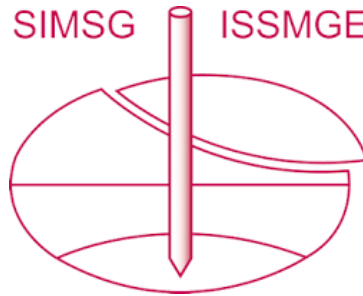


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Embankment stability works with quick solutions to improve resilience in roadway infrastructures

La stabilité du remblai fonctionne avec des solutions rapides pour améliorer la résilience dans les infrastructures routières

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ABSTRACT: This communication analyses the latest experiences in slope and foundation drainage, and runoff water management to improve resilience in roadway infrastructures. The actions resulted from temporary rain and adverse weather conditions during the months of January and February 2010 and 2016, which caused singular damage to several road slopes in Northern Spain. The objective of the repair was to restore road safety and road stability. With regard to the drainage of slopes and foundations, the action carried out on the slope of the A-8 motorway includes its stabilization by Biological Engineering. All the actions presented in this article have proven to be valid throughout the last year of road operation.

RÉSUMÉ : Cette communication analyse les dernières expériences en matière de drainage des pentes et des fondations, ainsi que la gestion de l'eau de ruissellement afin d'améliorer la résilience des infrastructures routières. Ces mesures ont été prises en raison du pluies temporaires et de conditions météorologiques défavorables au cours des mois de janvier et février 2010 et 2016, qui ont causé des dommages singuliers à plusieurs pentes de routes dans le nord de l'Espagne. L'objectif de la réparation était de rétablir la sécurité et la stabilité routière. En ce qui concerne la drainage des pentes et des fondations, l'action menée sur la pente de l'autoroute A-8 comprend sa stabilisation par génie biologique. Toutes les actions présentées dans cet article se sont avérées valables tout au long de la dernière année d'exploitation routière.

Mots-clés : résilience, infrastructures routières, remblai stabilité solutions

KEYWORDS: resilience, roadway, infrastructures, embankment stability works, climate change

1 INTRODUCTION

Cantabria region in the north of Spain has 5321 km². Basically, Cantabria region supports two different climatic zones, temperate oceanic climate (Cfb) and warm-summer Mediterranean climate (Csb).

Spanish Government by its Ministry for Transports, Mobility and Urban Agenda and its Spanish Road Directorate owns 600km of strategic roads in Cantabria region, giving access to the main health, tourism, and commerce services.

Strong weather, extreme events and climate change have resulted in cross-sectorial impacts mainly on some road assets, as slopes. So, in recent years, road manager has experienced the need for an increasing number of emergency actions in this strategic transport network.

In Spain, 45% of the main network and 4% of the total length is somehow impacted by climate (CEDEX, 2018). But this region is no exception, various studies state the increasing impacts related to weather in infrastructures, both extreme events and slow-onset processes. Road transport infrastructures are not an exception, finding that several assets are becoming more vulnerable to climate change all over the world (Alonso & Parra 2022). Climate hazards, impacts and cascading effects are a growing problem that worries the scientific community and governments all over the world.

So, this communication exposes and analyzes some of the latest experiences, applications and research projects relate to increasing resilience and sustainability on Cantabria's roads.

2 CLIMATE CHANGE AND RELATED EFFECTS

Climate change and its cascading effects are usually associated with heavy rains, hail, snow and ice, heavy winds, quick changes in temperatures, high temperatures, sea level rising or rise in rivers level swelling, permanent flooding are some extreme events, among others. All this frequently leads to insufficient capacity of the drainage systems and causes, among others, landslides, rock falls, slopes erosion, embankments, rutting and damage on pavements, foundations descaling, pillars damages, undermining of piers and contention works. This causes socioeconomic losses, traffic disruptions, travel delays and affects the functional and physical conditions of the road, hindering transport connections and its society service that ensure access, mobility and competitiveness from all social sectors. Main socioeconomic impacts will be identify too. Some of them are related to economic losses but also to traffic injuries and deaths due to accidents on the road caused by unexpected situations on the road and loss of vehicle control in unfavorable weather conditions that limit road safety features and can lead to concentration of dangerous spots in areas where driver's expectations are not kept (Alonso, Alonso, Esteban & Calatayud 2013, Alonso 2015). And it is that, simultaneously with the emergence of new paradigms and challenges, in a scenario where new multi-objective approaches are handled in the field of transport from a holistic point of view (Nicolosi et al 2019) recurring issues persist.

So, road transport infrastructures are essential elements in the transport network of a country, both economically and

socially, as they allow the flow of freight and people throughout the territory. In addition, the high construction and maintenance costs involved, as well as its long design life, must be taken into account (Parra & Sánchez 2018).

Within the framework of the working group dedicated to climate change and road resilience of Spanish Roads Association, a methodology is being worked on to analyze and evaluate resilience of roads to these climatic hazards. And precisely, it has begun with the pilot case of Cantabria network, due to its uniqueness and experiences in earthworks and taking into account that significant changes in temperatures and rainfall are expected in this region (Gutiérrez et al 2010, Losada et al 2014). This group must identify roads related with all the levels of resilience of the region. And conclusion of this work will help and allow an informed and more efficient decision making in the future (Alonso & Parra 2022). Nevertheless, studies must be updated taking into account the RCP scenarios and covering the lack of information at fine scale resolution.

Over the last few years, technicians of Spanish Road Directorate in the region have identified through their expert judgment those elements most exposed and count with a wide experience in preventive maintenance and emergency actions. Different mitigation and adaptation measures are used, but they need some support for updating and recording data, as all experiences need to be documented. Assets inventories have great room for improvement to facilitate information management. And, to help implementation in the future of monitoring, new measures, awareness, sharing information with end users to contribute transparency and dissemination to facilitate ultimately civil society engagement as last European policies are looking for.

The EU strongly encourages climate information to be reflected in climate indices that are useful in the decision-making process in different activities (energy, agriculture, housing, transport, etc.). In doing so, the so-called climate services are of great interest. Climate services are web applications where users can obtain climate information adapted to their needs.

In this sense, the CLARITY project, financed under the EU's H2020 program, has developed a climate service (CSIS) that hosts an online tool for risk assessment in urban and transport infrastructure, providing projections of the climate variables that have been considered more representative of the potential threats to both cities and roads (Parra 2021).

3 ACTIONS

The main actions carried out to adapt the roads to the effects of climate change have been due to the need to respond to extreme weather conditions in Winter. From 2011 to 2018, cantabrian roads suffered several damages and soil erosion due to continuous extreme precipitation, wind and snow. The damages were repaired by emergency civil Works to restore road and pedestrian safety returning its society service (Collazos et al 2017, Collazos et al 2022). Storms from 2011 and 2018 resulted in numerous complications in the environment and on the road that runs through Cantabria.

Learned lessons are based on recent years gained experience, with successful practical actions implemented to solve problems occurred, new means of prevention of emerging risks and increase of road's resilience within the operation phase.

Historical recorded information allows road manager to analyze benefits and motivate the costs of extreme weather events and climate impacts, with advantages for future decision making (Collazos, Parra & Alonso 2022).

In recent years, three main types of problems have been identified: slopes stability, traffic interruption due to flooding and settlement and overturning of walls.

We will focus on the three problems, and specifically on the action carried out on the slope of the A-8 motorway including its stabilization by Biological Engineering.

3.1 The problems to be solved

The problem to be solved of management of runoff water, is that of the currents of water that appear after a heavy downpour or in the event of avalanche or thaw fall on the road in the form of a waterfall from the escarpments that border the road, which stop or at least hinder the circulation of the vehicles (Figure 1).



Figure 1. Situation of PK 158,140 MI produced by heavy rains on rocky slope (upstream) without acting.



Figure 2 Situation in the road N-621 produced after intense rains with stone falling.

A multitude of karst caves exist, which when episodes as the ones described above take place are filled with water to the maximum and produce impressive waterfalls on the national road. In addition to the waterfalls stones are continuously falling: on average 50 stones are counted in a day in the stretch of the Gorge (Figure 2). A count carried out in 2009 in PK 171+800 gave as a result 58 incidences of falling stones with a total of 212 stones throughout the year, which compared to the year 2014, gave a result of 21 incidents for the same reason after the performance and with a count of 56 stones (from 3-5cm to 30cm-30cm). It should be borne in mind that the purpose of the action in such PK was to channel that waterfall so as not to hinder the traffic due to waterfalls of water. This has reduced the fall of stones (average size of 10x8 cm) by 74%.



Figure 3. Safety compromised due to stone falling in the road N-621 after intense rains.



Figure 4. Safety problems due to stone falling in the road N-621 after intense rains.

Regarding the Type 2 problem, there was a large slide of the right road (Figure 5), in this case embankment of the highway A-8 in PK 167, in Liendo, on February 8, 2013, with strong horizontal and vertical displacement of the right lane, of the order of 30 and 100 cm respectively. This led to cut traffic in the roadway and to the urgent set up of metal lanes in the central reservation to prevent the slippage from affecting the opposite lane, which is along where the two traffic directions circulated.



Figure 5 Cracking of the road way with descent of 100 cm in the A-8, Liendo.

3.2 Solutions adopted for the management of runoff water in Karstics areas

The energy of these cascades has been dissipated by placing sequences of metal modules based on profiles or rods placed on the ground, dynamic screens complemented by metal mesh and chain screens. The water curtain is channeled to the Deva River by placing a reduced opening metal net. Sometimes the rocky slope is very close to the road, so runoff water falls directly onto the road, watering it with little chance of drainage, even opening it transiently after a heavy down pour.

The actions carried out within the National Highway N-621 (Figure 6) is the water energy absorption of waterfalls based on dynamic screens and screens of chains complemented with metal mesh, arranged according to orography in sequence for the adaptation of the energy.

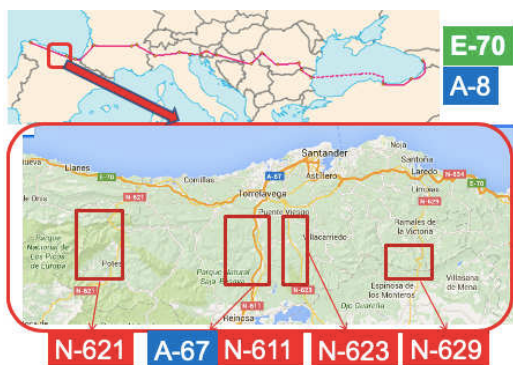


Figure 6 Map showing the location 1



Figure 7. Map showing the location 2

3.2.1 PK 158+140 MI Cascading energy of absorption "Lebeña"

The water curtain is channeled to the River Deva by placing a dense metal net and performing ditches and sewers crossing under the road.

It is associated with a rocky ballast that descends to the edge of the road, with a variable height between 50m and 75m and 17o. The speed and energy of the water force sprouting from two karst cavities and channeled to the Deva River has been decreased, through 5 consecutive levels, 1 of M2 and 4 of M1-2. The receiving bowl has been improved by rock bite and a masonry wall has been executed, with putlog holes being performed and mimetized with the natural environment, which allow for the integration of landscape (Figure 8).



Figure 8 Situation of PK 158,140 MI produced by heavy rains and situation of PK 158,140 MI with the finished stonework (national road side)

3.2.2 PK 169+050 MI Energy absorption at "Las Higueras" waterfall

The speed and energy of the water force that descends from four channels that converge in two and are channeled to the Deva River has been decreased. All this by arrangement of the different modules is shown in Figure 9.



Figure 9. Situation of the PK 169,050 MI produced by rains. Protection channels 2, 3 y 4.

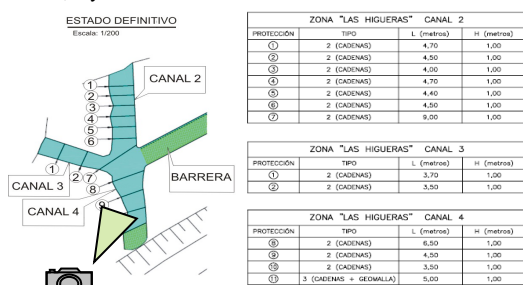


Figure 10. Protection channels 2, 3 y 4.

3.2.3 PK 171+800 MD Energy absorption at "Murcielagos" waterfall

The speed and energy of the water force that descends from two torrents and channeled to the Deva River has been decreased by: 26.00 m² of dynamic screen (Module No. 1) and 185.74 m² of string screen (Module No. 2) (Figure 11).

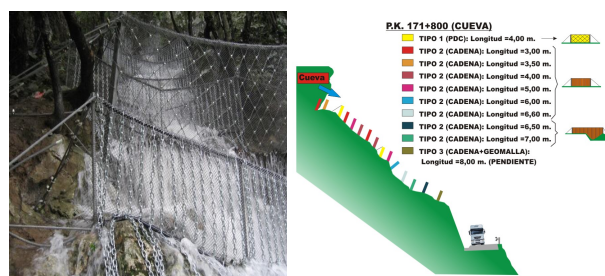


Figure 11. Operation of Modules No. 2 in lower slope in the face of rain events

3.3 Biological engineering solutions in A-8 Highway (problems types 2 and 3).

The action carried out on the slope includes its stabilization by means of a measure of Biological Engineering, consisting in the incorporation of a gravity wall formed by a cell structure of eucalyptus wood logs, with living stakes and container plants, with the aim that the future development of the plant replaces the trunk structure. The structure has been reinforced with a foot of slab. The performance has been completed with the execution of a coronation ditch with its corresponding descent.

With regard to other solutions that were carried out we could cite the following:

Mortar piles 60 cm in diameter net (Figure 12). Triangles equilateral mesh of 2,40 m side, in the center 80m and mesh of equilateral triangles of 2.70m side, in the 20m sides to the sinking area. With a total 248 pilots between 20 and 26m deep. Preparation of accesses, execution of drain 4m deep filled with draining material, construction of concrete-coated ditch. Execution of Californian drains and rail stake and topographic control. The movements recorded in the period leading up to the start of the repair works are elevated, greater than 20 cm at some points. During repair work, up to a maximum of 3-4 cm. After completion of the repair work, the movements on both the carriageway as in the slope practically have disappeared.

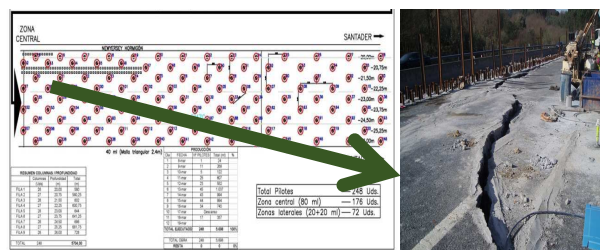


Figure 12. Embankment stabilization A-8 (E-70).

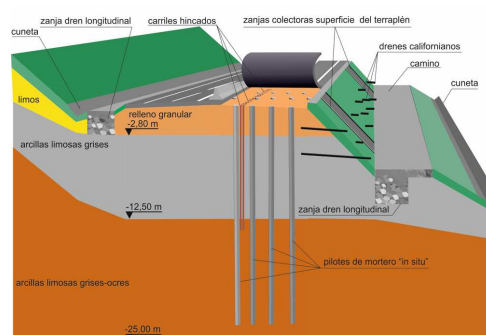


Figure 13 Comparison situation before and after embankment stabilization A-8 (E-70).

3.4 Problems types 3

Seat and overturning of walls, with problems, usually sliding at its base (excessive thrust) or the mass of land on which they rested; or increased compressibility of the wetting foundation. On the A-67 near the town of Pujayo, a landslide occurred on the 17 m high green wall with an inclination of 70°, which supports the dual carriageway at the access fill to the Pujayo viaduct. A superficial "spoon" type landslide over an approximate length of 15 m and a height of about 6 m. Also observed in other areas of the green wall was the beginning of a process of overturning/breakage of the top step of the wall (Figure 14). The solution consisted of securing the head of the slope of a green wall with a reinforcement system consisting of a volumetric three-dimensional geogrid, triple reinforcement mesh and 16 mm diameter steel cable, forming 8x3 m triangulations, all anchored to the ground by means of self-drilling bolts and cable nets. As this is a green wall with a pedraplén type fill, it was necessary to use self-drilling bolts with a greater amount of mortar in the anchoring bulb to ensure the strength required by the system (Figure 14).



Figure 14. Safety problems due to stone falling in the road N-621 after intense rains.

Another landslide occurred at KP 118+300, on 20 January 2013 (Figure 15), on the support wall of the N-623, a local road in Corvera de Toranzo, which did not suffer any damage due to the lanes being driven in at the time and which has been left exposed to the air. The solution consisted of clearing the slope, placing geogrid and bolted cable network. Channelling of the spring. Enlargement of the rail pile to reinforce the existing one with a welded and concreted head.



Figure 15. Lane swelling, laying of geogrid, bolted cable network and reconstruction of water trough on the N-629 road caused by heavy rains.

On the N-629 road (Figure 10), at PK 50+100, at Puerto de Los Tornos. Another landslide occurred in 2012, it is a very old road, more than 100 years old and with a meagre road surface. Among the solutions adopted was the installation of a metal structure composed of UPN-160 and HEB-160 type beams, braced and bolted to the ground using 30 mm TITAN 30/16 self-drilling bolts, similar to the one done in 2016, on the N-623a road (Figure 16), where a double-sided riprap was also installed.



Figure 16. Subsidence of the N-629 road platform caused by heavy rains and provisional signposting

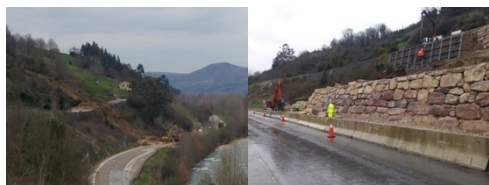


Figure 17. Landslide caused by heavy rains, causing the total cut of the N-623 and N-623a road in the afternoon of 10 March 2016. PK. 117+300 m.i

3.5 Full scale tests on dynamic barriers

Dynamic barriers are flexible metal structures specifically designed to stop detached rocks from slopes, to prevent them from reaching critical infrastructures or even dwellings. They have been a major measure to mitigate rock falls damages in northern Spain and in Cantabria in particular, especially in La Hermida Gorge. One of the main achievement has been to carry out a field test on dynamic barriers following ETAG 27 on two

products: IBT-150 and IBT-500. Forces in cables, stresses in foundations, displacements in membrane and energy dissipators deformation have been measured through load cells, strain gauges and high speed videocameras, among others.

3.5.1 Test description

Field tests were carried out on IBT-150 and IBT-500 in 2010 and 2015, respectively, following ETAG-27. For the particular case of the IBT-500, certain changes were made in the instrumentation with respect to IBT-150 in order to improve data recorded. Foundations were monitored in this case, directly attaching strain gages in the GEWI bars close to the wall (N15, N16). Four load cells for 8mm diameter cables were placed in the central functional module (N1, N2, N3, N4), 8 load cells for reinforcement cables of 22mm diameter were added (N5, N6, N7, N8, N9, N10, N11, N12) and two more load cells for 16mm diameter in upstream cables (N13, N14) were set up Figure 15.

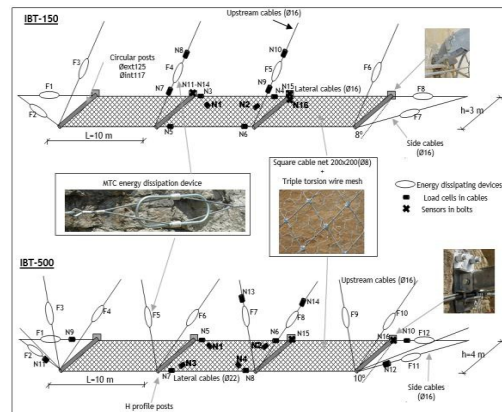


Figure 15. IBT-150 and IBT-500 full scale test.

Table 1. Characteristics of the SEL and MEL test of both barriers

Barrier type	IBT-150	IBT-500
mSEL(kg)	148.0	460.15
Vimp (m/s)	25.27	26.94
ESEL (kJ)	47.25	167.15
mMEL(kg)	504.0	1429.5
EMEL (kJ)	165.0	518.9
Vimp (m/s)	25.59	26.94

3.5.2 Test performance

Both tests were valid since the dynamic barriers stopped the MEL impact; furthermore, both barriers did not present significant damages. Although ETAG-27 does not state any specific acceptance criteria for the forces, and stresses recorded with the sensors, they are quite useful for design purposes, especially when a new and larger dynamic barrier is intended to be developed. Data recorded can be used to understand better which are the mechanisms of force transmission among components, also to determine which are the components that bear the higher forces, and finally, to calibrate numerical models (Castanon-Jano et al 2018) for future design purposes.

4 CONCLUSIONS

It can be said that the Cantabria region is an international benchmark both in terms of exploitation of resilient

infrastructures and pioneering research aimed at greater sustainability of Spanish roads.

The weather events that have occurred after the interventions have been installed compare in magnitude and frequency to those that occurred before the interventions were put in place are more extraordinary yet. For example, the amount of precipitation collected last November must be qualified as extraordinary, specifically, in the station of Tresviso, the 648mm (254.0mm normal) constitutes the maximum value registered since the series began in 1980. The time passed after the execution of the exposed solutions (1-2 years) has been shown they work efficiently and it is important to highlight the good results obtained with the use of chain curtains in the Hermida Gorge (Figure 16), which substantially improve road safety under rainy weather conditions; also, it is worth mentioning the stability achieved with the use of the cell structure of eucalyptus trunks on the A-8, which prevents slide accidents during winter.



Figure 16. Safety problems due to stone falling in the road N-621 after intense rains. Situation of PK 158,140 MI produced by heavy rains on rocky slope (upstream) performed the performance.

Full scale test according to ETAG-27 with the type of sensors used by University of Cantabria has shown to be a good monitoring system to determine maximum tensile forces on different cables, stresses on foundations and maximum elongations.

It must be emphasized problems found when trying to address earthworks and slopes in the application of a Climate Change resilience analysis, the importance of documenting any actions, inventorying and monitoring, when possible, earthworks and slope assets. And not only for preventive action but also for acquiring knowledge based on these previous documented experiences. Any databases and its management, integration and crossing between them it's crucial. And working at the local scale with better weather predictions seeking the objective of anticipating problems in the climate forecast, taking into account climate change in all phases of the infrastructure life cycle from its design and project to later operation.

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