consists on the implementation of signs, fences, doors or barriers that are able to prevent access and approach to the infrastructure.

Infrastructure	Police and Security Services	Architectural Measures	Access and approach prevention
Tunnel	✓	✓	✓
Bridge	✓	✓	✓
Embankment	✓		✓
Cut	✓		✓

4.3. Sabotage

The most usual measures for preventing or mitigate the effects of sabotage phenomenon are the following:

Police and Security Services

This measure consists on control and monitoring by police or security services, done with patrols, helicopter observations, presence, or other type of intervention.

Architectural Measures

This measure consists on avoiding the existence of hiding places, corners or other shapes where objects or persons can be placed or hidden (such as shelves, windows gratings, etc.).

Access and approach restriction

Access and approach restriction are measures intending access restriction and consists on the implementation of signs, fences, doors or barriers that are able to prevent access and approach to the infrastructure.

Parking Prevention

This measure consists on preventing vehicles from parking at specific locations nearby the infrastructure (for example, under a bridge or by a tunnel's entrance). This could be done by the means of signs, fences or barriers. This measure reduces the feasibility of an attack in the first place, but it also prevents the potential damage for relevant threats.

Preventing Disposal/Storage of Waste Materials

This measure has the goal of preventing the disposal and storage of waste materials in order to reduce the feasibility of an attack but also the damage potential. This could be done by implementing signs, barriers or fences.

Infrastructure	Architectural Measures	Police and Security Services	Access and approach prevention	Preventing Disposal/Storage of Waste Materials	Parking Prevention
Tunnel	✓	✓	✓	✓	✓
Bridge	✓	✓	✓	✓	✓
Embankment		✓			
Cut		✓			

4.4. Ramming

The most usual measures for preventing or mitigate the effects of ramming phenomenon are the following:

Structural Reinforcement

This measure consists on using high performance materials on structural elements that can resist to high loads (as ramming or explosion). The uses of micro-reinforced or high performance concrete are examples that could be used on bridge structures.

Collision Protection

Consists on barriers (steel or concrete) placed in front of structural elements in order to redirect the vehicle and reduce its impact intensity.

Collision Prevention

Consists on rail barriers (steel or concrete) used to redirect vehicles away from a structural element.

Infrastructure	Structural Reinforcement	Collision Protection	Collision Prevention
Tunnel	✓	✓	✓
Bridge	✓	✓	✓
Embankment	✓		
Cut	✓		

4.5. Explosion

The most usual measures for preventing or mitigate the effects of explosion phenomenon are the following:

Police and Security Services

This measure consists on control and monitoring by police or security services, done with patrols, helicopter observations, presence, or other type of intervention.

Gas detection

This measure relies on the installation of devices on the infrastructure capable of identifying the presence and/or leaking of gases that can potentially start an explosion.

Structural Reinforcement

This measure consists on using high performance materials on structural elements that can resist to high loads (as ramming or explosion). The uses of micro-reinforced or high performance concrete are examples that could be used on bridge structures.

Parking Prevention

This measure consists on preventing vehicles from parking at specific locations nearby the infrastructure (for example, under a bridge or by a tunnel's entrance). This could be done by the means of signs, fences

or barriers. This measure reduces the feasibility of an attack in the first place, but it also prevents the potential damage for relevant threats.

Preventing Disposal/Storage of Waste Materials

This measure has the goal of preventing the disposal and storage of waste materials in order to reduce the feasibility of an attack but also the damage potential. This could be done by implementing signs, barriers or fences.

Increase of Safety Height

This measure consists on securing a distance of safety between a bridge deck and the ground beneath.

Limiting Load's Nature

This measure can be employed by the means of signalization and/or devices, placed at certain points of the transport infrastructure, capable of identifying the load's nature. This way, vehicles carrying dangerous substances, whose release/leak (due to accident, for example) could provoke a fire, an explosion or damaging the pavement conditions for transportation.

Infrastructure	Police and Security Services	Gas Detection	Structural Reinforcement	Parking Prevention	Increase of Safety Height
Tunnel	✓	✓	✓	✓	
Bridge	✓		✓	✓	✓
Embankment	✓				
Cut	✓				

Infrastructure	Preventing Disposal/Storage of Waste Materials	Limiting Load's Nature
Tunnel	✓	✓
Bridge	✓	✓
Embankment		✓
Cut		✓

4.6. Landslide (Slide/Fall)

The most usual measures for preventing or mitigate the effects of landslide and rockfall phenomenon are the following:

Seismic flexible joints

Seismic flexible joints are joints especially designed to absorb large deformations due to the earthquake's forces. These elements have large movement capacity as to axial direction and rotation at joint parts.

Deep Mixing Method (DMM)

The deep-mixing method is a ground improvement thecnique that improves the characteristics of weak soils by mechanically mixing them with cementitious binder slurry. The grid pattern soil/cement mixture provides additional shear strenght for site to withstand strong ground motion.

Jet Grouting

Jet grouting is a technique that uses high pressure fluid jets to erode and mix/replace soil with grout thus forming columns or panels. This method strenghens unstable soils.

Soil nailing

Soil nailing is an earth retention technique using grouted tension-resisting steel elements, nails, which can be used to stabilize slopes and landslides.

Anchors

Anchors are stabilization and support elements that transfer tension loads using high-strength steel bars. These elements can be used to provide support and stabilization to slopes and landslides.

Diaphragm wall

Diaphragm walls are a method of creating a cast in-situ reinforced retaining wall. It is constructed in the ground using under slurry technique.

Reinforced concrete bridge piers

The reinforcement of bridge piers prevent shear failure and allows the structure (bridges) to maintain sufficient ductility.

Geotextile reinforcement

A geotextile geogrid is used to reinforce the base of an embankment since these elements are able to reach very high tensile strength. This allows the soil particles to interlock, thus providing an optimal lateral confinement to the granular soil, therefore limiting the related movements and increasing the shear resistance.

Metallic mesh draping and netting

The installation of metallic rockfall protection mesh provides a safety net where rocks can fall without hitting the infrastructure. These structures may be anchored at the top and/or at the bottom of slopes.

High Energy absorption (HEA) panels

The high energy absorption panels are structures that provide high tensile resistance while exhibiting low elongation thus ensuring that the debris accumulation will not impact directly the infrastructure.

Earthen barriers

These barriers are constructed of natural soil and rocks or mechanically stabilized earth are placed at the end of a catchment area having the capacity to absorb large impacts.

Controlled blasting

The blasting of unstable sections of rock in a controlled manner may prevent the consequences of hazardous rockfall.

Ditches and berms

The construction of a catch ditch or a berm at the toe of the slope provides an area for receiving and restraining the rockfall material. These elements reduce the energy of the falling projectile by trapping or slowing rockfalls. They should be covered by a layer of gravel in order to absorb the energy and a sturdy barrier to protect the infrastructure.

Rock bolts

The rock bolts are steel rods that are installed into holes drilled into the rock and are usually grouted and can be tensioned or not. This measure provides support to the outer surface of the slope.

Rock shed (avalanche shelter)

Rock sheds are structures installed over the infrastructure to withstand rockfalls. It provides the complete reduction in rockfall hazards over the length of the infrastructure encompassed by the rock shed.

Infrastructure	Seismic flexible joints	DMM	Jet-Grouting	Soil nailing	Anchors	Diaphragm wall	Reinforced concrete bridge piers	Geotextile reinforcement
Tunnel	✓	✓	✓	✓	✓	✓		
Bridge	✓	✓	✓	✓	✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓		
Cut	✓	✓	✓	✓	✓	✓		

Infrastructure	Metallic mesh and netting	HEA panels	Earthen barriers	Controlled blasting	Ditches berms	Rock bolts	Rock shed
Tunnel (*)							
Bridge	✓	✓	✓	✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓	✓	✓	✓	✓

(*) – Only the portals of tunnels are affected by rockfall hazards, therefore are considered to be either embankments or cut section of the road/rail ways

4.7. Avalanche

The most usual measures for preventing or mitigate the effects of avalanche phenomenon are the following:

Controlled blasting

The blasting involves the artificial triggering of smaller less destructive avalanches by detonating charges either above or on the snow surface.

Snow shed

A snow shed or avalanche gallery is a type of rigid-support structure for snow defense that promotes the passage in areas susceptible to avalanche hazards. This structure can either be fully closed, as an artificial tunnel, or consisting of framework elements.

Avalanche barrier (snow net)

This barrier is constituted by a high tensile strength steel wire mesh that extends across the slope preventing possible creeping within the snow cover and also the sliding of the snow cover on the terrain surface.

Braking mound

Braking mounds are used to retard the avalanche by breaking up the flow and increasing the dissipation of energy.

Snow fence

A snow fence is a type of fence used to accumulate windblown and drifting snow in a desired place. This can mitigate the effect of avalanche hazard by collecting snow that would otherwise be carried away thus decreasing the volume and the impact of the avalanche.

Snow deflection structures

A snow deflection structure is used to deflect and confine the moving snow within the avalanche track. It can either be earth fill structures or made by reinforced concrete and re-direct avalanches from the paths affecting the protected infrastructures.

Avalanche protection dam

An avalanche protection dam can either be a deflecting dam, used to divert avalanches away from the infrastructure at risk, or catching dam, intended to stop the avalanche completely before it reaches the infrastructure. Usually both these structures are used in combination.

Afforestation

The preservation and protection of forests can mitigate the impact of avalanches since forests fulfil all the functions of artificial avalanche defenses: retention, redistribution, retardation and catchment.

Infrastructure	Controlled blasting	Snow shed	Avalanche barrier	Braking mounds	Snow fence	Snow deflection structure	Avalanche protection dam	Afforestation
Tunnel	✓		✓	✓			✓	✓
Bridge	✓		✓	✓			✓	✓
Embankment	✓	✓	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓	✓	✓	✓	✓	✓

4.8. Fire

The most usual measures for preventing or mitigate the effects of fire phenomenon are the following:

Gas detection

This measure relies on the installation of devices on the infrastructure capable of identifying the presence and/or leaking of gases that can potentially start a fire.

Fixed Firefighting Systems

Fixed firefighting systems consist on firefighting equipment which is permanently attached to the tunnel, consisting of a piping system with a fixed supply of water or extinguishing agent (such as a sprinkler, deluge and mist systems).

Fire Resistance Concrete

This type of concrete includes the addition of polypropylene fibers (PP), the use of selected aggregates, maximum aggregated size limit or a mesh reinforcement to reduce spalling.

Fire Protection Cladding

This method consists on covering hard materials with a substance (spray or paint) that can provide fire protection to those.

Closer Emergency Exits

This measure consists on reducing the space between emergency exists in order to reduce the damage extend.

Smoke Exhaust System

Smoke exhaust system consist on devices capable of ventilating the smoke produced by a fire. By clearing the smoke from the infrastructure, this measure can enhance the visibility during a fire occurrence inside a tunnel having, then, a positive impact on the operability of the asset. This measure also diminishes the exposure of the users to the inhalation of potentially dangerous smokes.

Increase of Safety Height

This measure consists on securing a distance of safety between a bridge deck and the ground beneath.

Parking Prevention

This measure consists on preventing vehicles from parking at specific locations nearby the infrastructure (for example, under a bridge or by a tunnel's entrance). This could be done by the means of signs, fences or barriers. This measure reduces the feasibility of an attack in the first place, but it also prevents the potential damage for relevant threats.

Preventing Disposal/Storage of Waste Materials

This measure has the goal of preventing the disposal and storage of waste materials in order to reduce the feasibility of an attack but also the damage potential. This could be done by implementing signs, barriers or fences.

Limiting Load's Nature

This measure can be employed by the means of signalization and/or devices, placed at certain points of the transport infrastructure, capable of identifying the load's nature. This way, vehicles carrying dangerous substances, whose release/leak (due to accident, for example) could provoke a fire, an explosion or damaging the pavement conditions for transportation.

Infrastructure	Gas Detection	Fixed Firefighting Systems	Fire Resistance Concrete	Fire Protection Cladding	Closer Emergency Exit Spacing
Tunnel	✓	✓	✓	✓	✓
Bridge		✓	✓	✓	
Embankment					
Cut					

Infrastructure	Smoke Exhaust System	Increase of Safety Height	Parking Prevention	Fixed Firefighting Systems	Preventing Disposal/Storage of Waste Materials	Limiting Load's Nature
Tunnel	✓		✓	✓	✓	✓
Bridge		✓	✓	✓	✓	✓
Embankment						✓
Cut						✓

4.9. Flood

The most usual measures for preventing or mitigate the effects of flood phenomenon are the following:

Flood barrier

A flood barrier is a specific floodgate designed to prevent extreme flooding from occurring in the protected infrastructure.

Flow deflector

The installation of a "V" shaped flow deflector on or immediately upstream the piers and abutments can redirect the flow velocities thus protecting footings and pillars from scouring.

Drainage system

A drainage system may comprise several different types of components such as gutters, inlet boxes, pipes, spillways, energy dissipaters, and its main purpose is to collect water and dispose it in the most appropriate points therefore preventing the impacts that the free water flow would sustain to the infrastructure and/or its traffic.

Riprap protection

Riprap material is made from a variety of rock types, commonly granite or limestone and its use around the pillars and abutments of a bridge can prevent scour, and its application on embankments construction may defend the infrastructure from water erosion.

Vegetation

The use of deep-rooting vegetation in slopes promotes the removal of water and prevents surface erosion by limiting the processes of sheet wash and overland flow.

Protective Wall

A protective wall (constructed with rock, gabions, concrete, piles, etc) can prevent slopes from suffering surface erosion due to flooding events.

Levee

Levees are a method of river flood control that consists of earthen embankments built between the river and the protected infrastructure.

Floodway

Floodways are dedicated pathways to divert floodwaters into topographical depressions near the river and are controlled by hydraulic structures that capture the overbank floodwaters.

Dyke

Dykes are protective structures, usually with a trapezoidal cross-section, erected from earthen material along a watercourse to prevent overflow of high waters.

Infrastructure	Flood barrier	Flow deflector	Drainage system	Riprap protection	Vegetation	Protective wall	Levee	Flood way	Dyke
Tunnel	✓		✓				✓	✓	✓
Bridge	✓	✓	✓	✓			✓	✓	✓
Embankment	✓		✓	✓	✓	✓	✓	✓	✓
Cut	✓		✓		✓	✓	✓	✓	✓

4.10. Intense Water Front

The most usual measures for preventing or mitigate the effects of intense water front phenomenon are the following:

Flood barrier

A flood barrier is a specific floodgate designed to prevent extreme flooding from occurring in the protected infrastructure.

Protective fenders for bridge piers

A fender is a protection system that can be developed to prevent, redirect or reduce the impact loads on bridge elements to non-destructive elements.

Flow deflectors

The installation of a "V" shaped flow deflector on or immediately upstream the piers and abutments can redirect the flow velocities thus protecting footings and pillars from scouring.

Deep foundations

An infrastructure has deep foundations when they are installed at a deeper depth below ground surface. This renders the infrastructure less vulnerable to the potential effects of scour.

Seawalls

A seawall is a coastal defense construction to protect the infrastructure from the direct impact of the sea. They may be made from a variety of materials and the three main types are vertical, curved and mound.

Riprap protection

Riprap material is made from a variety of rock types, commonly granite or limestone and its use around the pillars and abutments of a bridge can prevent scour, and its application on embankments construction may defend the infrastructure from water erosion.

Geosynthetic reinforcement

Geosynthetic materials are manufactured from polyester or polypropylene and have high-strength and durability being commonly used to reinforce earth structures. This reinforcement can reduce the impact of water erosion in embankments.

Coastal Vegetation

The existence of coastal vegetation works as a natural barrier and can effectively prevent the spread of tsunamis as well as mitigate the flood and surge of water.

Infrastructure	Flood barrier	Protective fender	Flow deflector	Deep foundations	Seawalls	Riprap protection	Geosynthetic reinforcement	Coastal vegetation
Tunnel					✓			✓
Bridge	✓	✓	✓	✓	✓	✓		✓
Embankment	✓	✓	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓		✓	✓		✓

4.11. Hazardous Release

The most usual measures for preventing or mitigate the effects of hazardous release phenomenon are the following:

Closer Emergency Exists

This measure consists on reducing the space between emergency exists in order to reduce the damage extend.

Preventing Disposal/Storage of Waste Materials

This measure has the goal of preventing the disposal and storage of waste materials in order to reduce the feasibility of an attack but also the damage potential. This could be done by implementing signs, barriers or fences.

Limiting Load's Nature

This measure can be employed by the means of signalization and/or devices, placed at certain points of the transport infrastructure, capable of identifying the load's nature. This way, vehicles carrying dangerous substances, whose release/leak (due to accident, for example) could provoke a fire, an explosion or damaging the pavement conditions for transportation.

Infrastructure	Traffic Redundancy	CCTV	Closer Emergency Exits Spacing	Preventing Disposal/Storage of Waste Materials	Limiting Load's Nature
Tunnel	✓	✓	✓	✓	✓
Bridge	✓	✓		✓	✓
Embankment	✓	✓			✓
Cut	✓	✓			✓

4.12. Blackout

The prevention of blackouts affecting transport infrastructure is a subject of national management and therefore there is not any direct preventive measure any transport infrastructure owner or operator could undertake. Nevertheless, the most usual measure for mitigate the effects of blackout phenomenon is the following:

Power supply redundancy

This measure can be done by resorting to the redundancy of all the critical power systems of the infrastructure, namely centralized systems, with an alternative power source.

Infrastructure	Power supply redundancy
Tunnel	✓
Bridge	✓
Embankment	✓
Cut	✓

4.13. Ground Subsidence

The most usual measures for preventing or mitigate the effects of ground subsidence phenomenon are the following:

Flood barrier

A flood barrier is a specific floodgate designed to prevent extreme flooding from occurring in the protected infrastructure.

Drainage system

A drainage system may comprise several different types of components such as gutters, inlet boxes, pipes, spillways, energy dissipaters, and its main purpose is to collect water and dispose it in the most appropriate points therefore preventing the impacts that the free water flow would sustain to the infrastructure and/or its traffic.

Vegetation

The use of deep-rooting vegetation in slopes promotes the removal of water and prevents surface erosion by limiting the processes of sheet wash and overland flow.

Protective Wall

A protective wall (constructed with rock, gabions, concrete, piles, etc) can prevent slopes from suffering surface erosion due to flooding events.

Levee

Levees are a method of river flood control that consists of earthen embankments built between the river and the protected infrastructure.

Floodway

Floodways are dedicated pathways to divert floodwaters into topographical depressions near the river and are controlled by hydraulic structures that capture the overbank floodwaters.

Dyke

Dykes are protective structures, usually with a trapezoidal cross-section, erected from earthen material along a watercourse to prevent overflow of high waters.

Seawalls

A seawall is a coastal defense construction to protect the infrastructure from the direct impact of the sea. They may be made from a variety of materials and the three main types are vertical, curved and mound.

Infrastructure	Flood barrier	Drainage system	Vegetation	Protective wall	Levee	Floodway	Dyke	Seawall
Tunnel	✓	✓			✓	✓	✓	✓
Bridge	✓	✓			✓	✓	✓	✓
Embankment	✓	✓	✓	✓	✓	✓	✓	✓
Cut	✓	✓	✓	✓	✓	✓	✓	✓

4.14. Excessive vehicle weight/height

The most usual measures for preventing or mitigate the effects of excessive vehicle weight/height phenomenon are the following:

Loading Gauge

A loading gaugue is physical structure incorporating devices, sometimes using electronic detectors using light beams on an arm or gantry placed at the entry point to a restricted part of a network in order to detected if a vehicle surpasses the size/weight limit imposed for an asset.

Infrastructure	Loading Gauge
Tunnel	✓
Bridge	✓
Embankment	
Cut	

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