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Road Stabilization and Drainage Improvements in North Potosi, Bolivia - Improving Access to Markets, Clinics, Schools, and Facilitating Future Development

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ABSTRACT In a remote and extremely impoverished region of southwestern Bolivia, the only road connecting five communities to the outside world has been historically washed out multiple times per year. With the support of TRANSNOW, the University of Washington chapter of Engineers Without Borders (EWB-UWS) partnered with these small communities to implement a rural roads improvement project in July and August, 2010. Over the course of these two months, the EWB-UWS team implemented a number of robust but low-cost designs aimed at improving drainage and reducing the impact of erosion. These designs included gabion walls, drywalls, cemented drywalls, and armored crossings. The implemented designs promise to keep the road open for nearly the entire year, and reduce the burden of maintenance for the estimated 380 residents of the communities who rely on the road.			
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Improving Access to Markets, Clinics, Schools, and Facilitating Future Development

Engineers Without Borders
University of Washington Chapter
(EWB-UWS)

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Introduction

In a remote and extremely impoverished region of southwestern Bolivia, the only road connecting five communities to the outside world has been historically washed out multiple times per year. With the support of TRANSNOW, the University of Washington chapter of Engineers Without Borders (EWB-UWS) partnered with these small communities to implement a rural roads improvement project in July and August, 2010. Over the course of these two months, the EWB-UWS team implemented a number of robust but low-cost designs aimed at improving drainage and reducing the impact of erosion. These designs included gabion walls, drywalls, cemented drywalls, and armored crossings. The implemented designs promise to keep the road open for nearly the entire year, and reduce the burden of maintenance for the estimated 380 residents of the communities who rely on the road.

Background

Location

Road between Yanayo Grande, Tuquiza and the Acacio-Cochabamba highway
Municipality of Acacio, Department of Potosí, Bolivia
Latitude: 18° 02' 18" S
Longitude: 65° 59' 6" W

The communities served by the road directly are Yanayo Grande, Yanayo Chico, Tuquiza, Cueva Pata, and Llut'ara. These communities are located in the municipality of Acacio, situated in a remote area of the Andes Mountains in the northern part of the department of Potosi, Bolivia. The region is approximately 100 kilometers southeast of Cochabamba, the closest major city, and the trip by car takes four to six hours over rugged, unpaved roads. The indigenous villagers in the region maintain their culture and primarily speak Quechua, but most also speak some Spanish.

The road to Tuquiza and Yanayo Grande begins at a junction of the main Acacio-Cochabamba highway. The distance from the junction past Tuquiza and to Yanayo Grande is 11km. The surrounding communities of Yanayo Chico, Cueva Pata, and Llut'ara also use this road.

Original Road

The original road was built less than ten years ago and was designed for very low-volume, single vehicle traffic, with virtually no features to ensure proper drainage. The construction used the basic cut-and-fill method with a D8 bulldozer. The road is very narrow, with very steep upslopes and downslopes at many locations. As a result, the soil is unstable and rockslides are common, especially during the rainy season, when the region is often subject to large flash floods that cause road erosion and can make the road impassable. Examples of this erosion and instability are shown in Figures 1 and 2.

Figure 1: Major erosion and rutting along roadway before implementations

Figure 2: El Truncal before implementation with erosion clearly visible

Community Partnership

EWB-UWS has built an extensive connection with the communities in the region through previous projects aimed at health and income generation. The citizens of Tuquiza and Yanayo Grande have expressed great interest and motivation in improving and increasing the sustainability of this road since EWB-UWS first began work in the area in 2005.

The current roads project built on previous partnerships with three of the local communities - Tuquiza, Yanayo Grande, and Llut'ara – which all committed to contribute their labor to the project. Two more communities, Cueva Pata and Yanayo Chico, also benefitted from the project, though they were unable to contribute labor due to other commitments.

Relationship with Previous Projects

The project was a continuation of a previous, smaller-scale roads improvement project executed in 2008. This pilot project provided modest drainage and erosion control for the road with rock drywalls and armored crossings. The project was very successful given the modesty of the designs. However, with only a $10,000 budget and no heavy equipment or gabions, there was a need for future, more robust work.

As the second road improvement implementation, the current project focused on creating long-term improvements that required much more technical and financial support than previous trips. TRANSNOW's funding provided this support. Professional geotechnical engineering mentors, students, and the community members worked together both at the University and in the field to determine the appropriate designs for every site. The Acacio municipality's road engineer also provided technical advice throughout the implementation trip.

Problem Statement

Extremely heavy rains during the wet season in Northern Potosi, Bolivia, combined with steep slopes and poor soil result in major erosion of the only road that directly serves 380 people directly in five communities. This massive erosion frequently renders the road impassable by motor vehicles.

This is a key concern because the condition of the road drives the health, income, and education potential of the communities:

- The communities use the road for travel between communities, usually on foot. It is the sole means for transporting crops to Cochabamba to sell, as well as getting supplies and materials from out of town.
- Health personnel use this road to access the communities for vaccinations or emergencies. In total, the road serves nearly 5000 people in the surrounding communities.
- Students above fifth grade must use the road to get to school.

When the road is impassible, access to these critical services is impossible. Given the importance of health, income generation, and education to the overall development of the communities, road improvements were a top priority for both the communities and EWB-UWS.

Project Objectives

1. ***Access****:* Keep the road open longer each year to improve community access for an estimated 380 residents to:
    a. ***Health:*** routine and emergency healthcare
    b. ***Education****:* schools above grade five
    c. ***Income****:* markets to sell crops and access to financing and supplies
2. ***Future Development****:* Facilitate future EWB-UWS project implementations aimed at improving the quality of life of the communities in the region linked by the road by keeping the road passable for supply delivery.
3. ***Technology Transfer:*** Continue educating the community on roadway maintenance and construction of various implemented designs to promote the sustainability of the project.
4. ***Education****:* Provide valuable hands-on engineering, project management, and international experience to University of Washington students working on the project.

Methods and Design Details

The project team focused primarily on three large sites. The construction process and designs for each site are detailed below:

A. Tarcuni

This site, where the road crosses the Tarcuni River, was the largest and most important site in the project. The river drains a large watershed and, at full force, can move boulders the size of a sedan. The erosion at Tarcuni after only a mild storm is shown in Figure 3.

Figure 3: Tarcuni during the rainy season with stream and debris crossing perpendicular to roadway

The design at Tarcuni, depicted in Figure 4, consisted of:

- A three tiered gabion wall placed about 3.5 meters from the road
- Rocks reinforced by flat gabions, attached to each tier of gabion wall, between the wall and the road
- A 2:1 slope of large rocks on top of the gabion wall
- A large armored crossing on the surface of the road

The gabion wall and 2:1 rock slope should provide a massive support that will prevent the entire road from washing out. The armored surface of the road should maintain a better driving surface throughout the rainy season.

Figure 4: The robust design at Tarcuni, after laying concrete

The construction process was as follows:

1. Construction footprint was excavated with a backhoe, and site preparation was finished with hand tools
2. Gabion baskets were assembled and placed, and flat gabions were attached to the backs of baskets.
3. Rocks were filled inside baskets first, and then on top of flat gabions.
4. 30-cm-thick layer of sand and gravel was placed between road and rock layer.
5. Rocks were placed in front of baskets, up to basket level, then sloping down to ground.
6. Process was repeated for next two levels of gabion baskets and flat gabions. Rocks on both sides of the gabions were added before next layer.

7. Surface of the road was leveled and graded.
8. Layer of dirt and sand placed on road surface, and then large, flat rocks placed on top.
9. A cordon was dug around the outside perimeter of the armored crossing, with large rocks placed 30 cm into the ground to protect the edges of the armored crossing.
10. Concrete was mixed and placed between flat rocks.
11. Concrete was placed on top of rock slope to provide a more cohesive layer protecting the gabions.
12. Concrete cured and dried

B. El Truncal

This site is the entrance to the communities from the highway and is especially important to the communities' because it provides outsiders their first impression of the communities. The site required a large 27 gabion barrier, which was justified based on the importance of the site to the communities.

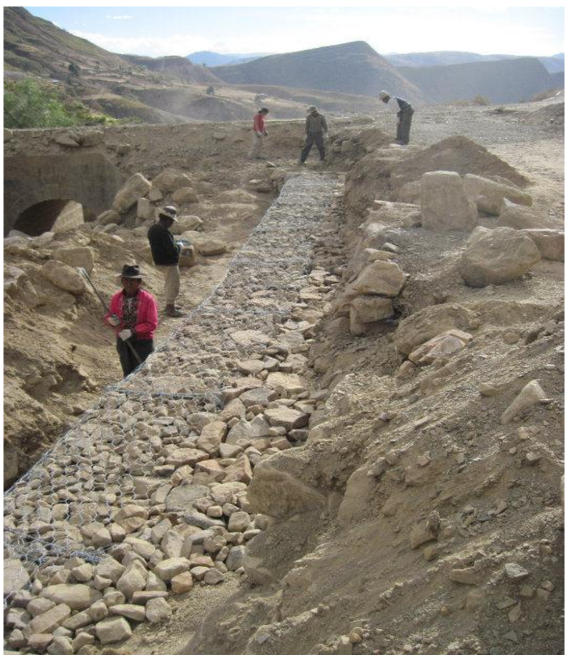

Figure 5: Llut'arans completing the first layer of gabions at El Truncal.

The government of Acacio previously built a large culvert under the main road at this site. During the rainy season, the flow volume and velocity through this culvert are large. As the flow nears the crossing, it rebounds off the main road and swirls around, creating a large whirlpool-like basin between the main road and the road to Tuquiza and Yanayo. Much of the water flows over the Tuquiza-Yanayo road, eroding the edges of the road and making travel difficult and dangerous. In addition, an offshoot of the flow hits the Tuiquiza-Yanayo road at an angle, washing over the road with high velocity. To mitigate erosion caused by this flow, we built a barrier to prevent water from washing over the edge of the basin and onto the roadway. We also tried to construct a wall of boulders to redirect the offshoot back into the basin. The flow path was also modified slightly to better direct the flow to the culvert.

The construction at El Truncal consisted of:

- A two tiered gabion wall adjacent to the road, with an 11-gabion bottom layer and a 16-gabion top layer, offset about 10-20 centimeters. This wall is shown in Figure 5.
- A 16-m wall of boulders moved into location by the backhoe
- A slight re-grading of the flow channel

The first layer of the wall consisted of 11 gabions, properly filled and tied together; the second layer of 16 gabions was placed on top of the 11 gabions and was offset by 10-20 cm in a stair-like pattern. The wall rose above the level of the road by 10 cm. After all gabions were constructed and placed, the backhoe was used to backfill the wall with rock for more support along the road, and to clear the mounds of rock debris out of the flow path in front of the wall. The 16-meter wall was constructed using the backhoe. The excavation extended approximately 16 meters along the road and 0.5 meters in depth. Large rocks (about 1 meter in diameter) were then placed in the excavated area. Tuquizans then filled the gaps with smaller rock.

C. El Molle

At this site, a two-meter wide runoff stream crosses the road twice, before and after a switchback. This stream runs down the road, eroding the surface and washing out the downslope edge of the road, narrowing the road.

The design at El Molle consisted of two main components:

- Two armored crossings, at both places where the water crosses, one of which is detailed in Figure 6.
- A three tiered, cemented drywall to reinforce under the upper armored crossing, detailed in Figure 7.

Figure 6: The completed cemented drywall

Figure 7: The completed upper armored crossing

The armored crossings should protect the road surface and allow the water to quickly cross the road. The drywall should support the edge of the road, preventing erosion and loss of road width.

The upper armored crossing was approximately two meters long and four meters wide. The backhoe was used to excavate both armored crossings. Flat rock was then placed into the armored crossings and stabilized with concrete. The lower armored crossing was two meters long and three meters wide. The cemented drywall was about four meters long and had three tiers of tapered levels to support the top level, which connected to the armored crossing via rock and concrete. All rock for this site was collected near the site.

D. Near El Truncal (approximately 1 km from the junction)

At this site, Tuquizans complained of difficult driving conditions during the rainy season. The edge of the downslope erodes with heavy rainfall, narrowing the road and making driving precarious. Rain discharge also creates ruts along this patch of road (about 15 m long and 4.5 m wide). These ruts, along with loose, muddy soil, cause trucks to get stuck and have to be freed using shovels, pickaxes and ropes.

The construction at this site consisted of installing a 15-m cemented drywall. The wall was built on the downslope and had two tiers. The bottom tier was 2.5 m high, while the top was 1.5 m high. The completed wall is shown in Figure 8.

Figure 8: The 2-tiered cemented dry-wall

The wall was built by:

1. Excavating the bottom tier and making a footpath for wheelbarrows
2. Placing the largest boulders on bottom and laying concrete on top
3. Continuing with large cobbles and thin layers of concrete
4. Excavating slightly for the second tier, and continuing the pattern.

E. Yanayan drywalls w/o concrete

At several places along the Yanayan section of the road, simple drywalls were built at places where water crosses the road. The walls provide erosion support for the road. Simple drywalls are less durable than those with concrete, but they are much cheaper and easier to build, and for low flows are sufficient. Most of these walls took 3-4 hours to complete.

The walls were built by:

1. Digging into the hillside to establish a flat, stable base
2. Placing large rocks to form the base of the wall
3. Fitting smaller rocks in between large ones

F. Armored crossings

At one location along the Yanayan section, and at the Molle site near Tuquiza, small armored crossings were built at places where water crosses the road and erodes the edges of the road or creates ruts down the road. The purpose of these armored crossings is to direct the water flow across the road efficiently, reducing erosion and eliminating standing water on the roadway. These armored crossings were approximately 2 meters in length. The armored crossing near Yanayo was simply a widening of a 1-meter armored crossing created on the previous implementation trip. A typical crossing is shown in Figure 9.

Figure 9: The completed armored crossing near Yanayo Grande

The armored crossings were built by:

1. Digging into the road to create the trench for the armored crossing (by backhoe or hand-labor)
2. Placing large flat rocks along the trench
3. Mixing and placing concrete on top of the trench, spreading a thin layer over and in between the rocks.
4. Curing the concrete for approximately 3 days

Results

The work completed during the project is summarized in Table 1.

Table 1: Summary of design aspects

Site	Designs	Details
Tarcuni	Gabion Wall	21 gabions; 3 layers with 6,7, and 8 gabions respectively; Each layer offset 0.9 m
	Cobble Slope	2:1 grade over the gabion wall; large cobbles (10-30 cm); thin layer of concrete applied above 2 meters
	Armored Crossing	22 meters by 6 meters; loose gravel/sand covered with 10-20 cm flat cobbles; 5° grade; cordon of large boulders keyed 30 cm into the ground; concrete mortar
El Truncal	Gabion Wall	27 gabions; 2 layers with 11 and 16 gabions respectively; Each layer offset 10-20 cm
	Rock Wall	16 m of large boulders keyed about 20 cm
	Channel Re-grade	Slight re-grading of the channel using backhoe
El Molle	Cemented Drywall	3 tiered; about 3.5 m height, 4 m width; large cobbles 20-40 cm; concrete mortar
	Armored Crossing Above	2.3 m by 4 m; large flat rocks; concrete mortar and top
	Armored Crossing Below	2.5 m by 3.1 m; large flat rocks; concrete mortar and top
Near El Truncal	Cemented Drywall	2 tiered; bottom tier- 2.5 m height; top tier - 1.5 m height; 15 m in length; large cobbles; concrete mortar
Near Yanayo	Four Drywalls	2-5 m in width by 1-4 m in height; large cobbles
	Armored Crossing	1 m of length added to old armored crossing; 4.6 m wide; large flat cobbles; concrete mortar

Conclusions and Impact

In the area of this project in the municipality of Acasio, Bolivia, there was a clear need for road improvement. The existing road has no pavement or cobbling, and the area is often subject to intense seasonal rainfall and flash floods, which can cause rutting, erosion, and sometimes global instability of the road. For these reasons, the communities of Yanayo Grande, Tuquiza, and Llut'ara expressed an interest in working with Engineers Without Borders to implement designs to improve their road's stability, drivability, and year-round use.

While some problematic sites could be improved using simple approaches such as constructing drywalls, others required more sophisticated approaches, such as construction of armored crossings and gabion walls. Specifically, there were large designs at two sites. One site (Tarcuni) needed a gabion wall and massive rock slope to prevent global instability of a section of the road that is subject to a massive, seasonal flow. The other site (El Truncal) needed a gabion wall to act as a barrier to prevent a large flow from flooding the road. EWB-UWS provided the technical knowledge, materials, and heavy equipment to ensure that these designs were implemented correctly.

These improvements will make the road significantly more drivable, especially during the rainy season. The drywalls and armored crossings will prevent local erosion from significantly affecting travel along the road. The two larger designs will potentially allow the road to remain open year-round. In particular, the design at Tarcuni should prevent the road from washing away every rainy season. In past years, this has prevented any road travel for approximately 3 months out of the year. With the gabion wall and rock slope, the road should now be able to withstand the destructive rainwater runoff flows that occur at this site.

As the road will now be passable nearly year-round, the communities will have much better access to larger cities. The community impact of this access is enormous. First, access is crucial for routine medical care and emergencies, thus improving health outcomes. Second, suppliers will be able to bring goods directly to the communities year-round, and the communities will be able to sell their crops at market, providing a crucial source of income. Third, education will be more accessible for the dozens of students in the communities. Finally, future EWB-UWS projects in the region aimed at health, income, and general quality of life will be more feasible.

Transportation was thus at the heart of issues of *access* – in both the physical and socioeconomic dimensions – for these communities. The net effect of this project is an investment in the communities' future, one now linked together a bit better by a winding dirt road which is stronger and better-prepared to take on the hydrologic extremes of the deep Andes.