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Geotechnical problems in Sierra Valle Fertil road crossing

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Abstract. National Road 150 passes through the central region of Argentina and is part of a bi-oceanic corridor from Brazil to Chile. In Sierra de Valle Fertil it has traversed sedimentary rock formations where they have built five bridges and six tunnels. During construction, instabilities phenomena were seen in both tunnels and surface works. In tunnels different behaviors were observed on hard rock and soft rock. Slope instability processes include mass displacement and failures due to decompression generated by excavation. Some reported cases occured during the execution of the work, including various types of failures. In many sectors, rock masses showed a high degree of weathering. Analyses for the design and mitigation actions undertaken are described. Details emerged in the foundation of the bridges that make the section also arise.

Keywords. Excavations, sedimentary rock foundation, tunnels, slope stability

1. Introduction

The Sierra de Valle Fertil is located in the west of Argentina (San Juan province). It is crossed by the National Road 150. This road is a part of a bi-oceanic corridor that runs from Porto Alegre (Brazil) to La Serena (Chile) (figure 1) (Aceituno et al 2014).

Figure 1. Location of Valle Fertil crossing (circle), within bi-oceanic corridor (Porto Alegre-La Serena).

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This road sector has 40 km in length including six bidirectional road tunnels with a total length of 2000 meters and five bridges.

All tunnels have the same horseshoe shape cross section, 11.9 m wide and 8 m. high with an area of about 70 m^2. Details can be found elsewhere [1].

Two of the bridges are arch bridges with about 60 m span width between abutments.

2. Geological setting

The geological formations are various Carbonic-Permian (Paganzo Basin) and Triassic (Ischigualasto-Villa Union Basin) sedimentary rocks, close to a National Reserve [1]. The Sierra has been formed by the reactivation of the basin during the formation of the Andes (10my bp) with a thick-skinned tectonics. (Figure 2).

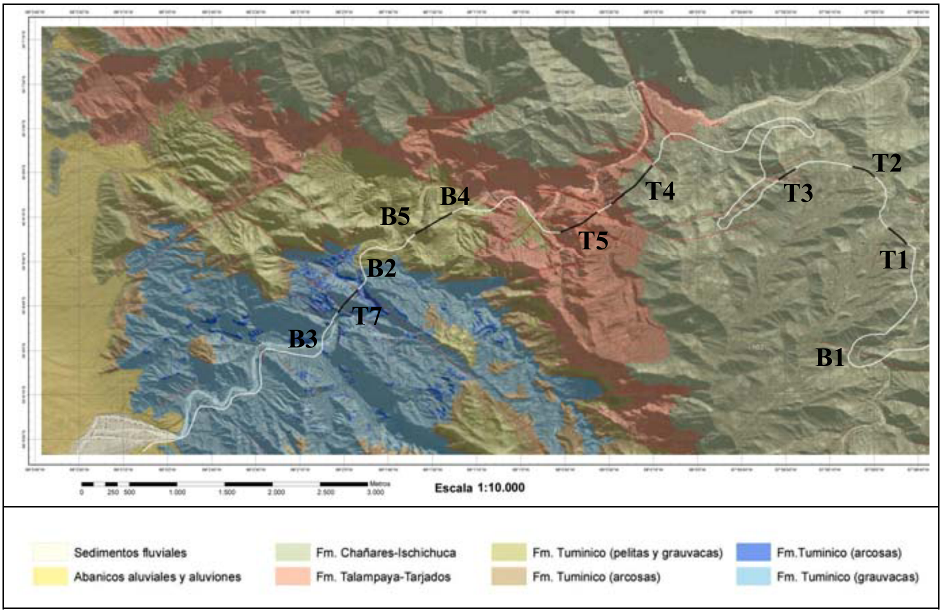

Figure 2. Geological map crossed by the road. T1 to T7 are tunnels. B1 to B5 are bridges.

GPS measurements show that Valle Fertil fault, that is the west limit of the range, is a feature that separates two tectonic regions, with high seismogenetic potential. The trace of the route follows a creek carved by Agua de la Peña River that cuts anticlinal folds.

3. Geotechnical properties

Rock mass characterization was done following the Hoek Brown model. Table 1 summarizes results of compression tests and diametrical uniaxial compression (Brazilian test) samples of sandstone and mudstone.

It is observed that intact rocks samples present are of medium to high resistance. During construction geological surveys were conducted on the outcrops as it were excavated, and expected support was adjusted according to them.

Table 1. Geotechnical properties of sedimentary rocks

Id	Location	Lithology	Unconfined Compression strength (Mpa)	Brazilean Test (Mpa)
CP1	PS T2	Yellow sandstone	108	4.3
CP2	PS T5	Red sandstone	81	3.0
CP3	PS T5	Red sandstone	75	4.3
CP4	PE T7	Black Sandstone	220	10.6
CP5	PE T7	Black Sandstone	182	2.4
CP6	PS T5	Mudstone	128	9.9
176-06	Portal	Mudstone	87	

4. Failure modes in tunnels

4.1. Support types

Tunnel support provided by the design was estimated by using RMR [2] and Q [3] methods. The solutions were raised in five kinds of support, modifying the provisions of the RMR method, using passive rock bolts, shotcrete and steel sets. Additionally, in faulty sectors, swellex bolt and spiling were applied [1][4].

4.2. Tunnels in soft rocks

Tunnels T1, T2 and T3 were excavated in a sequence of fine silty and tuffaceous sandstones with interbedded siltstones and triassic dark shales. They have similar structural geology features, but as the tunnel alignments changed, their influences were different (figure 3) [4].

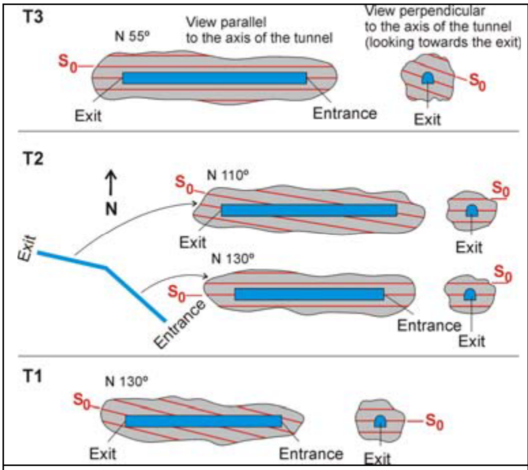

Figure 3. Influence of geological features on T1, T2 and T3

Figure 4. Cataclastic fill between rock blocks in T3

The main fault areas have been mapped in outside outcrops, with strike sub-parallel to the valley and T3 axis, and perpendicular to the direction of movement of the slide. This morphology was generated by the relaxation of the valley sides during the formation of the hill and the erosion of the antecedent river that carved it (figure 4).

4.3. Tunnels in hard rocks

Tunnels T4 and T5 shared the same geology and structural features (figure 5). In this case, they are formed by red cross-stratified sandstone (Fm. Talampaya), with red clay levels and layers and lenses of coarse matrix. Tunnel T7 was in grey greywakes, formed in Carboniferous age. They have well stratified planar layers of variable thickness (from 0.5 to 0.10 m to 1 m). There are thin layers of white sandstone lens shaped, of centimeter thickness, interspersed in the gray greywacke.

The main problem encountered during excavation was the falling wedge blocks of rock formed by the combination of discontinuities. These falls caused some overbreaks mainly in the crown and shoulder (figure 6).

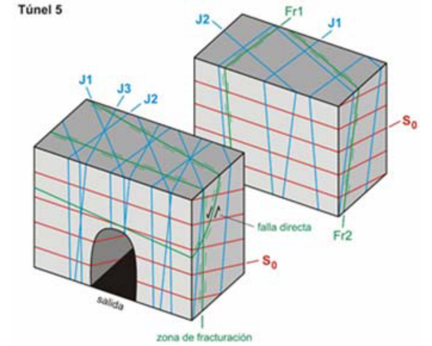

Figure 5. Structural features of T4 and T5

Figure 6. Typical rock wedges formed in T5

The effectiveness of the support was verified with convergence measurements at stations located at specific positions of the tunnels. The measurements were performed with tape extensometer.

5. Slope stability

The trace of the road crosses the different sedimentary formations through cuts across the mountainside, which affects slope stability. Examples of different types of faults are described in this paper.

5.1. Planar failures

The example is in Sta. 30 + 800. There are a group of blocks having approximately 13 m high, 22 m wide at the front, parallel to the axis of the road and 43 meters long.

These blocks are of red sandstone on whit a unit weight of 2.4 t/m^3 and a total weigh of about 28240 tons. They rest on a bedding plane with dip 20 to 25° at 36° towards the sector of road (figure 7). There is no interstitial water in the ground.

Stability calculations were performed with peak ground acceleration values due to earthquake of $a_h = 0.25g$ (horizontal) and $a_v = 0.05g$ (vertical).

Two scenarios (without earthquake and with earthquake) were analyzed. The first one requires a safety factor of 1.5, while for the second one, a value was equal to 1.1.

Based on these conditions, pairs of values of cohesion (c) and friction (φ) for which safety factors required were evaluated. In sum, the ratios obtained set a "limit" of combinations of strength parameters, for which the conditions which required stability is achieved (Figure 8).

Figure 7. Block with Planar discontinuity

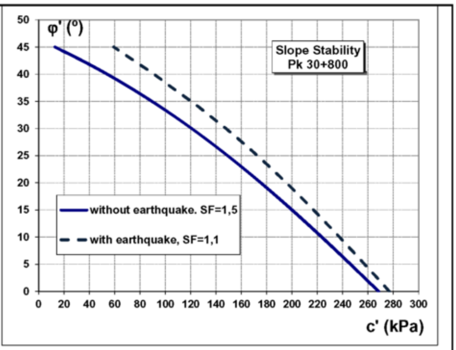

Figure 8. Combination of strength parameters necessary to achieve safety factors set

As a result of the analysis, it was decided to reshape part of this unstable mass.

5.2. Toppling

One example was located in Sta. 34+200. There is a case of breakage by rotation of the upper part of columns of rock formed by two discontinuities sets (Figure 9).

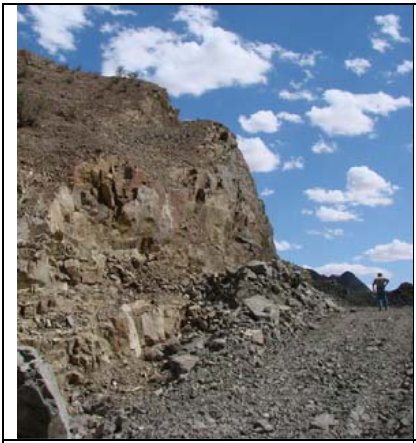

Figure 9. Block fall due to toppling

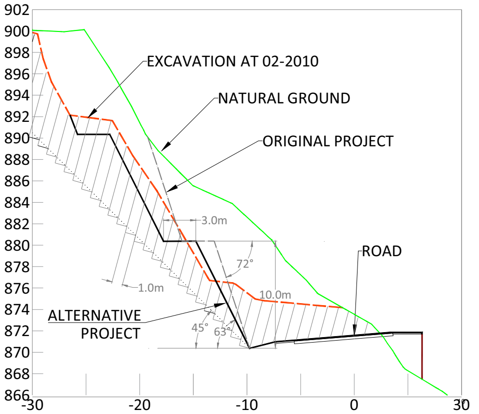

Figure 10. Redesign of slope

The arrangement of family joints in the sector showing the presence of a sandstone formation with dip slightly vertical, arranged towards the slope.

In order mitigate the problem, a new slope was redesigned and verified. It involves consideration of the average slope, including berms. This average slope equals 1H: 2V, i.e. an angle of 63° to the horizontal with berms 3 meters wide each and 10 meter high. (figure 10). The earthquake acceleration values used were: $a_v = 0.05g$; $a_h = 0.25g$.

5.3. Circular failure

A very good example was developed in Sta 22 + 090 to 22 + 380, where there was a significant incident, with massive failure and invasion of the road trace. Subsequently, it was observed that the monoliths measurement showed no signs of movement.

To check the security status of the slope in the pre-sliding conditions, a numerical model of the slope was performed to simulate the observed slip (figure 11). Having verified the failure, a back-analysis with a factor of safety of 1, was performed to determine the average properties to justify the observed slip (figure 12).

Figure 11. Detail of the bulge from the floor to the ground level of the road

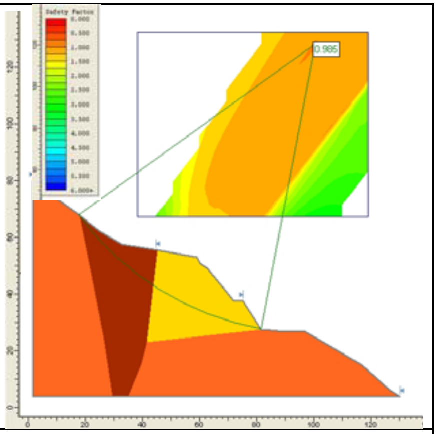

Figure 12. Results of numerical modeling of the slope

As a solution, the trace was relocated, the slided mass was lightened and channel runoff pathways were constructed.

5.4. Instabilities of rigid layers by erosion of weak layers

The characteristics of the interbedded sedimentary formations with rigid over weak rock layers produces unstable situations. This case corresponds to the slope at Sta. 17 + 900 (Figure 13).

The profile forming materials are: a) laminar shale and sandstone at the bottom, b) massive sandstone on top. Lower shales have a sub-horizontal dip, with a slight tilt to the road.

Lower shales have a tendency to accelerated weathering on its surface that begins after the excavation. Over time, due to daily thermal daily oscillations, or wind action, rocks mass are drying and undergoes contraction and expansion processes. Consequently it is fragmented and loses its cohesive components.

Upper sands have blocks with metric dimensions and sub-vertical jointing planes. Many of these planes are sealed, giving the appearance of continuous mass.

After the excavation, there is side deconfinement in sandstone formation that tends to open discontinuities in the vertical direction, and lower the strength in overall stability. When the vertical crack is formed, upper sandstone acts as an overload to the lower shale. Figure 14 shows the safety factor in limit equilibrium condition obtained for earthquake scenarios.

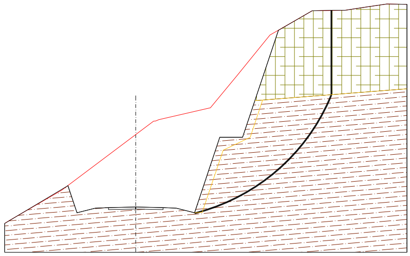

Figure 13. Cross section type in Sta. 17 + 900.

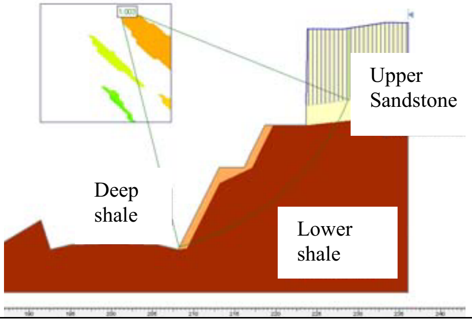

Figure 14. Alternative Profile with Quake (FS = 1,0)

Such problems warrant the reshape of the cuts and where possible, the use of shotcrete to prevent erosion.

6. Bridge foundations

All bridges were founded on rock. Some features are described elsewhere [5].

The example described corresponds to one of the abutment of arch bridge 5, that requires small levels of deformations. The abutment is founded on competent fine sandstones. However, subhorizontal stratification produces marked discontinuities (Figure 15 and 16).

Figure 15. Overview of the excavation for the foundation and abutment 2, from the opposite bank

Figure 16. View of excavation face where discontinuities are observed

It can be seen that the major joints are continuous along the excavation and consequently extend below the plane of the foundation level (Figure 16).

The sum of the openings of the discontinuities in the excavation front was in the order of 40 mm. From a static point of view, it is unlikely to be closed when requested externally bridge structures. In case of an earthquake, the breakage of the asperities that limit the discontinuities, can resulting in settlements, whose limit is given by the sum of the openings.

To avoid settlements in case of an earthquake, a deep foundation was chosen, with transmission of loads below discontinuities, using piles made of 4 inch hollow pipes like those employed in the umbrella tunnel portals.

7. Conclusions

The excavation of the tunnels and slopes crossing the Sierra del Valle Fertil was controlled by sedimentary rock formations.

Failure incidents were related with the rock mass characteristics. Soft rock, shale and sandstone presented in tunnels T1 and T2, produced horizontal slabs that tend to fall. In T3, the valley generated by the river induced stress relaxation and direct faulting. One of this was observed along the tunnel axis.

In hard rock, mainly sandstone and conglomerate, crossed by tunnels T4, T5 and T7, the stability of rock wedges were the main problem.

Convergence was monitored by measurements with extensometer tape sections. Its measurement showed stabilization within a few weeks after the excavation.

Excavation along the road faced different types of slope failures, including planar, toppling and rotational. Additional, erosion of weak rock layers generated instabilities of upper rigid sandstones layers.

Foundations of bridges were all on rock mass. In some cases, it was necessary to anchor the abutment to avoid settlements during earthquake of arch bridge.

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