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Adaptive Risk Management in Road Construction: Oyon-Ambo Highway Insights, El Niño 2019 Case Study

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Abstract. This research provides an in-depth analysis of the challenges faced during the construction of the Oyon-Ambo highway in Peru, particularly during the extreme rainfall events associated with the 2019 El Niño phenomenon. Situated in the high Andean area of the Pasco region, this rigid pavement road project encountered significant disruptions due to the extraordinary weather conditions. The adjacent Chaupihuaranga River experienced increased flow rates, causing extensive damage to the road and necessitating substantial modifications to the engineering plans. Focusing on 14 critical sectors identified in the project's technical file as prone to instability, the study details the accelerated degradation and eventual destruction of these sectors due to the intense rainfall. Emphasizing the importance of adaptive risk management in road construction, especially in regions susceptible to natural phenomena like El Niño, the paper underscores the need for responsive reengineering approaches based on specific damage types. It also highlights the critical role of continuous monitoring and evaluation in adapting to environmental changes. The insights from the Oyon-Ambo highway case offer valuable lessons for future road construction projects, underscoring the importance of proactive and adaptive risk management strategies to minimize the impacts of extraordinary natural events.

1. Introduction

Peru has endured a significant history of disasters linked to the El Niño-Southern Oscillation (ENSO), notably during the worldwide El Niño occurrences in 1982–83 and 1997–98. This historical experience has fostered advancements in ENSO prediction and readiness, as well as in the general enhancement of the nation's disaster risk management (DRM) strategies. However, despite these advancements, in early 2017, Peru faced severe devastation due to a localized "coastal El Niño" phenomenon [1].
Extraordinarily intense and devastating rains affected much of Peru during the austral summer 2016-2017. These rains favored widespread landslides and extensive flooding and generated one of Peru's most severe disasters since the 1997-1998 El Niño event. The amount of rainfall recorded between January and March 2017 only compares to the largest El Niño events of the past 40 years (i.e., 1982–1983 and 1997–1998) and exceeded the 90th percentile of available records (1981–2017) for much of the period. northern and central coasts of Peru, the Andean region and the Amazon. The occurrence of these heavy rains was very anomalous, as it occurred during the first austral summer after the development and decline of a very strong El Niño in 2015-2016 [2].

1.1 El Niño

At the end of the nineteenth century, the fishermen of northern Peru appreciated that every year towards the end of December, around Christmas, there used to be an increase in the temperature of the sea water, which was observable along the north coast. They attributed this warming to the arrival of a warm-water marine current they called the "El Niño" current (SENAMHI, 2022). El Niño/Southern Oscillation (ENSO) is a natural phenomenon characterized by the fluctuation of ocean temperatures in the central and eastern part of the equatorial Pacific, associated with changes in the atmosphere. This phenomenon has a great influence on the climatic conditions of various parts of the world [3].
In Peru, the responsibility for reporting on the progress and evolution of the El Niño phenomenon is vested in the Multisectoral Commission in Charge of the National Study of the El Niño Phenomenon – ENFEN. This commission was established by Supreme Decree No. 007-2017-PRODUCE.

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1.1.1 Probable causes of abnormal rainfall

The probable cause of the anomalous rainfall can be attributed to a combination of factors. Firstly, there was an especially intense wet period over the central Andes, which was related to a deep, long-lasting anticyclone situated off the Chilean coast. Secondly, there was the unusual development of warm sea water off the coast of Peru in the region typically referred to as El Niño 1 + 2. This warming has been associated with an anomalous weakening of the mid-to-high subtropical westerly flow. This, in turn, led to a weakening of the southeast trade winds off the coast. The diminished strength of these winds made upwelling near the Peruvian coast more difficult, consequently facilitating the warming of the eastern Pacific [1].

1.1.2 El Niño in 2019

The El Niño phenomena and altiplanic winter of 2019 [4]– called the 2019 rainy season – were part of a meteorological event that developed with intensity since mid-January 2019 between south-central Peru, north-central Bolivia and northern Chile, all located in South America. The occurrence of heavy rainfall during this period is linked to the "altiplanic winter" experienced in Chile and Peru, as well as to the effects of the El Niño phenomenon in Peru and Bolivia [5-6].
On January 4, 2019, the Multisectoral Commission responsible for the National Study of the Phenomenon (ENFEN) initiated a state of El Niño Alert, categorized as of weak magnitude. Subsequently, on February 14, 2019, the United States Oceanic and Atmospheric Agency (NOAA) officially announced the presence of the El Niño phenomenon, also specifying that it was in a weak condition [7]. However, following these announcements, there were significant meteorological developments. Heavy rains were recorded in the Sierra and Amazon regions of Peru and Bolivia, along with a notable rise in temperature leading to heat waves on the coasts of Peru and Chile. In Bolivia, intense rainfall commenced from the beginning of January, particularly in the north-central part of the country. In Chile, the northern area experienced substantial rains that led to the flooding of its principal urban centers. From mid-February, these conditions also began to affect the northern coast of Peru. Furthermore, by the end of January in Peru, there was an increase in rainfall, which predominantly concentrated in the south-central part of the country [8-9].

2. Methodology

In this section the description of the methodology of applied research in this work is made. Clarity and precision in defining the research method are critical aspects in any engineering work. This meticulous methodological approach not only enhances the understanding of the study, but also establishes a solid and coherent knowledge base. Such a foundation is essential as it provides a valuable reference point for future research, allowing for a progressive accumulation and evolution of knowledge in the field.[10]

2.1. Focus, scope and design

The approach developed in the present research is qualitative, because the research will be based on data collection methods that are not standardized or predetermined in detail, depending on the perspectives and point of the researcher. The scope is descriptive given that the phenomenon is studied; however, it is convenient to describe the entire existing theoretical framework to order it and describe the risk management proposal of the road project subject of the investigation. The design is phenomenological as it seeks to explore, describe and understand the impacts produced by El Niño in the construction of the Oyon Ambo highway in Peru.

2.2. Population and sample

The research focused on the roads comprising Peru's road network, managed by Provias Nacional and Provias Descentralizado. These are government entities tasked with the formulation, execution, and maintenance of Peruvian roads. Road projects under these entities are financed with public funds. Provias Nacional is in charge of developing and bidding out projects for the national road network, as well as overseeing and executing contracts. This includes the technical initiation and completion of construction works. Conversely, Provias Descentralizado is responsible for handling departmental and local road projects across all regions of Peru.

Table 1. Peruvian entities in charge of the execution of the national road network

	State entity 1	**State entity 2**
Entity in charge	NATIONAL PROVIAS	DECENTRALIZED PROVIA
Project to be carried out	Roads	Roads
Longitude, km	27,109.61	141,363.46
Scope	National	Regional

In terms of the total kilometers constituting the Peruvian road network, there is a distinction between the national road network and the departmental and neighborhood road network. Specifically, the national road network comprises

27,109.61 km of paved roads, while the departmental and neighborhood road network includes 141,363.46 km of paved roads. Consequently, the total population for the study amounted to 26,916 km of paved roads.

Table 2. Characteristics of the Oyon Ambo Road

Description	Parameters	Observation
Road network	PE-18	
Road classification	Second class	Type 3 and 4
Type of pavement	Rigid	
Roadway width, m	6.60	
Berm width, m	1.20	
Screed, m	0.15	
Concrete base, m	0.15	
Right of way gauge, m	20	10 on each side
Artwork and drainage	Platform, ditches, coronation, ditches, cutting sidewalk ditches, culverts, sub-drains, curbs, horizontal drains, causeways, riparian defenses.	
Major bridges (L > 10m)	Construction of four (4) bridges	
Major bridges (L < 10m)	Construction of five (5) pontoons	

The sampling method employed in this study was non-probabilistic, meaning that the selection of the sample was based on the discretion of the researcher. The specific sample chosen for analysis was the Oyon Ambo Section II Road, which features 49 km of rigid pavement and includes nine bridges with a total length of 145 meters of reinforced concrete. This particular road is a part of the national road network and is designated as PE-18. The road's construction utilizes rigid pavement, which is chosen for its enhanced capacity for vehicular traffic and greater resilience to weathering. This is particularly pertinent given its location, which spans elevations from 3,300 meters above sea level to 4,800 meters above sea level, as detailed in the subsequent Table 2 [11].

3. Case study: Oyon Ambo highway in Peru

The Ministry of Transport and Communications (MTC) of Peru, through its agency Provias Nacional, is dedicated to enhancing the road connectivity for the central region's population by continuing the improvement works on Section II of the Oyon – Ambo highway. This particular section, which spans 49 kilometers, starts at km 181 - near the turnoff to Cerro de Pasco, and extends to km 230 - near the turnoff to Chacayan, located in the province of Daniel Alcides Carrión. The enhancement of this segment involves expanding the roadway to two lanes, constructing various types of road infrastructure such as culverts and bridges, and implementing signage on both sides of the two-lane carriageway, which accommodates one lane for each direction of traffic. The road features a rigid pavement surface, selected for its increased durability and reduced maintenance costs. Positioned in the high Andean area of the Pasco region in Peru, this road, with elevations ranging from 3,500 meters to 4,800 meters above sea level, is recognized as one of the most geographically challenging roads in the world [12].

Fig. 1. Oyon Ambo Road Information Panel

In this specific segment of the road, nine permanent bridges are being constructed, with their lengths varying between 7 and 35 meters. The project also includes the construction of pedestrian walkways alongside these bridges to enhance the

safety of residents who will use them. As of December 2022, the progress of the construction work has reached 65.2%. Upon completion, it is anticipated that the project will benefit approximately 140,000 residents from the departments of Lima, Pasco, and Huanuco. The investment for this project amounts to $116.5 billion.
This construction is a part of a larger initiative to comprehensively improve the Oyon – Ambo highway. The overall project is divided into three sections, cumulatively spanning 150 kilometers. The first section covers a distance of 44.22 km, the second is 49 km, and the third section will extend for 52.84 km, as illustrated in Figure 1. Currently, the final study for the third section of this route is in progress
Construction on this road commenced in January 2019. This initiation took into consideration the forecasts provided by the National Service of Meteorology and Hydrology of Peru – SENAMHI. According to SENAMHI, the El Niño event in 2019 was categorized as weak. However, there was a predicted scenario of above-normal accumulated rainfall, with a 45% likelihood, followed by a 35% probability of rainfall typical for the region [13]. The primary regions impacted in Peru were the high Andean areas and the Peruvian jungle, where rainfall exceeded 25.7 mm per day

3.1. Watersheds

Along the Oyon Ambo Highway, specifically in Section II, thirteen hydrographic sub-basins have been delineated, each having channels that impact the road. The physiographic characteristics of these identified sub-basins are detailed in Table 3.

Table 3. Watersheds

N°	Basin name	Location	Area, km²	Flow rate, m³/s			
				Return period, years			
				50	100	175	500
1	Qda. Huachos	188+092.50	18.62	11.99	17.50	22.63	33.55
2	Qda. Saint John of Baths of Rabbi	201+518.50	72.00	46.41	63.50	78.65	110.31
3	Blanco River	204+926.00	181.32	96.84	130.09	159.79	221.76
4	Qda. Curpash	206+938.00	21.20	10.43	16.20	21.47	33.25
5	Yanahuanca River	207+679.55	664.11	302.30	387.99	462.75	614.46
6	Yanahuanca River	210+012.75	676.78	447.40	565.72	465.04	616.49
7	Qda. Huarautambo	212+028.50	58.20	31.98	44.98	56.75	81.88
8	Qda. Bacuri	214+620.00	4.79	1.06	2.36	3.80	7.30
9	Qda. Lucmapampa	219+789.05	9.23	3.74	6.37	8.92	14.73
10	Qda. Michivilca Rumi	223+369.50	36.99	19.91	28.83	36.93	54.23
11	Qda. Chaupimarca	225+328.50	15.55	6.45	10.83	15.08	24.75
12	Qda. Ushpacacha	227+977.80	2.99	0.21	0.76	1.52	3.60
13	Chaupihuaranga River	229+929.00	1095	472.00	600.06	773.20	935.97

3.2. Effects produced by El Niño on the Oyon Ambo Road

The Oyon Ambo Highway runs alongside the Chaupihuaranga River, which is a tributary of the Huallaga River. Originating from the peaks of the Raura and Huayhuash mountain ranges, the Chaupihuaranga River flows in a northeasterly direction until it joins the Huallaga River near the city of Ambo in Huánuco. Due to the high rainfall associated with this extreme natural event, the river experienced a significant increase in its flow. This surge caused considerable damage and necessitated alterations to the engineering design of the road project. Figure 2 provides an illustration of the 2019 El Niño's impact, showcasing examples of slope undermining and flooding in urban areas proximate to the road construction [14-15].

Fig. 2. Effects produced by El Niño 2019 in the construction zone of the Road

A specific incident took place in the Milpopampa canal reservoir, triggering a severe flood in the San Juan Baños de Rabí community, situated between kilometers 200.0 and 201.8. This resulted in damage to houses and infrastructure, as documented in Figure 3[16].

Actualizado al 31 de enero 2019, a las 11:20 horas.

UBICACIÓN	VIDA Y SALUD		VIVIENDAS Y LOCALES PUBLICOS			VÍAS DE COMUNICACIÓN
	FAMILIAS DAMNIFICADAS	FAMILIAS AFECTADAS	VIVIENDAS COLAPSADAS	VIVIENDAS AFECTADAS	INSTITUCION EDUCATIVA AFECTADA	PUENTE VEHICULAR COLAPSADO
DPTO. PASCO						
PROV. DANIEL ALCIDES CARRIÓN						
DIST. YANAHUANCA	10	30	10	30	4	1
TOTAL	10	30	10	30	4	1

Nota: Instituciones Educativas (secundaria, primaria e Inicial) - centro poblado de San Juan Baños de Rabí.
Institución Educativa "Bernardo Chacón Tello" - Centro Poblado Astobamba
Fuente: Director de la Dirección Desconcentrada INDECI – Pasco.

Fig. 3. Damage assessment in the San Juan Baños de Rabí Community

3.3. El Niño Damage to Oyon Ambo Road

The primary cause of damage in the road construction area is attributed to rotational landslides. These occur along a failure plane, formed as a result of changes in the geomechanical characteristics of the materials on the slope. Such changes arise from heightened moisture levels within the soil structure. When this moisture surpasses the soil's shear strength, it facilitates the downward movement of the land mass along the slope.

Table 4. Unstable sectors of the Road affected by El Niño 2019

N°	Progressive	Progressive	Event Type	Technical File
1	194+280 -194+300194+360 -194+440	194+280 -194+300194+360 -194+440	Collapse Soil Crawling	52 - 6 Km. 194+260 - Km. 194+450Landslide
2	194+560 - 194+580	194+560 - 194+580	Collapse	52 - 7 Km. 194+550 - Km. 194+720Rotational Slip.
3	194+610 - 194+720	194+610 - 194+720	Slide	52 - 7 Km. 194+550 - Km. 194+720Rotational Slippage
4	196+380 - 196+460	196+380 - 196+460	Slide	52 - 10 Km. 196+380 - Km. 196+58·0Soil crawling
5	202+840 - 203+200	202+840 - 203+200	Landslide {Upper slope)	52 - 12 Km. 202+840 - Km. 203+030Rotational slippage
6	203+670 - 203+780	203+670 - 203+780	Soil Crawling	S2 - 13 Km. 203+590 - Km. 203+790
7	206+570 - 206+690	206+570 - 206+690	Landslide (Upper slope)	52 - 15 Km. 206+590 - Km. 206+69-0Landslide
8	213+690 - 213+710	213+690 - 213+710	Riverbank Erosion	ER-5 Km. 213+670 - Km. 213+71OEribereña River Spray.
9	213+890 -213+920	213+890 -213+920	Riverbank Erosion	ER - 6 Km. 213+880 - Km. 213+915Riverine River Erosion.
10	213+990 -214+090	213+990 -214+090	Riverbank Erosion	ER - 7 Km. 213+985 - Km. 214+080Riverine River Erosion.
11	214+220 -214+240	214+220 -214+240	Riverbank Erosion	ER - 8 Km. 214+180 - Km. 214+200Riverine River Erosion.
12	219+080 -219+100	219+080 -219+100	Riverbank erosion	ER - 9 Km. 219+070 - Km. 219+115Riverine River Erosion.
13	219+170 -219+260	219+170 -219+260	Riverbank Erosion	ER - 10 Km. 219+175 - Km. 219+260Riverine River Erosion.
14	228+970 - 229+000	228+970 - 229+000	Riverbank Erosion	ER - 12 Km. 228+940 - Km. 229+000Riverine River Erosion.

Similarly, the erosion issues observed on the banks, impacting various parts of the road's platform, can be linked to the hydrodynamic effects of the Rio Chaupihuaranga's currents. This was due to the region experiencing intense and prolonged rainfall, leading to increased discharge volumes exceeding the projections in the Technical File. Such

conditions resulted in the weakening of the platform at the base of the lower slope and potential overflow onto the platform in the lower areas.
The project's technical file identified 14 critical sectors, which are prone to instability due to their steep slopes and/or susceptibility to saturation. Consequently, the high rainfall associated with the El Niño phenomenon in 2019 exacerbated the instability of these sectors, accelerating their degradation until their complete destruction. These unstable sectors are detailed in Table 4.
Likewise, when carrying out a verification in the work, 29 new sectors affected by the occurrence of high rainfall were identified. These sectors are not included in the technical file of the work and also presented damages associated with the climatic event, which are described in Table 5.

Table 5. New sectors of the Road affected by El Niño 2019

N°	Initial location	Final location	Type of event	Proposed solution
1	193+650	193+710	Sinking of the entire platform	It requires geotechnical investigations to determine the depth and the alternative solution to be proposed.
2	194+930	194+950	Unstable sector, collapse of upper slope	
3	198+410	198+440	Collapse, critical sector	
4	200+470	200+530	Landslide that does not affect the road	It is not necessary to consider as additional
5	201+518	201+518	Discharge of the Rabí reservoir, demolished sewer	In the technical file is considered a sewer type MCA 2.0X2.0
6	201+560	201+580	Punctual affectation of reservoir discharge	It requires continuity to dead-end ravine.
7	201+580	201+680	Punctual affectation of reservoir discharge	
8	210+680	210+840	Destruction of platform by reservoir discharge	
9	202+320	202+340	Water collapse and seepage	Channel small ravine
10	202+820	202+850	Platform settlement and lower slope slide	Requires comprehensive geotechnical evaluation, including drainage system.
11	203+100	203+170	Slope crawling and lower slope slippage	
12	203+260	203+300	Platform settlement and lower slope slide	
13	205+890	205+900	Sewer collapses due to riverbank erosion	Requires erosion protection system
14	206+140	206+180	Collapse of left slope due to leaks with slight loss of platform	Requires drainage system to capture upper filtration water and erosion protection
15	209+100	209+140	Discharge from a small creek with sludge flow	Comprehensive sludge flow assessment
16	209+200	209+200	Landslides	Collapse cleaning for volume greater than fifty m3
17	209+380	209+400	Erosion of banks at the base of the lower slope	Requires erosion protection system
18	209+920	209+960	Upstream erosion of the Tambochaca Bridge	Requires erosion protection system
19	210+380	210+500	Vulnerable sector due to overflow of the Chaupihuaranga River	Requires evaluation of erosion protection system, after the water level drops
20	210+740	210+780	Discharge of landslide through a ravine with no exit to the river	Requires evaluation of discharge from stream to the river
21	211+325	211+335	Erosion of banks at the end of the protective wall	Requires erosion protection system.
22	211+430	211+450	Longitudinal cracks in berm	
23	212+100	212+120	Erosion of banks on the side of the platform	
24	213+780	213+800	Riverbank erosion	
25	213+960	213+970	Riverbank erosion	
26	219+010	219+060	Collapse in upper slope and cracks in berm due to erosion	
27	225+328	225+328	Uylupampa creek with landslide generated the obstruction of the Jatunragra Bridge	The file considers the construction of a bridge of 7m span
28	228+420	228+480	Fall of loose blocks of the upper slope	It is not necessary to consider as additional work
29	228+970	229+700	Fall of loose blocks of the upper slope	It is not necessary to consider as additional work

4. Reengineering in the execution of the road

During the project implementation, it was recognized that additional construction works were essential to meet the project's objectives. According to Peruvian public procurement laws, an additional work is defined as a service not anticipated in the initial technical documentation but is crucial and indispensable for achieving the project's intended goals. The primary aim of this project is to establish a road linking cities and communities within the designated area. However, this goal cannot be realized without constructing structures that ensure the stability of the base on which the road surface is laid. The necessity for these additional works arose due to the weakening of the base, compounded by landslides and floods in regions near the project, thereby mandating the implementation of reengineering solutions specific to the types of damage observed.

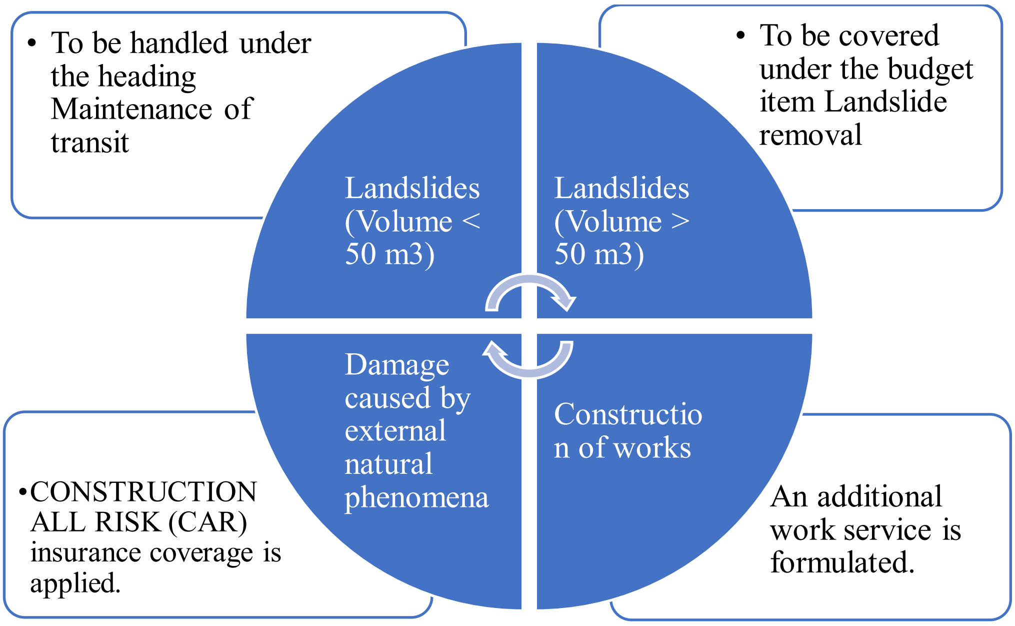


Fig. 4. Criteria for project reengineering in affected sectors

Should landslides occur, associated with the instability of the slope as outlined in the technical file, they can be addressed through either 1) Traffic Maintenance or 2) Removal of Landslides. In the scenario of Traffic Maintenance, the allocated budget caters to volumes less than 50 cubic meters. Conversely, in the case of Landslide Removal, the budget provision covers costs for collapse volumes exceeding 50 cubic meters. The primary distinction between these two items lies in their unit of measurement. The first item represents a comprehensive cost for the entire duration of the project, encompassing essential fixed resources such as workforce, equipment, and signaling apparatuses. The second item, however, specifically accounts for the costs associated with labor and equipment per cubic meter for the cleaning, transportation, and disposal of materials resulting from the collapse.

In cases where landslides are triggered by natural phenomena, leading to slippage, the procedure involves activating the Construction All Risk (CAR) insurance, a mandatory requirement stipulated in the contract. This insurance enables an insurer to cover damages inflicted by natural events on the construction undertaken. Such natural occurrences have the potential to impact various aspects of the construction, including pavements, bridges, and auxiliary areas. However, CAR insurance provides coverage for the reconstruction of these structures, contingent upon their damage being caused by natural phenomena as specified in the insurance policy. There has been an instance in Peru where a road construction project was halted due to the absence of this essential risk insurance [17].

However, it is important to note that risk insurance does not cover the construction of works that are not included in the original technical file. To address such needs, it becomes necessary to implement an additional work service. This can be categorized into two types: a) emergency nature and b) definitive. The emergency nature category pertains to works that require rapid execution, as their omission could compromise road safety and pose risks to the people residing in the vicinity of the affected area.

4.1. Works conducted with risk insurance coverage

The incidence of meteorological events, including the El Niño phenomenon which can lead to landslides, mudslides, and floods, is classified under the coverage of Construction All Risk (CAR) insurance. As a result, it was not required for the budget of the work to be increased due to landslides. Instead, the responsibility fell to the risk insurance company to cover these damages. These damages have been quantified at approximately 26,512 cubic meters, with an estimated cost of USD 697,684.00

4.2. Construction of emergency works

On the road project in question, it was deemed necessary to carry out only two emergency works: 1) in the San Juan Baños de Rabí sector, spanning from km 200 + 000 to km 201 + 700, and 2) in the sector with complete undermining of the platform, located between km 219 + 170 to km 219 + 260. For the first emergency work, measures included constructing a temporary speed bump, building a paved channel for the conduction of rainwater, and expanding the work platform. In the second case, a new support platform was constructed using a rock base to shield it from river undermining, as illustrated in Figure 5 and Figure 6. The total cost for these emergency works was estimated at USD 96,578.00.

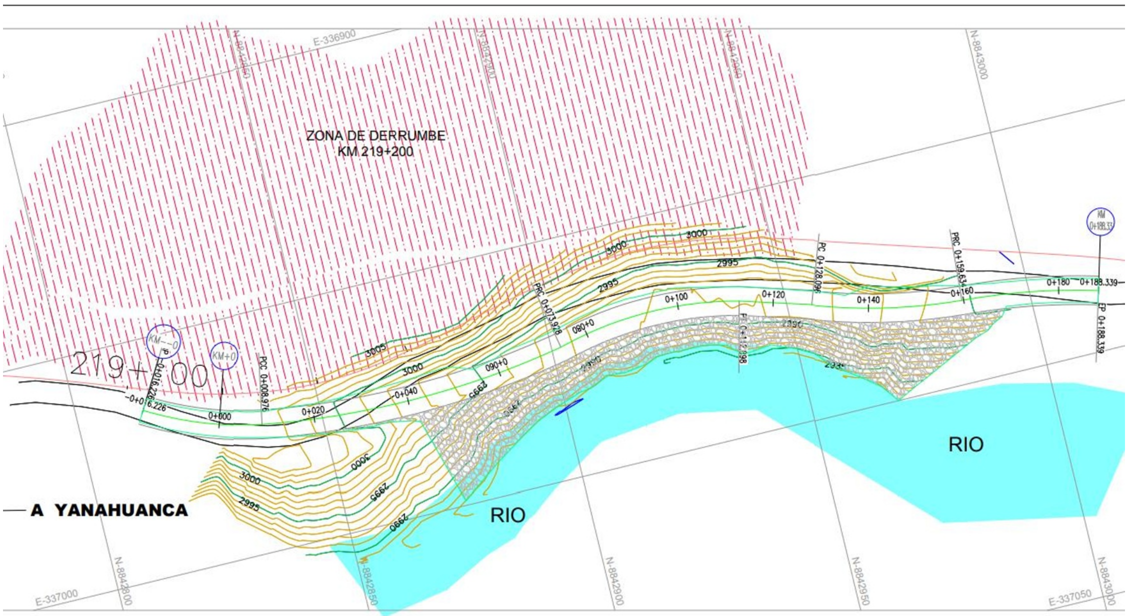


Fig. 5. Floor plan of the emergency works of the sector from km 219+170 to km 219+260

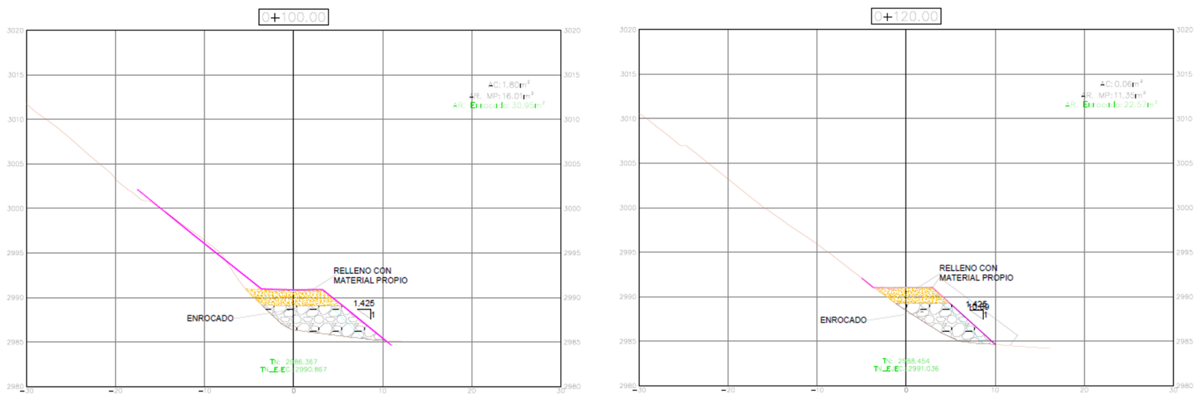
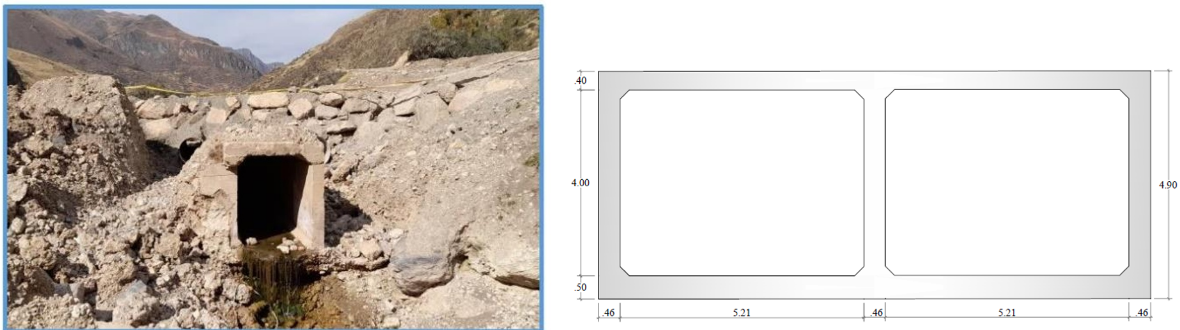


Fig. 6. Cross-sectional plan of emergency works in the sector from km 219+170 to km 219+260 (partial stakes 0+100 and 0+120)

The emergency additional works represent essential minimal interventions required to ensure vehicle movement and the safety of residents near the impacted zone. These tasks were carried out in April 2019.

4.3. Construction of definitive additional works

In the area with complete undermining of the platform situated between km 200+000 and km 201+700, it was proposed to construct two primary structures. The first is a two-eyed frame type culvert, with dimensions of 10.20m x 4.90m, as depicted in Figure 7. This culvert is designed to replace the current sewer, which has a 1.20m x 1.20m section, deemed inadequate for the evacuation of rainwater and waters collected in the ravine of the San Juan Baños de Rabí peasant community.



Alcantarilla existente visto desde aguas abajo

Sección transversal esviajada, alcantarilla marco de 2 ojos

Fig. 7. Two-eyed frame sewer solution approach

The second structure, as illustrated in Figure 8, is designed as a protective measure for the platform of the newly aligned projected road. Based on the fundamental study of hydrology and hydraulics, the construction of a reinforced concrete channel is recommended. This channel is to be built starting from the exit of the two-eyed frame sewer. The design of this structure was conducted in accordance with the AASHTO LRFD 2017 design specifications and the Bridge Manual issued by the Ministry of Transport and Communications. To ensure its structural integrity, it was confirmed that the sizing of each of the retaining walls adheres to stability criteria, including the pressures exerted on the foundation floor. Additionally, the reinforcement in the footings and walls was calculated to meet the limit states as per the design specifications. The total cost for the execution of all necessary structures in the sector between km 200+000 and km 201+700 has been estimated at USD 1,657,894.00.

Vista hacia aguas bajo del canal de descarga, requiere protección

Sección típica del canal de concreto armado

Fig. 8. Platform protection structure solution approach

In the area between km 219 + 170 and km 219 + 260, the construction of a definitive work has not yet commenced. This is due to ongoing permanent topographic monitoring aimed at detecting any differential movements between established control points on the slope. Following this verification process, a decision may be made to proceed with the construction of a definitive work. This would involve building a permanent platform, implementing drainage works, and forming embankments.

5. Results and Discussion

The Oyon Ambo highway's road infrastructure is pivotal in the ongoing development of Peru's national road network. While the technical file for this project includes a twenty-year hydrological study, the El Niño phenomenon of 2019, classified as a weak event by SENAMHI, inflicted considerable damage along Section II of this road. These damages encompassed landslides, undermining of the base, destruction of the road platform, and flooding.

During construction, the focus was on identifying the most appropriate technical solutions for each specific situation. A key factor in selecting these solutions was the optimization of costs, given that the project is financed with public funds from the Peruvian state. This approach underscores the importance of cost-efficient, yet effective, methodologies in addressing the challenges posed by such natural events in the construction and maintenance of critical infrastructure.

To address the issues related to each type of damage encountered, a detailed technical evaluation is conducted in each affected sector. As demonstrated in Figure 9, this evaluation encompasses three potential scenarios. Landslides are immediately cleared; however, other forms of damage necessitate the construction of new structures. For these, it is essential to formulate additional work services, which must be completed prior to the preparation of the technical file.

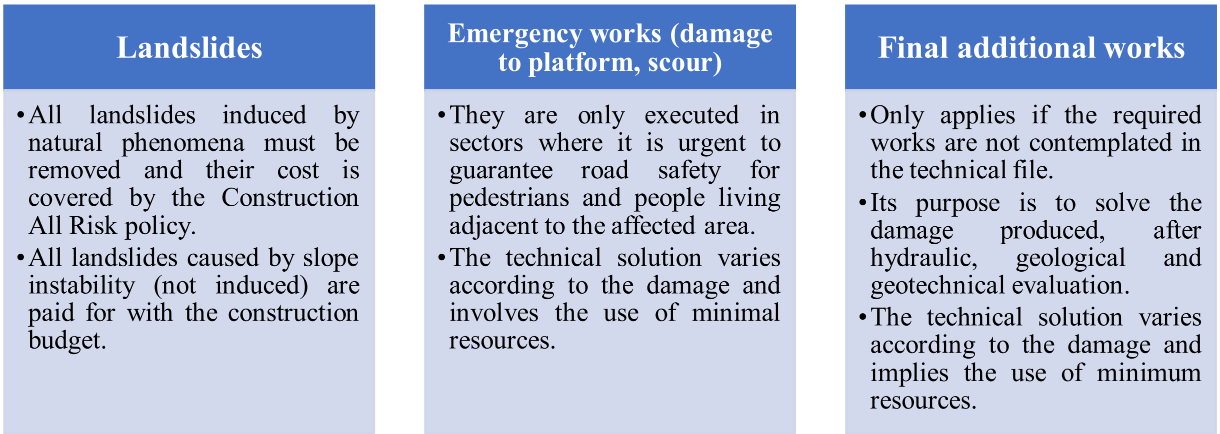


Fig. 9. Platform protection structure solution approach

6. Conclusions

The Oyon Ambo highway, Section II, is a road infrastructure project situated in the high Andean region of the Pasco area in Peru. It spans altitudes ranging from 3,500 meters to 4,800 meters above sea level, positioning it as one of the most geographically challenging roads in the world. This highway runs adjacent to the Chaupihuaranga River, a tributary of the Huallaga River. The river originates from the peaks of the Raura and Huayhuash mountain ranges, flowing in a northeasterly direction until it joins the Huallaga near the city of Ambo in Huánuco. The extreme natural event of high rainfall significantly increased the river's flow, leading to severe damage and necessitating substantial modifications to the engineering aspects of the road project.
The occurrence of this extreme natural event necessitated significant alterations to the engineering plans of the road under construction, adapting the project to the newly altered topography. Four years subsequent to this phenomenon, a comprehensive assessment of the damages and modifications to the project's technical file has been completed. This assessment was due to the impact of this extreme natural event. Additionally, valuable lessons have been documented to inform future road construction projects. Risk management has emerged as a crucial strategy to mitigate the impacts of such events, particularly when the likelihood of these extraordinary phenomena is considered low.

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