Analysis and Recommendation of Landslide and Road Damage on State Road PR-167, Km 7.2 Naranjito, PR

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Abstract *— The State Road PR-167 segment, where the project is located, is a primary state highway road bordering La Plata River, in the municipality of Naranjito, that serves as a connector between Naranjito and Comerío and represents the primary access to the second one to the metropolitan area. The steep rock slope, with frequent rock falls located on state highway PR-167 Km 7.2 in Naranjito was identified, and several road damages need to be addressed to ensure the stability of the slope condition and the safety of the road users. The proposed improvements include strategies and counter-measurements to repair and stabilize the rock slope. These counter measurements include repair works for the damages caused by the rockfall on the roadway and preventive works to reduce the possibility of future damages.*

Key Terms *— Landslide, Puerto Rico Highway and Transportation Authority, Repair Recommendation, Rock Falls.*

INTRODUCTION

The Puerto Rico Highway and Transportation Authority (PRHTA) collected information from previous visits to the site on the PR-167, km7.2. The inspection report of PRHTA [1] was used to develop the analysis of improvement alternatives that will enhance the general safety conditions in the affected area.

The segment of the state road PR-167 affected by this project has a typical section [2] of two (2) lane roadways of approximately 3.9 meters wide lanes, one (1) in each direction. The traffic flow is divided by a single yellow skip center line. It is located on mountainous terrain with a posted speed limit of 40 mph. The existing right of way was determined as approximately 15 meters, 7.5 meters from the centerline to both sides of the road.

From kilometers 7.1 to 7.3 on the PR-167 highway, there is a steep rock slope with frequent rock falls that represent a safety issue for road users due to the geological conditions of the zone. Figure 1 provides an identification of the site.

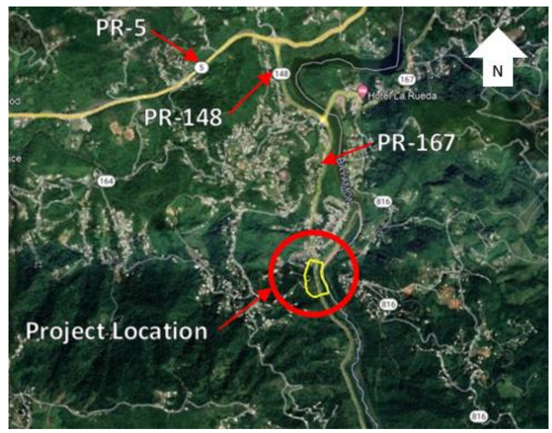

Figure 1
Location Map

As indicated in the assessment report [1], highway PR-167 was built within a complex geology of various types of volcanic clastic rocks and quartz diorite. The material that makes up the rocks of the fault area is a conglomeration of sedimentary rocks, sandstone, siltstone, and lava volcanic that is considerably fractured.

Figure 2 shows the segment where the project is located. The length of the rock slope is approximately 185 meters, and the average height is 16 meters, but it reaches up to 40 meters in height. The angle of inclination of the slope concerning the horizontal is approximately 78 degrees.

Figure 2
Aerial View of Rock Slope

Currently, there is a temporary safety solution implemented in the rockfall area. The temporary solution consists of partially closing the road using temporary concrete barriers at the center of the road and a chain-link fence at the back of the concrete barriers to provide a safety buffer zone between the rock slope and the traveled way, providing a landing area for the rockfall, also to prevent the pass of the rocks to the traveled way. Figure 3 shows PRHTA buffer zone for rock fall.

Figure 3
Buffer Zone

The implemented temporary solution reduces the operational capacity of the PR-167 highway due to the partial closure of the road and presents vulnerabilities due to the types of materials implemented for the fence and the limited safety buffer zone provided. It is urgent to provide a permanent solution to mitigate the rock fall and guarantee the stability of the rock slope considering the geometric restrictions of the road (space limitations) and the geological conditions (height of the slope, a dip of the discontinuities, size of the fallen rocks. A cost-benefit analysis of different alternatives and recommendations is presented in this analysis.

Justification

After Hurricane Maria, PRHTA have implemented countermeasures, that are neither permanent nor completely safe for road users, and its impact is affecting the operation of the road. For this reason, it is recommended that measures be implemented to improve the temporary alternative using competent materials existing in the geotechnical industry to resist the impact of rockfall.

Review Of Literature

Rockfall Alternatives

The alternatives considered in this project are:

- Rockfall protection using mesh system with ground anchors [3];
- Surface protection using shotcrete with ground anchors;
- Rock slope cut with draped mesh, concrete barriers, and chain-link fences.

Alternative 1: Rockfall Protection Using Mesh System with Ground Anchors

Ground anchors [4] are one of the most common types of internal reinforcement. Ground anchors are threaded steel bars inserted into the rock via drilled holes and bonded to the rock mass by cement grout. Because the bond strength between the cement grout and the rock is less than the steel's maximum yielding stress, it significantly impacts the rock reinforcement's design load.

Rock anchors [3] can be tensioned or untensioned. Untensioned ground anchors are recommended for the internal stabilization of the rock slope evaluated in this analysis. Two types of untensioned anchors are used in rock stabilization: rock dowels and shear pins. Both are untensioned, fully-grouted steel bars used for passive reinforcement. Dowels are used on steep slopes in the same fashion as rock bolts, while shear pins are used on flatter slopes where bedding planes and discontinuities determine the slope angle and failure plane.

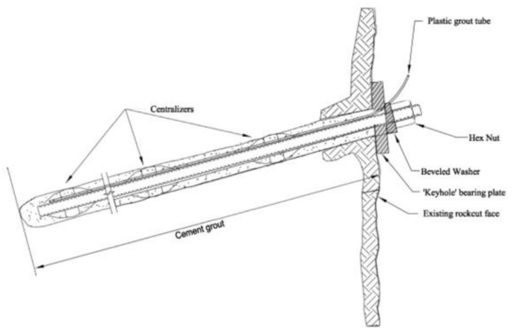

Figure 4
Typical Untensioned Rock Dowel

Rock dowels [5], as illustrated in Figure 4, are typically used on newly excavated slopes. They can be installed in a grid pattern to support an entire face or used to support one block. They provide initial reinforcement through the shear strength of the steel, which increases friction along the potential plane of weakness. Once block movement occurs, depending on dowel orientation, the tensile strength of the bar is engaged, and the normal force between opposing discontinuities is increased. Dowels can be used in highly fractured and weak rocks that cannot hold a tensioned rock bolt, and because dowels are installed in one step, they are quicker to install than tensioned bolts.

Ground anchors [3] are often used with facing systems to stabilize slopes and landslides. Different methods of facing systems may be used to transfer the ground anchor loads to the ground at the slope surface, provided the ground does not “run” or compress and is able to resist the anchor reaction forces at the excavated face. Cost, aesthetics, and long-term maintenance of the exposed face will affect the selection of the facing system.

Figure 5 show an example of wire mesh facing system in combination with ground anchors.

Figure 5
Wire Mesh Facing Over Rock Slope Example

Advantages

- Causes less environmental impact.
- Less expensive
- The construction is normally faster.
- Requires less material.
- Require less impact to the existing conditions on the road section.

Disadvantages

- Anchor execution would affect the land of surrounding construction works, which their owners must accept.
- Challenging to apply anchors in weak soil and implement them with great depth.

Alternative 2: Surface Protection Using Shotcrete with Ground Anchors

The ground anchors technique used in this alternative is the same as in Rockfall Protection [6], using a mesh system with ground anchors except for the facing protection. To stabilize the slope facing, a facing of shotcrete is proposed to be installed as part of this alternative.

The bearing plates of the ground anchors are supported on the initial facing. The final facing is constructed over the initial facing and provides structural continuity throughout the design life. The final facing may also include an aesthetic finish. The initial facing most commonly consists of reinforced shotcrete.

The final facing generally consists of CIP-reinforced concrete, reinforced shotcrete, or precast concrete panels. Shotcrete facing is illustrated in Figure 6.

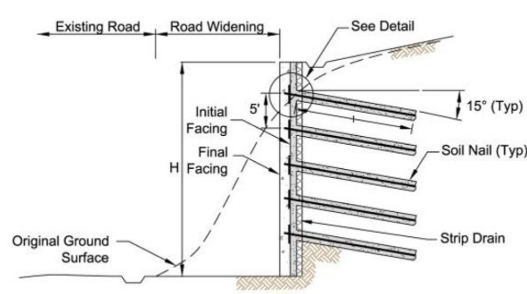

Figure 6
Typical Cross-Section of Shotcrete in Combination with Reinforcing Elements

Figure 7 shows an example of shotcrete facing system in combination with ground anchors.

Figure 7
Shotcrete Facing Over Rock Slope Example

Advantages

- Requires less material.
- Easy site adjustments

Disadvantages

- Anchor execution would affect the land of surrounding construction works, which their owners must accept.
- Challenging to apply anchors in weak soil and implement them with great depth.
- Concrete is typically more expensive.
- Start to dry beforehand, creating a substance too hard to spray.
- Causes environmental impact.
- Required more right of way acquisitions.

Alternative 3: Rock Slope Cut with Draped Mesh, Concrete Barriers and Chain-Link Fences

This alternative consists in cutting the rock slope at an offset distance of approximately 4 meters from the edge of the road to create a safety buffer zone that serves as a deposit zone in case of any rockfall.

This alternative is combined with a draped mesh system to allow rockfalls to be controlled and guided into the deposition zone. The safety buffer zone is delimitating using concrete barriers and chain-link fences to prevent the pass of the rocks to the traveled way. Draped mesh facing as illustrated in Figure 8.

The proposed slope cut inclination is 1H:3V, similar to the existing slope inclination. The impact of implementing a cut of this magnitude in the rock slope is significant because there are residences and infrastructure on the top of the mountain that would be affected.

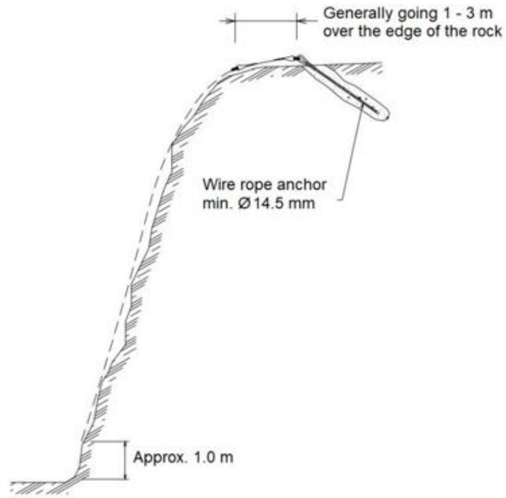

Figure 8
Typical Cross Section of Draped Wire Mesh System

For that reason, this alternative is presented with an inclination similar to the existing one in combination with a rockfall protection system [6]. Figure 9 show an example of shotcrete facing system in combination with ground anchors.

Figure 9
Drape Mesh Facing Over Rock Slope Example

Advantages

- Requires less material.
- Reduce the risk of rocks passing into the traveled way.

Disadvantages

- Future erosion by rain could affected the stability and rock fall will affect traffic.
- More expensive due to the earthworks.
- Rocks that compose the cut slope are extremely susceptible to chemical and mechanical breakdown once exposed.

- Required more right of way acquisitions.
- Cutting the rock slope could cause structural weakness.

METHODOLOGY

The following information explains the methodology used in this research. Through the data and information collection process, were made three (3) visits to the PR-167 Km 7.2. With the information provided by PRHTA and data initially obtained during the site visits, it was possible to propose three (3) different alternatives that could qualify to solve the rock fall problem and improve the operation of the road.

In addition, the data provided by the PRHTA was considered in the evaluations of the alternative. For each alternative, an investigation was carried out to analyze their advantages and disadvantages.

After analyzing the alternatives and the data provided by PRHTA, a conclusion of results was reached, and the most viable alternative was selected.

FINDINGS

Based on the considerations discussed in the Review of Literature and Methodology, the most feasible alternative must be the one that repairs the rock slope damages with:

- Shortest construction time
- Least disruption in traffic
- Less right of way impacts
- Less environmental impacts
- Less construction costs.

The preliminary cost was made using the historical cost of the past auction by the PRHTA. The preliminary cost of the entire project considering alternative 1, which consists of the installation of rockfall protection using a mesh system with ground anchors, is approximately $2,806,225.59. Table 1 presented a breakdown of alternative 1.

Alternative 2, which consists of the installation of rockfall protection using a shotcrete system with ground anchors, is approximately $3,114,853.00. Table 2 presented a breakdown of alternative 2.

Table 1
Alternative 1 Cost Estimate

ITEM	SPEC NO.	CLASS OF WORK	UNIT	APPROX. QUANTITY	UNIT PRICE ($)	AMOUNT ($)
		General Requirements				
1	151	Mobilization (10%)	LS	1	$188,971.42	$188,971.42
2	611	Field and Laboratory Office Model 2	Month	6	$3,500.00	$21,000.00
3	661	Project Sign	Each	1	$3,500.00	$3,500.00
		Sub-Total General Requirements				*$213,471.42*
		Improvements				
4	201	Clearing and Grubbing	Cda	1.00	$10,000.00	$10,000.00
5	203	Unclassified Excavation	CuM	887	$35.00	$31,045.00
6	210	Temporary Stabilization Entrance	Each	2	$1,500.00	$3,000.00
7	210	Silt Fence	LnM	40	$10.00	$400.00
8	210	Straw Bales	Each	45	$15.00	$675.00
9	401	Hot Plant-Mix Bituminous Pavement S(75)(12)	Ton	213	$190.00	$40,470.00
10	403	Cold Milling Bituminous Concrete Pavement	CuM	77	$350.00	$26,919.20
11	617	Concrete Paved Waterway	SqM	244	$120.00	$29,280.00
12	617	Bed Course Material	CuM	49	$250.00	$12,250.00
13	618	Thermoplastic Pavement Marking Stripes	LnM	500	$4.00	$2,000.00
14	638	Flashing Arrow Sign	Day	180	$85.00	$15,300.00
15	638	Construction Signs	SqM	46	$200.00	$9,200.00
16	638	Drums	Each	112	$150.00	$16,800.00
17	638	Temporary Concrete Barriers	LnM	220	$160.00	$35,200.00
18	638	Flagger	Day	180	$75.00	$13,500.00
19	638	Portable Changeable Message Sign	Month	6	$300.00	$1,800.00
20	640	Reflective Raised Pavement Markings One Way, Clear	Each	25	$15.00	$375.00
21	640	Reflective Raised Pavement Markings Two Way, Yellow	Each	25	$20.00	$500.00
22	-	Ground Anchors & Mesh System	SqM	2,969	$500.00	$1,484,500.00
23	-	ROW Acquisition Allowance	SqM	8800	$15.00	$132,000.00
		Sub-Total Improvements				*$1,865,214.20*
		SUB-TOTAL				**$2,078,685.62**
		35% ENGINEERING AND CONTINGENCIES				$727,539.97
		TOTAL				**$2,806,225.59**

Table 2
Alternative 2 Cost Estimate

ITEM NO.	SPEC NO.	CLASS OF WORK	UNIT	APPROX. QUANTITY	UNIT PRICE ($)	AMOUNT ($)
		General Requirements				
1	151	Mobilization (10%)	LS	1	$209,754.42	$209,754.42
2	611	Field and Laboratory Office Model 2	Month	6	$3,500.00	$21,000.00
3	661	Project Sign	Each	1	$3,500.00	$3,500.00
		Sub-Total General Requirements				*$234,254.42*
		Improvements				
4	201	Clearing and Grubbing	Cda	1.00	$10,000.00	$10,000.00
5	203	Unclassified Excavation	CuM	887	$35.00	$31,045.00
6	210	Temporary Stabilization Entrance	Each	2	$1,500.00	$3,000.00
7	210	Silt Fence	LnM	40	$10.00	$400.00
8	210	Straw Bales	Each	45	$15.00	$675.00
9	401	Hot Plant-Mix Bituminous Pavement S(75)(12)	Ton	213	$190.00	$40,470.00
10	403	Cold Milling Bituminous Concrete Pavement	CuM	77	$350.00	$26,919.20
11	617	Concrete Paved Waterway	SqM	244	$120.00	$29,280.00
12	617	Bed Course Material	CuM	49	$250.00	$12,250.00
13	618	Thermoplastic Pavement Marking Stripes	LnM	500	$4.00	$2,000.00
14	638	Flashing Arrow Sign	Day	180	$85.00	$15,300.00
15	638	Construction Signs	SqM	46	$200.00	$9,200.00
16	638	Drums	Each	112	$150.00	$16,800.00
17	638	Temporary Concrete Barriers	LnM	220	$160.00	$35,200.00
18	638	Flagger	Day	180	$75.00	$13,500.00
19	638	Portable Changeable Message Sign	Month	6	$300.00	$1,800.00
20	640	Reflective Raised Pavement Markings One Way, Clear	Each	25	$15.00	$375.00
21	640	Reflective Raised Pavement Markings Two Way, Yellow	Each	25	$20.00	$500.00
22	-	Ground Anchors & Shotcrete Wall System	SqM	2,969	$570.00	$1,692,330.00
23	-	ROW Acquisition Allowance	SqM	8800	$15.00	$132,000.00
		Sub-Total Improvements				*$2,073,044.20*
		SUB-TOTAL				**$2,307,298.62**
		35% ENGINEERING AND CONTINGENCIES				$807,554.52
		TOTAL				**$3,114,853.14**

The preliminary cost was made using the historical cost of the past auction by PRHTA. The preliminary cost of the entire project considering alternative 3, which consists of the rock slope cut with draped mesh, concrete barriers, and chain-link fences, is approximately $4,631,001.00. Table 3 presented a breakdown for alternative 3.

Table 3
Alternative 3 Cost Estimate

ITEM NO.	SPEC. NO.	CLASS OF WORK	UNIT	APPROX. QUANTITY	UNIT PRICE ($)	AMOUNT ($)
		General Requirements				
1	151	Mobilization (10%)	LS	1	$400,921.92	$311,851.92
2	611	Field and Laboratory Office Model 2	Month	6	$3,500.00	$21,000.00
3	661	Project Sign	Each	1	$3,500.00	$3,500.00
					Sub-Total General Requirements	***$336,351.92***
		Improvements				
4	201	Clearing and Grubbing	Cda	1.00	$10,000.00	$10,000.00
5	203	Rock Excavation (Cut)	CuM	13,479	$150.00	$2,021,850.00
6	210	Temporary Stabilization Entrance	Each	2	$1,500.00	$3,000.00
7	210	Silt Fence	LnM	40	$10.00	$400.00
8	210	Straw Bales	Each	45	$15.00	$675.00
9	401	Hot Plant-Mix Bituminous Pavement S(75)(12)	Ton	213	$190.00	$40,470.00
10	403	Cold Milling Bituminous Concrete Pavement	CuM	77	$350.00	$26,919.20
11	607	Chain-Link Fence, Type	LnM	220	$85.00	$18,700.00
12	610	Concrete Barrier, Type "C"	LnM	220	$500.00	$110,000.00
13	617	Concrete Paved Waterway	SqM	244	$120.00	$29,280.00
14	617	Bed Course Material	CuM	49	$250.00	$12,250.00
15	618	Thermoplastic Pavement Marking Stripes	LnM	500	$4.00	$2,000.00
16	638	Flashing Arrow Sign	Day	180	$85.00	$15,300.00
17	638	Construction Signs	SqM	46	$200.00	$9,200.00
18	638	Drums	Each	112	$150.00	$16,800.00
19	638	Temporary Concrete Barriers	LnM	220	$160.00	$35,200.00
20	638	Flagger	Day	180	$75.00	$13,500.00
21	638	Portable Changeable Message Sign	Month	6	$300.00	$1,800.00
22	640	Reflective Raised Pavement Markings One Way, Clear	Each	25	$15.00	$375.00
23	640	Reflective Raised Pavement Markings Two Way, Yellow	Each	25	$20.00	$500.00
24	-	Draped Mesh System	SqM	2,969	$200.00	$593,800.00
25	-	ROW Acquisition Allowance	SqM	8800	$15.00	$132,000.00
					Sub-Total Improvements	***$3,094,019.20***
					SUB-TOTAL	**$3,430,371.12**
					35% ENGINEERING AND CONTINGENCIES	$1,200,629.89
					TOTAL	**$4,631,001.01**

Table 4 presents the comparison of the results between the evaluated alternatives based on the criteria indicated above. For the comparison, points from 1 to 3 were assigned for each alternative based on compliance with the criteria, where 3 is the best score and 1 is the lowest, for a total of 15 points considering the five items in the evaluation criteria.

Table 4
Evaluation Results Comparison Table

Criteria	Alternative 1	Alternative 2	Alternative 3
Shortest construction time	3	3	1
Least disruption in traffic	1	1	1
Less right of way impacts	3	3	1
Less environmental impacts	3	3	1
Less construction cost	3	2	1
Total points	**13**	**12**	**5**

Summary and Conclusions

Based on the results from Table 4, Alternative #1 (Rockfall Protection using mesh system with ground anchors) provides the most feasible alternative.

It is important to consider that Alternative 1 do not include the scope the consideration of a safety buffer zone to reduce the risk of rocks passing into the traveled way and increase the comfort perception of users. Alternative 3 consider a safety buffer zone between the road and the rock embankment, but this alternative was not selected because it obtained the lowest score of the three alternatives included in the evaluation. Also, for alternative 3 exists the risk of structural weakness during the implementation of the techniques for cutting the rock slope due to the high fracturing and hydrothermal alteration suffered by the rock within the project area.

This recommendation was not fully evaluated in this analysis due to the limitation on the original scope of the project. However, this recommendation was preliminarily evaluated as additional works for the evaluated alternatives in this analysis, to be able to provide a preliminary cost estimate.

Acknowledge

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