

# Landslide Prevention Costs in Road Construction Projects: A Case Study of Diezma Landslide (Granada, Spain)

E. Bergillos, J. Garrido, J. Ordóñez, J. Delgado, and J. M. Bueno

## Abstract

During the construction of many roads, slope stability problems can occur, resulting in a delayed completion of the construction as well as an increased final budget. However, there is still limited data collected that reveals the actual costs of geotechnical issues. The Diezma landslide, affecting the A-92 highway (Granada, SE Spain), is a great example of this situation. The construction project, which was started in 1988, did not identify the geotechnical instabilities of this zone, thus no preventive measures were recommended. The landslide-induced disruption of the highway involved economic losses related to the implementation of corrective measures and to indirect costs. In this paper, an evaluation of direct and indirect costs induced by the landslide is developed, and as a result, the potential cost savings of an adequate geotechnical survey are obtained.

## Keywords

Landslides • Road cuttings • Direct and indirect costs • Preventive measures • Construction projects

## 1 Introduction

Landslides affecting linear infrastructures usually occur on mountainous terrain, where cuttings and embankments are very high and steep. When these landslides happen during the construction stage, they result in delays and excessive costs, as well as in modifications of the construction projects. However, when they happen during the operation stage, damages may require the closure of traffic lanes or even the whole highway, in order to make repairs. In both cases, the resulting costs are substantial for the Administration as well as for the users, and these costs could have been avoided with an adequate geotechnical survey during the planning stage.

One infrastructure notably affected by this issue is the A-92 highway in Granada, (SE Spain). Cuttings and embankments of up to 40 m high had to be undertaken due to the geometric and width requirements of a highway, and due to the hilly terrain. However, these huge earthworks were not supported by an adequate geotechnical survey; therefore, many cuts and landfills were affected by landslides. After the landslide events, numerous emergency works and stabilization projects were initiated to repair the damage, to reinforce slopes and road pavements, and in some places the highway had to be closed during these repairs. The Diezma landslide on the A-92, located 3 km west of the Diezma village (Fig. 1), has been selected for this analysis due to its huge impact. Construction works in this section started in October 1989 and ended in December 1992. Since then, additional works have been undertaken due to landsliding, including three projects under emergency conditions and two stabilization projects (Delgado et al. 2015).

Geotechnical surveys are usually carried out at minimal costs, which does not achieve the thoroughness required to avoid future issues. However, if the costs of later investment in repairs and indirect costs were taken into account, the need to give greater importance to geotechnical studies when

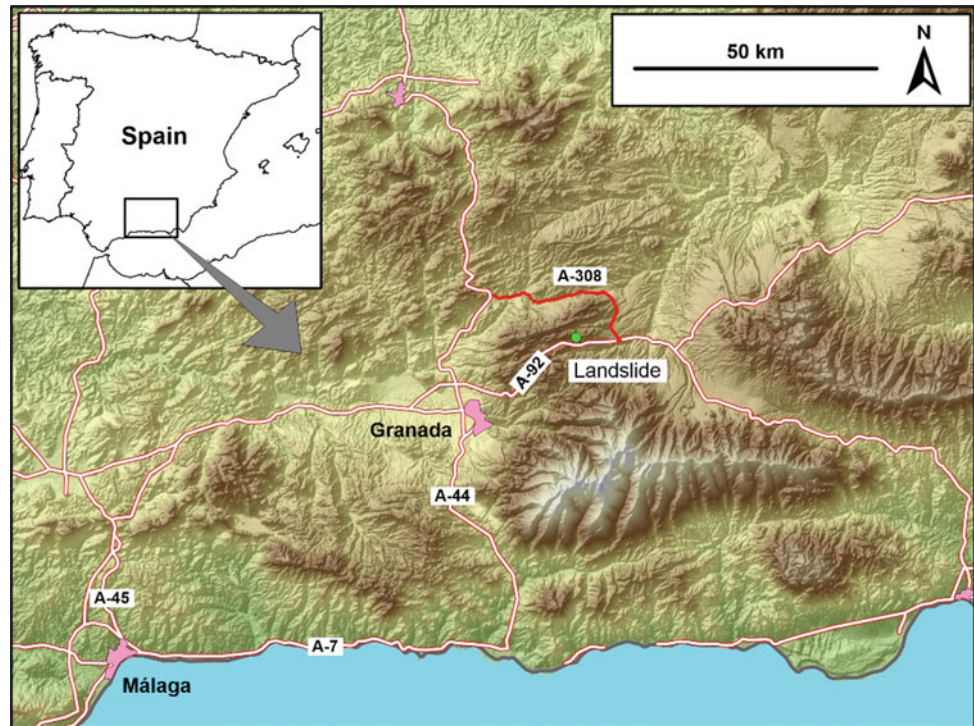
E. Bergillos (✉) · J. Garrido  
Dpto. Ingeniería Civil, Universidad de Granada, Campus de Fuentenueva s/n, 18071 Granada, Spain  
e-mail: eduardobergillos@correo.ugr.es

J. Ordóñez  
Dpto. Ingeniería de la Construcción y Proyectos de Ingeniería, Universidad de Granada, Campus de Fuentenueva s/n, 18071 Granada, Spain

J. Delgado  
Dpto. Ciencias de la Tierra y Medio Ambiente, Universidad de Alicante, Po. Box: 99 03080 Alicante, Spain

J. M. Bueno  
Consejería de Fomento y Vivienda, Junta de Andalucía, Avda. Joaquina Eguaras 2, 18071 Granada, Spain

**Fig. 1** Location of the study area in Granada, (SE Spain)



assigning budgets in projects could be clearly justified. A cost/benefit analysis has proven that economic losses cost more than preventive measures (Salbego et al. 2015), and that even the economic losses suffered by the users match or surpass the repair costs (Zêzere et al. 2007; Vranken et al. 2013).

## 2 Geological Setting and Background

Geologically, the area is characterized by the tectonic contact between the Maláguide and the Dorsal domains of the Betic Cordillera chain, where the Numidoide Formation also outcrops. The materials which constitute the Maláguide are red silt, green clay, and black schist with phyllites as bedrock. The Numidoide Formation is composed of a silty-clay silo-clastic matrix with heterometric blocks of limestones and the upper part of the area consists of the limestones of the Dorsal Domains outcrop (Rodríguez-Peces et al. 2011). These limestones have been thrust over the Numidoide Formation and give rise to an accumulation of water over the impermeable layer, forming several springs.

Since its construction, this area has suffered from instabilities (Fig. 2), but applied solutions were at most re-shapes of the slopes. However, on 18 March 2001, a period of intense rainfall triggered the main landslide, with a depth of 10–30 m and an approximate volume of 1,250,000 m<sup>3</sup> mobilized. Its toe coincided with the bottom of the

highway's trench, so this landslide collapsed over the highway entirely burying one roadway and partially burying the other.

As a temporary solution, during emergency works and the first stabilization project, a provisional roadway was built in order to restore traffic. However, it required 20 days to complete this road and traffic had to be detoured. Between March 2001 and February 2002, the main constructed corrective measures were: 5 barriers of 89 drainage wells (6–25 m deep), a superficial drainage system composed of ditches and 31 French drains, and a retaining barrier founded by 36 piles (cross-section of 5.70 m<sup>2</sup>), 12–37 m deep, anchored with 35 anchors (Fig. 3). Later in 2008, a new stabilization project was needed because of the damage that this landslide, which was still in motion, caused to the previous structures upslope of the retaining wall. It consisted of repair works on the ditches, and the drilling of 14 new wells in order to restore broken drainage connections between affected wells (Delgado et al. 2015).

## 3 Methodology

The methodology applied in this study consisted of assessing two scenarios and applying a post-event cost/benefit analysis. Scenario 0 is the actual situation, considering the costs of geotechnical surveys and stabilization projects, all the aforementioned works done so far to stabilize the landslide,



**Fig. 2** Damages: **a** landslide (October 1991), **b** landslide (May 2000), **c, d** main landslide (March 2001), **e** broken drainage well (May 2006), **f** crack near the landslide crown (November 2009)

and the traffic disruption. Scenario 1 is a hypothetical situation where a thorough geological-geotechnical survey would have allowed the design of preventive measures. This would have resulted in most of the works being done during the actual highway construction (some of them would not have been necessary because the landslide would not have happened) and would have avoided remedial work and traffic interruption.

Both direct and indirect costs have been considered. Direct costs are those directly caused by the landslide, and in this study were the costs derived from construction, reconstruction, repairs or maintenance of the affected infrastructure, with their corresponding data acquisition surveys, studies and projects. Indirect costs are those caused by not being able to use the affected infrastructure due to a landslide (Schuster and Highland 2001).



**Fig. 3** Countermeasures: **a** provisional roadway (April 2001) **b** anchors (October 2001) **c** retaining barrier (August 2001) **d** drilling new wells (October 2009)

In order to estimate direct costs, an analysis of projects and studies developed in the area of the Diezma landslide has been made. This analysis resulted in an inventory of all work construction units, measurements and prices, that composed the corrective measures, and has been represented in 2017 monetary units to facilitate comparisons. Project redaction and geotechnical survey (boreholes, laboratory tests, etc.) costs have also been considered, and they added up to 446,744.64 € (being 270,315.78 € for project

redaction and 176,428.86 € for geotechnical surveys). This way, overall direct costs of Scenario 0 have been obtained. Then, to assess direct costs in Scenario 1, all work construction units regarding repairs (such as resurfacing or re-drilling wells, and construction of the provisional roadway) have been removed since the landslide would not have occurred and remedial work would not have been needed. The rest of the remaining work construction units have been considered as preventive measures being part of the initial

construction project designed in 1988. To estimate the value that each work construction unit would have had in 1988, unitary prices for machinery, materials and salaries have been adopted from the initial project whenever possible and those that were not in the project have been extracted from a construction price base from 1988 (Fundación Codificación y Banco de Precios de la Construcción 1988).

In order to estimate indirect costs, we identified the alternative path of the A-92 highway and compared it to the original route. The most direct and used route was the A-308 road (Fig. 1), which was 18 km longer. Applying the methodology suggested by the Ministry of Civil Works (MOPU 1990; Ministerio de Fomento 2014), together with route geometry (length, travel time, average speed, average gradient) and traffic characteristics [daily light and heavy mean traffic and fuel type data from the Traffic General Directorate (DGT)] gathered (see Table 1), different types of costs endured by users have been assessed for both routes and converted to 2017 monetary units. Finally, once all these costs of vehicle depreciation, maintenance, fuel and oil consumption, tyre usage and time loss were obtained, the difference between the two routes was calculated, and is the total of indirect costs induced by the landslide.

## 4 Results and Discussion

The outcomes obtained (Table 2) indicate that the application of preventive measures in Scenario 1 are 5,094,503.87 € (2017 monetary units) cheaper than the current works considered in Scenario 0. This difference is due to avoidable

costs, being 1,262,837.15 € of construction direct costs (Fig. 4a), 446,744.64 € of project redaction and geotechnical surveys, and 3,384,922.08 € of indirect costs (Fig. 4b). Therefore, these avoidable costs can be interpreted as the available margin for boreholes and laboratory tests without surpassing the cost already spent.

However, there are certain parameters that could not be considered in this methodology and that would have greatly affected these results. Firstly, economy of scale would be the most important. Applied to construction works, the greater the magnitude of the works, machinery and methods employed, the less their unitary prices because of higher performance, making the difference even higher. Some construction units such as reshapes of the slope were done several times over. So, if all these earthworks and measures had been made once during construction stage, economy of scale would have taken place and this efficiency would have reduced the costs.

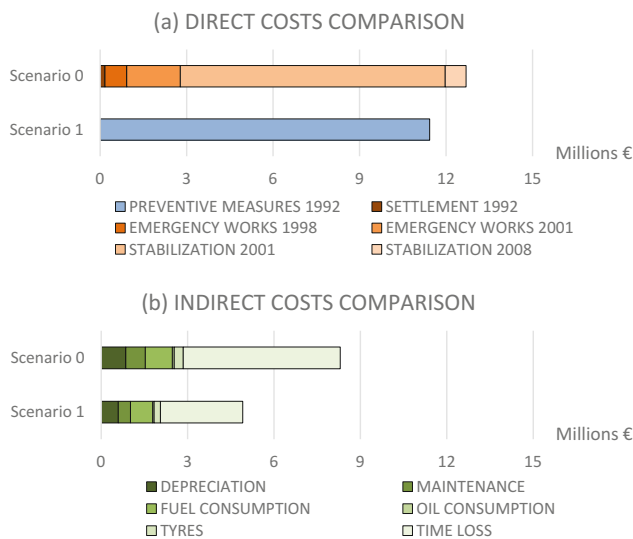
On the other hand, if preventive measures had been performed before the landslide happened, geotechnical parameters used in the countermeasures design would not have been residual ones. This greater shear strength of the ground would have allowed the definition of cheaper and less impacting measures than the ones implemented. Therefore, direct costs difference could have been even higher. Regarding indirect costs, it must be considered that all the traffic redirected from A-92 highway was sent through the A-308, a conventional road not prepared for such traffic. If it was proven that this detour increased the number of car accidents, indirect costs would have risen hugely. Moreover, this study considered the vehicle occupation rate as only the

**Table 1** Parameters considered in the analysis of indirect costs

Section characteristics	Length (km)	Travel time (h)	Average speed (km/h)	Average gradient (%)
Scenario 0 (reroute by A-308)	59	0.82	72	0.64
Scenario 1 (A-92)	41	0.43	95	0.91
Affected vehicles per day	Total	Gasoline vehicles (%)		Diesel vehicles (%)
Light vehicles (LV)	13,106	72.71	27.29	
Heavy vehicles (HV)	1235	20.31	79.69	
<i>Fuel prices</i>				
Gasoline (€/liter without taxation in 2001)			0.55	
Diesel (€/liter without taxation in 2001)			0.56	
<i>Tyre prices</i>				
Light vehicle (€/4 tyres) in 2001			327.76	
Heavy vehicle (€/6 tyres) in 2001			4491.98	
<i>Oil prices</i>				
Light vehicle oil (€/liter) in 2001			3.58	
Heavy vehicle oil (€/liter) in 2001			4.00	

**Table 2** Construction direct costs and indirect costs obtained

	Scenario 0	Scenario 1
<i>Direct costs (€)</i>		
Preventive measures 1992		11,431,169
Settlement 1992	167,273	
Emergency works 1998	755,380	
Emergency works 2001	1,858,745	
Stabilization 2001	9,189,061	
Stabilization 2008	723,546	
<i>Indirect costs (€)</i>		
Depreciation	853,084	592,821
Maintenance	679,456	424,059
Fuel consumption	938,179	770,444
Oil consumption	65,194	51,862
Tyres	316,406	219,876
Time loss	5,449,141	2,857,476

**Fig. 4** Comparison of total direct and indirect costs

driver, due to lack of available data. So, taking into account more passengers would have multiplied indirect costs related to time lost. There are also more types of indirect costs such as loss of value of affected land or economic losses of business in the area. However, this cost assessment has not been considered due to the lack of available data. But despite them being underestimated, indirect costs constitute 66.44% of the total difference in costs, highlighting the economic importance of the traffic interruption to a critical highway such as the A-92.

## 5 Conclusions

This study analysed all projects and corrective measures focused in the area of the Diezma landslide in order to assess the direct costs it caused. Then, it employed traffic data and the methodology suggested by the Ministry of Civil Works to estimate economic losses caused to users of the A-92 highway (indirect costs). These costs have been compared with an assessment of how much it would have taken to make these stabilization works as part of the initial construction project in July 1988 (only direct costs, because there would not have been traffic interruption). This way, an approximation of the potential cost savings of doing a correct geological-geotechnical survey during the planning stage were obtained. Both direct and indirect costs demonstrate that an adequate geotechnical survey at the start of the project would have been economically beneficial, saving up to 5,094,503.87 € (2017 monetary value), 30.83% of total costs. That survey would have disclosed the potential for landslide occurrence and its derived costs during the planning stage, so it could have meant developing better and cheaper solutions or even choosing an alternative route with better geotechnical characteristics. Either way, these economic costs plus the costs of time and resources spent on additional works and projects after the triggering of the Diezma landslide could have been focused on the construction of new infrastructure and/or conservation works on older roads, rather than on repairing a recently constructed highway.

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