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Impacts and adaptation measures of state roads in Spain to climate change

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ACT: The resilience of transport infrastructure, particularly road networks, is a critical aspect of ensuring their functionality in the face of external impacts, especially those driven by climatic factors. Cantabria, a region in northern Spain, serves as a notable example of proactive measures in this domain. With frequent climate-induced disruptions to its road network, the region has leveraged its extensive experience to implement and refine methodologies for assessing and mitigating climate-related risks. The methodology, as highlighted by Alonso et al. (2022), emphasizes evaluating risks across key dimensions: sensitivity, probability, severity, and criticality. These evaluations guide the development and application of adaptation measures to strengthen the network against anticipated impacts. The ongoing initiatives in Cantabria not only enhance the resilience of its road infrastructure but also contribute to a broader body of knowledge. This knowledge facilitates the identification of effective practices and the quantification of measures' efficacy, helping to mitigate current and future impacts of climate change on road networks. Through these actions, Cantabria underscores the importance of continuous assessment and adaptation, presenting a valuable case study for other regions aiming to enhance the resilience of their transportation systems

KEYWORDS: Resilience, Vulnerability, Landslides, Storm Damage, Adaptation Measures

1 INTRODUCTION

From the point of view of the adaptation of roads to climate change, the concept of resilience comes into play, seeking to ensure that the road network is capable of: resisting possible impacts produced by external agents (including climatic ones) without suffering major damage; but, in the event of such damage, being able to recover as quickly as possible. In this area, the Safe, Sustainable and Connected Mobility Strategy 2030, the framework that will guide MITMA's actions in terms of mobility, infrastructures and transport over the next 10 years, establishes the following lines of action: On the one hand, the adaptation of criteria and regulations for planning and/or design of linear infrastructures to climate change (with special emphasis on drainage and drainage) and, on the other hand, the analysis and programming of actions for the adaptation of infrastructures and operation of transport networks to climate change. It should be borne in mind that the effects caused by climatic agents are frequent in the road network. Thus, in the region of Cantabria, located in the north of Spain and with an area of 5,321 km2 , there is already experience of great interest in the programming of actions to increase the resilience of the network (Collazos et al, 2022). This experience continues to accumulate and is allowing the methodology for assessing the risks associated with climate change on the State Road Network, hereafter referred to as RCE (Alonso et al, 2022). The dissemination of good practices and lessons learned in relation to increasing the resilience of road networks is necessary in order to contribute to the development of action programs, as it has been detected that one of the main barriers to progress is the lack of objective information. It is also necessary to carry out technical studies which allow the quantification of the impacts of environmental variables on the functional and structural behavior of the different road assets, as well as on mobility.

The aim of this communication is to contribute to the creation of a state of knowledge to reduce the impacts of climate change (present and future) on the road network by highlighting the actions carried out on the state road network in Cantabria.

2 CASE STUDY

The main impacts and associated risks are described first, followed by a list of some of the most significant adaptation measures that have been implemented.

2.1 *Traffic disruption due to heavy rain*

Runoff water from a heavy downpour can abruptly hit the road and stop (or hinder) traffic flow (Figure 1).

Figure 1. This is the conference logo. The situation after heavy rains with falling stones and situation of the PK 169+050 MI produced by the heavy rains on the rocky slope (upstream) without action.

Another possible impact related to heavy rainfall is rockfall. This impact occurs in karst areas. In the Desfiladero section, an average of 50 stones can fall per day (Figure 2). In 2009, at KP 171+800, 58 incidents of rockfall were recorded, with a total of 212 stones falling over the year. In 2014, after the implementation of some protection measures, only 21 incidents were recorded for the same reason and 56 stones (from 3-5cm to 30cm-30cm). It should be borne in mind that the objective of the action on this KP was to channel the water fall, so as not to hinder traffic due to the presence of water on the pavement. In this way, the fall of stones (average size of 10x8 cm) has been reduced by 74%. The adaptation measures can be found in sections 3.2.1 to 3.2.3.

Figure 2. Safety compromised by falling stones on the N-621 road after heavy rains and Road safety problems due to falling stones on the N-621 road after heavy rains

2.2 *Landslides due to heavy rainfall*

Another impact was caused by a large landslide of the right-hand carriageway (Figure 3), in this case the slope of the A-8 motorway at KP 167, in Liendo, on 8 February 2013, with strong horizontal and vertical displacement of the right-hand carriageway, of the order of 30 and 100 cm respectively. This led to the closure of traffic on the carriageway and the urgent installation of metal lanes in the median to prevent the landslide from affecting the left-hand carriageway, which is where the two directions of traffic circulated

Figure 3. Cracking the carriageway with a 100 cm drop on the A-8 motorway, Liendo.

The first line of authors is followed by the affiliation of those authors. Use the “Affiliation” style and the structure: [Department], [Affiliation], [City], [Country], [Corresponding author’s email address]. As soon as it rains in the area of the N-634, mud and stones are washed onto the road, creating a risky situation for users of the N-634 road, despite the speed with which the conservation services act. The origin of this problem is due to the lack of channeled drainage of the runoff water which runs along the various tracks on the slope, to which the lack of support for the slope is added, which is significantly high, a factor which adds to the risk in extreme rainy situations. Thus, for example, on 4 January 2021, a landslide occurred, which partially invaded the carriageway of the N-634 road and caused the partial closure of traffic (Figure 4). A possible solution to this problem is detailed in section 3.2.4.

Figure 4. N-634, between KP 247+100 and 248+10, Cabezón de la Sal.

On 28 December 2020, a rotational landslide occurred on the right-hand side of the N-629 road at the Ampuero junction (Figure 5). In section 3.2.5 a possible solution is proposed based on the driving in of rails and breakwater walls.

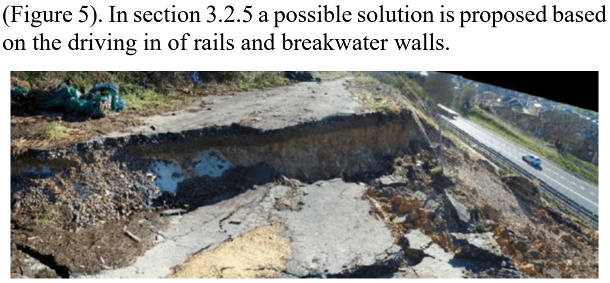

Figure 5. N-629. Slope landslide. Initial situation. Road platform at the head of the slope.

Another impact recorded on previous dates, between 3 and 4 a.m. on 11 November 2017, the central part of the slope at the A-8 KP experienced a translational slide from the head of the slope of about 10 m in length, invading the three lanes of traffic and leaving the advance party of the slide just a few centimetres from the median barrier separating the two carriageways of the dual carriageway (Figure 6). The left-hand carriageway was immediately closed to traffic for the removal of the landslide material (Figure 7). In this respect, the adaptation measures described in section 3.2.6 can be consulted.

Figure 6. Landslide occupying the entire left-hand carriageway of the dual carriageway. Morning of 11 November 2017. Left lane enabled traffic and constant pushing of the landslide bending the driven lanes.Laying of geogrid, triple twist mesh and cable nets.

Figure 7. . Slope detachment. Removal of material to provide traffic on the left lane.

Recently, in the early hours of 23 April 2022, on the section of the A-8 dual carriageway (which runs through the north of Spain from east to west), between Castro Urdiales and the border with the province of Vizcaya, there was a landslide of the slope, with a large volume of material and stones of significant size, causing an accident and the complete cutting of the road in the direction of Santander (towards the west). This is an area of slope approximately 180 m long and 23 m high, covered with a layer of gunite without any drainage system for the back of the slope. This lack of drainage caused cracks and buckling of the gunite (Figure 8), which eventually led to the cuttings breaking off. The solutions are also described in section 3.2.6.

Figure 8. Slope detachment. Initial situation. Removal of material to provide traffic.

2.3 *Overturning of retaining walls due to heavy rainfall*

Another impact that has been recorded in the area is the overturning of retaining walls due to heavy rainfall, as shown in Figure 9. In this case, it is necessary to consider the difficulty of building breakwater walls, as well as reinforcement of existing masonry in the area. Section 3.2.7 contains solutions for dealing with the impacts related to the overturning of retaining walls.

Figure 9. Collapse of wall N-621 pk 161.950

3 ADAPTATION MEASURES

Some of the adaptation measures carried out are listed below

3.1 *Impacts related to heavy rainfall in karst areas.*

The energy of these waterfalls that appear in karst areas has been dissipated by placing sequences of metal modules based on profiles or rods placed in the ground, dynamic screens complemented with metal mesh and chain screens. The water curtain is channeled towards the river Deva by placing a metal net with a reduced opening. On occasions, the rocky slope is very close to the road, so that the runoff water falls directly onto the road, flooding it and with little possibility of drainage, even temporarily flooding it after a heavy downpour. The energy of these waterfalls that appear in karst areas has been dissipated by placing sequences of metal modules based on profiles or rods placed in the ground, dynamic screens complemented with metal mesh and chain screens. The water curtain is channelled towards the river Deva by placing a metal net with a reduced opening. On occasions, the rocky slope is very close to the road, so that the runoff water falls directly onto the road, flooding it and with little possibility of drainage, even temporarily flooding it after a heavy downpour.

The actions carried out on the N-621 National Road (Figure 10) are the absorption of waterfall water energy based on Dynamic Screens and Chain Screens complemented with Metal Mesh, arranged according to the orography in sequence for adequate energy dissipation. The following three sites are highlighted:

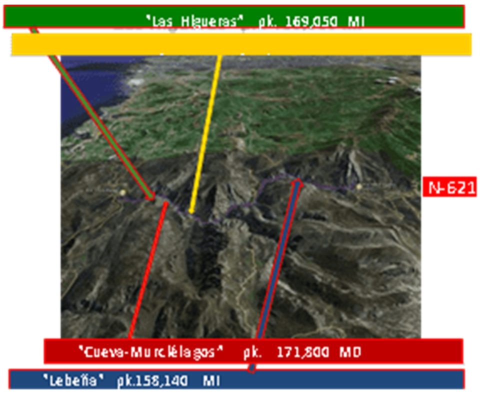

Figure 10. The actions carried out on the N-621 National Road

3.1.1 *Table captions N-621, PK 158+140 MI Energy Absorption in "Lebeña" Waterfall.*

The water curtain is channeled towards the river Deva by means of a dense metal net and the creation of ditches and culverts (ODT) which cross under the road. It is associated with a rocky outcrop which descends to the edge of the road, with a height varying between 50 m and 75 m and a 17º slope. The speed and energy of the force of the water flowing from two karst cavities has been reduced and channeled to the river Deva, through 5 consecutive levels. The receiving basin has been improved by cutting into the rock and a masonry wall has been built, with mechinales and blending in with the natural environment, which allows it to be integrated into the landscape (Figure 11).

Figure 11. Situation of PK 158.140 MI caused by heavy rains.

3.1.2 *N-621, PK 169+050 MI Energy absorption in "Las Higueras" waterfall.*

The speed and energy of the force of the water descending from four channels which converge into two and are channelled into the river Deva has been reduced. All this has been achieved by means of the layout of the different modules shown (Figure 12).

Figure 12. Situation at KP 169.050 IM caused by heavy rainfall and distribution of protections in channels 2, 3 and 4.

3.1.3 *N-621, PK 171+800 MD Energy absorption in "Murciélagos" waterfall*

The speed and energy of the force of the water descending from two torrents has been reduced and channelled into the river Deva, by means of: 26.00 m2 of Dynamic Screen (Module No. 1) and 185.74 m2 of Chain Screen (Module No. 2) (Figure 13).

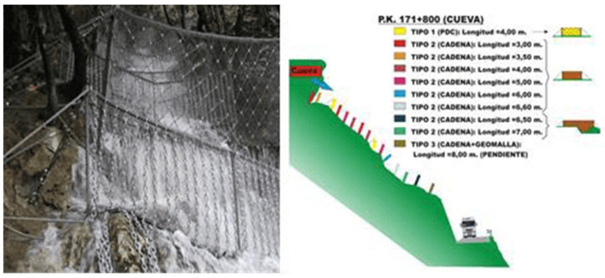

Figure 13. Functioning of Modules No. 2 at the bottom of the slope in the event of rainfall events

3.2 *Impacts related to heavy rainfall: geogrids and cable nets reinforced with diagonal cable and bolts*

In the area around KP 167+000 of the N-611, due to water runoff on the slope on the left bank, mud and stones fell and affected the roadway. To resolve this situation, a reinforced geogrid was installed, after clearing and cleaning up the affected slope.

Subsequently, a 10 KN/m2 slope support treatment was installed, consisting of cable netting on triple twist mesh reinforced with diagonal reinforcement cable and 25 mm diameter bolts (Figure 14).

Figure 14. N-611 PK 167+000 Laying of cable netting, triple twist mesh and bolting.

3.3 *Impact due to falling stones: dynamic screens*

In relation to falling stones, only the action of placing dynamic screens in the different locations due to the adverse meteorological phenomena that have taken place during the months of March and April 2020, has meant a budget of 950,000 euros (Figure 14b).

Figure 14b. This is the conference logo. Situation at KP 160.700 MD caused by heavy rains after cleaning the remains of stones from the roadway and placement of material by helicopter.

3.4 *Landslides: widening of forest tracks*

Another adaptation measure to minimize the risk derived from landslides has consisted of the widening of two existing forest tracks. One of them with layers of blast rockfill and a subsequent layer of natural gravel in the area of the landslide. And the other forest track, in addition to the previous layers, with a steel mesh reinforcement (Figure 16). For the channeling of the water that reaches the forest tracks, ditches have been built, factory works have been cleaned with pressurized water, ditch guards and concrete walls.

Figure 15. This is the conference logo. Situation of the N-634, PK 247+100 and 248+100. Excavation and cleaning up, and action completed.

3.5 *Landslide of the slope: biological engineering, driving of rails and rockfill walls*

To contain the platform of the CA-502 road above and on the slope of the N-629 road (Figure 16), a pile of rails has been driven in, arranged in staggered staggered rows, the heads of which have been braced with welded rails. The upper area of the rails has been embedded in concrete, forming a beam parallel to the road (Figure 19) and the service road. The latter was also affected by the landslide, so a breakwater wall has been built with a concrete breakwater footing and provided with longitudinal drainage, solving the water problem with ditches, drainpipes, gullies and transversal drainage pipes.

Figure 16. Welding the rails of the rail jacking to contain the CA-502 platform.

A breakwater wall was built to contain the slope of the N-629. First of all, the volume of loose material was removed to subsequently build a concrete breakwater footing, directly supported on the rocky substrate, and then the body of the breakwater wall was built (Figure 17).

Figure 17. N-629 PK 81+800 MD. Slope detachment. Construction of a breakwater wall

3.6 *Engineering solutions on the A-8 motorway: removal of weight on slope, breakwater wall as a reinforced dam, gunite and slope reinforcement*

At KP 254 (Caviedes) of the A-8 Cantabrian motorway, in the municipality of Valdáliga, a retaining wall was designed to support the thrust of the slope which is currently moving. The breakwater has to support the thrust of the earth, but it is also necessary to remove the material from the slope, which is likely to detach, thereby reducing the weight of the thrust of the earth (Figure 18).

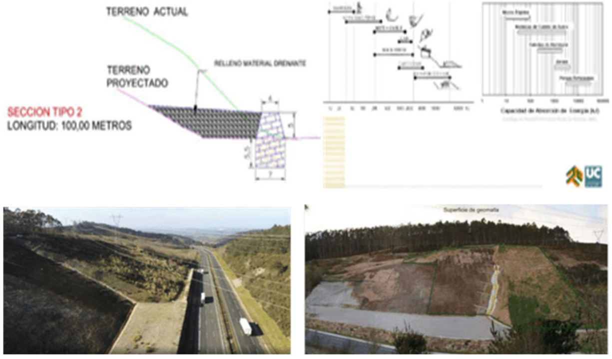

Figure 18. N-629 PK 81+800 MD. Slope detachment. Construction of a breakwater wall

In the case of Castro de Urdiales, at KP 139+300 MD, the cracked gunite that has not collapsed is demolished, followed by scarification of the layer of loams and micritic limestone altered by the effect of the water retention of the cuttings on the undrained gunite layer (absence of mechinales). To adapt the slope, a triple torsion mesh and a layer of gunite are placed. After the slope has been prepared, a layer of electrowelded mesh is placed and a first layer of concrete 10 cm thick is projected. After this first layer, a layer of electrowelded mesh is placed (Figure 19).

Figure 19. Stabilisation of the slope of the A-8 motorway (E-70). Placement of electrowelded mesh and anchors.

The second layer of gunite is then sprayed. The stabilisation of the massif is designed using a mesh of permanent active bolts of 40 mm in diameter, with a yield load of 1,1190 KN (119 ton) tensioned to 35.4 tonnes, with an anchorage zone of 5 m (80 mm diameter perforation) arranged at 20º to the horizontal, in a mesh of 3. 25x3.25 m staggered mesh, forming a total of 7 rows depending on the geometry of the slope, with a length of 18 m for the two upper rows, 15 m for the two subsequent rows and 11 m for the three lower rows. Californian drains of 15m in length are laid out in 10x10m mesh, with an upward slope of 5º and the upper path is reinstated. On the left bank, geogrid and triple twist mesh is placed with its supporting cables (Figure 20).

Figure 20. Placement of anchor cables and hydroseeding.

Biological engineering can be used in the case of sliding of the cut slope, as well as in the case of a collapse of the embankment platform with mortar piles (Figure 21).

Figure 21. Biological engineering, platform lowering and completed action schemes.

3.7 *Impacts related to the overturning of retaining walls: reinforcement with cables or metal structures*

To solve the problem of overturning retaining walls on the A-67, the head of the slope of a green wall was secured with a reinforcement system consisting of a volumetric three-dimensional geogrid, triple torsion 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 22).

Figure 22. Green wall with self-drilling bolts on the A-67 motorway.

In the case of another detachment which occurred at KP 118+300, on 20 January 2013 in the supporting wall of the N-623, local road of Corvera de Toranzo, it should be noted that there was no damage due to the lanes being driven in at the time and which were left exposed. The slope was cleaned up and geogrid and bolted cable netting was installed. The spring was also channelled and the rail jacking was enlarged to reinforce the existing one with a welded and concrete head.

On the N-629 road (Figure 23), at KP 50+100, at the height of Puerto de Los Tornos, a landslide occurred in 2012. It is a very old road, more than 100 years old, 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 self-drilling bolts, similar to the one done in 2016 on the N-623a road (Figure 24), where a breakwater was also built and a masonry wall was rebuilt.

Figure 23. Sinking of the N-629 roadbed caused by heavy rains, provisional signalling and reinforcement of the masonry wall.

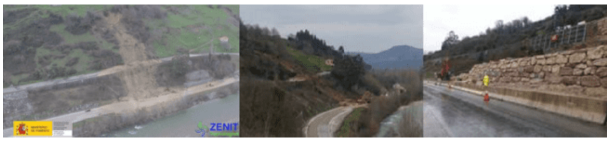

Figure 24. Landslide caused by heavy rains, causing the total cut of the N-623 and N-623a road in the afternoon of 10 March 2016. PK 117+300 left bank

3.8 *Impacts related to drainage works: ODT reinforcement and extension*

On the N-623 at PK 103+800 an ARMCO type group collapsed (Figure 25). To solve the problem, the pipe was cleaned and the accesses were conditioned. Subsequently, a series of HEB-160 profile metal beams were placed in the lower part of the pipe, in a transversal direction, as reinforcement. A black corrugated polyethylene pipe Ø 630 mm was then installed, attached to the bottom of the ARMCO pipe by welding a metal profile in the shape of a "Y", to channel the water from the stream during the works (Figure 26). A mass concrete slab was laid, and the reinforced concrete structure was mounted on it, consisting of a horizontal slab, curved gables and a vault (Figure 26).


Figure 25. N-623 KP 103+800. ARMCO pipe collapse. Initial situation and river diversion


Figure 26. N-623 PK 103+800. ARMCO pipe collapse. Formwork and exit with natural projections.

Another case related to the collapse of a corrugated metal pipe is the N-611 PK 141+100 road (which is replaced by a tri-articulated structure). It occurred due to adverse weather conditions in the first week of February 2012 (Figure 27). Following this corrugated metal pipe, there is another prefabricated segmental pipe cased under the adjoining embankment. Due to its damage and in order not to destabilise the adjacent slope, a metal reinforcement ring was built on the inside of the pipe to ensure stability.


Figure 27. Initial situation and execution of the interior structure.

In connection with the flooding of the roadway, the transversal drainage works are extended by adding 3 cellular pipes on top of the initial and old drainage work consisting of two vaults (Figure 28).


Figure 28. Initial situation with enlargement and subsequent operation.

In relation to the platform subsidence, the restoration of this channeling was carried out (with the specialised help of miners) and the stabilisation of the embankment by means of repetitive selective injections, and always with a treatment system in order to purify the discharge so that the purified water is suitable for discharge into a public watercourse (Figure 29).

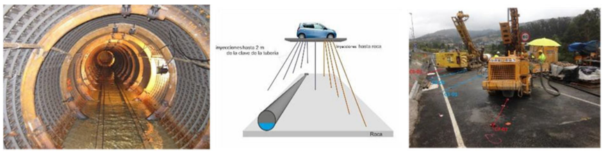

Figure 29. Platform subsidence, drainage works channelling and embankment stabilisation.

3.9 *Impacts related to runoff: chain screens, reinforcement and ODT extension*

The good results obtained with the use of chain curtains in the Hermida gorge (Figure 30) are noteworthy, substantially improving road safety conditions in times of heavy rain.


Figure 30. Safety problems due to falling stones and hydroplaning on the N-621 road after heavy rain. Situation PK 158.140 MI produced by the heavy rains on the rocky slope where the work was carried out.

4 CONCLUSIONS.

The actions carried out in Cantabria to increase the resilience of its road network can be considered a reference for other administrations. Furthermore, it is worth highlighting the application of innovative solutions aimed at achieving greater sustainability, both in the field of construction and in the field of maintenance and operation. Proof of this are the national and international initiatives in which Cantabrian roads have become demonstrators for different studies and projects, such as the Horizonte Europa projects LIAISON and CIRCUIT.

The experience acquired in Cantabria is of great value in advancing in the proposal and implementation of methodologies for the evaluation of risks associated with climate change. Numerous actions have been carried out: reinforcement of slopes, increasing the drainage capacity of drainage works, energy dissipating screens, etc

5 ACKNOWLEDGEMENTS

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