Subsidence due to special geological and groundwater conditions

Affaissement du à des conditions géologiques et de nappe spéciales

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SYNOPSIS: This paper presents the results of a geotechnical investigation performed at a site where large structural damage occurred as a result of surface subsidence. The site is located at a mining area in the peruvian andes.
The exploration program included detailed geological mapping, and rotary diamond drilling with core recovery. In addition, core samples were tested in the laboratory.
A probable failure mechanism was developed, a subsidence control program was implemented, and satisfactory results were obtained.

INTRODUCTION

The Huaron mining district is located in the central andes of Peru, about 135 kilometers north east of Lima. The district is at an altitude ranging from 4,200 to 4,800 meters over sea level. It is one of the richest polymetalic ore deposits (lead,silver,cooper, and gold) of central Peru. The mining works started in 1914 with the exploitation of a very rich cooper mine. Today's richness is primarily due to the relatively high silver content in the ore. Present installed processing capacity at the plant allows treatment of 1,500 tons per day.
The exploitation of "Veta Pozo D" (an ore body under the mining camp) started in June of 1979; and as a result of it large surface subsidence occurred. As result, heavy structural damage occurred affecting the mining operations(Figure 1)

Consequently, a detailed study was performed to define the controlling factors producing subsidence in the critical areas of the mine (Carrillo, 1988)

RELEVANT GEOLOGICAL INFORMATION

In general, the area under study is formed by soft rocks of sedimentary origen from the mesozoic era which belong to the geological formation called "Capas Rojas" This formation is composed primarily by sandstones, tufs, and marl, besides quaternary materials with traces of mineralization (Nelson, 1977)

The geotechnical mapping of the geological structures showed critical areas within a thin strip about 500 meters long; where two faults intersect generating a fracture zone wherethere is presence of breccia with clay cement fillings. These two faults are complex structures composed of numerous ramifications separated by lenses. Within the zone of intersection of these faults, the direction of the displacements of the two systems constitute a sigzagin shear zone, formed by horizontal compression with an average strike of north 70 degrees.
This direction is compatible with the re-opening of small shear zones (reflexes of the major

Figure 1. General view of the site plant area and location of the damaged structures

faulting) in east-west direction, these mining faults intersects the large faults locally in the east-west direction, also there is a presence of small minerallized segments with the same strike of main fault. Non-mineralized minor faults also show the same re-openings (Figure 2).

MINING WORKS IN THE AREA OF STUDY

In general, the complex mineralization shown by the structure of the ore bodies at the site cause difficulties in the exploitation and control of the related minerals. This is the reason why different mining methods have been adopted for each type of ore body.

The methods of exploitation that have been used in mining, have been under cut and fill and over cut and fill hidraulic fill and cemented fill. Other methods used have been the "Square-set"and "Shrinkage" methods. Today, there is a tendency to standardize exploitation to one method,namely the over cut and fill mining (Miranda, 1987).

An important aspect relative to the utilized methods corresponds to the exploitation with artificial maintenance.

These are used in situations in which the mineral and the side walls of the galleries show poor geomechanical characteristics. This occurs in the area of the site particularly in the mining works. These show fracturing and alterations both within the minerallized veins and the side walls in the adits.
The adits are potentially instable and there stability is further complicated by the presence of water.
Were the ore has a low shear strenght the roof is supported by timber lagging and by back filling in the ascending direction using slabs of cemented hidraulic fill. The latter are approximately 1.20 meters thick and a part of the ascending cut and fill.

FIELD EXPLORATION AND LABORATORY TESTING

Using the results of the borings and geological mapping a structural analysis of the area was carried out. The results are presented in the stereographic diagrams (Figure, 3).

All the geological discontinuities are associated with faults, generally forming slickensided surfaces, altered with an oxidation film, clay-sandy films somewhat silty with mineralization and fill thicknesses greater than 50 millimeters (Thouvenin, 1983)

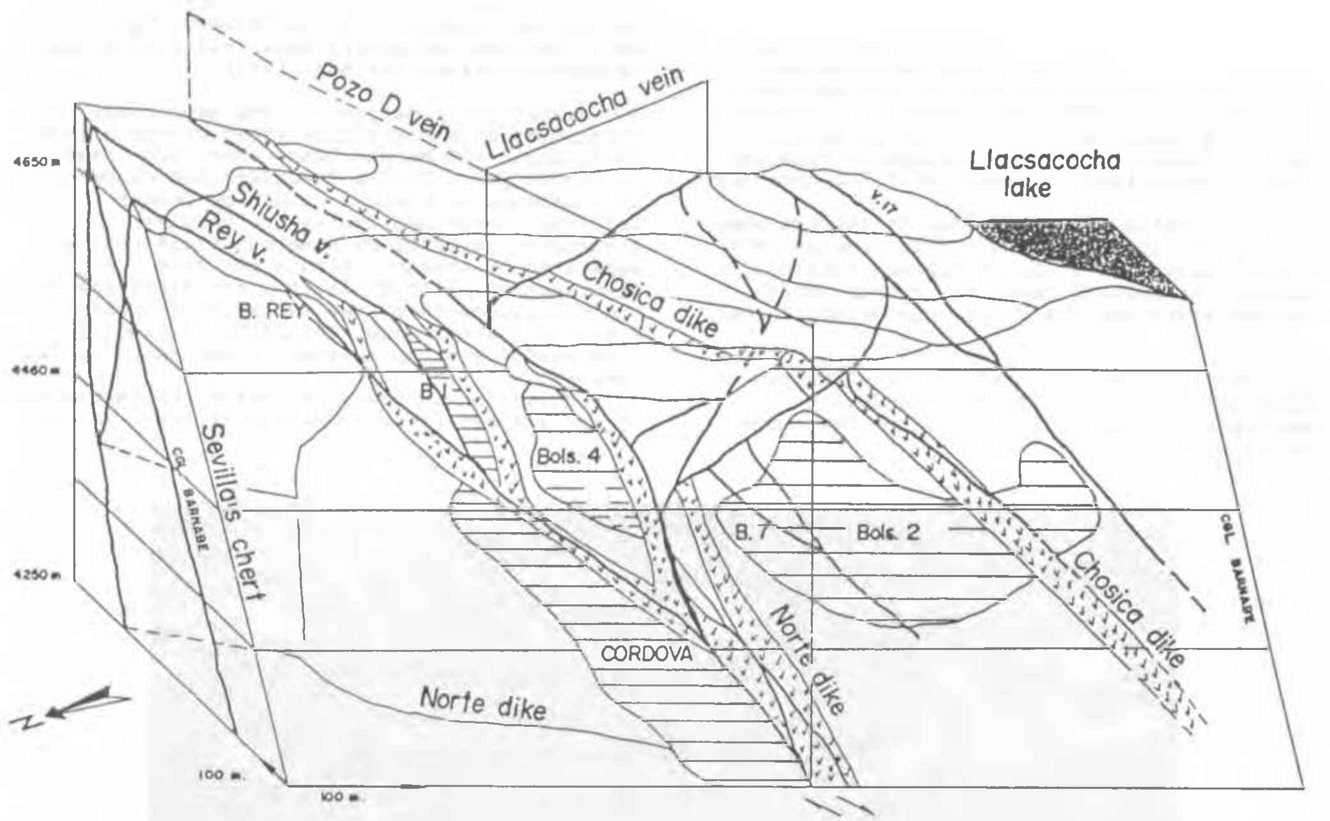


Figure 2. Sketch of the intersection Llacsacocha and Pozo D faults

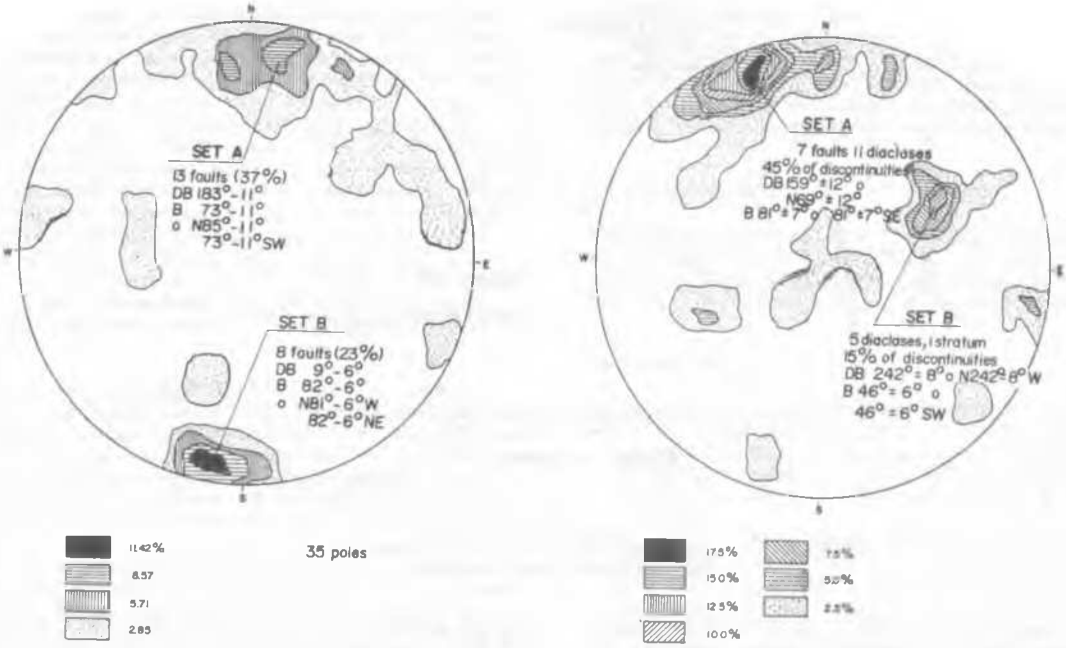


Figure 3. Stereographic Diagrams

Geotechnical borings performed by diamond drilling indicate that the rock mass situated around the mine's principal buildings are highly fractured, there is an abundancy of discontinuities of various orientations and dipping generally 80 to 85 degrees in a sub-vertical direction. Hence, the complete recovery of drill cores has been an exceptional case (Figure, 4). The alteration of the rock is almost external and the joint are filled by materials ranging from clay to sandy silt, the geometry of the joints suggest that these deposits were formed in a secondary manner by infiltration of water from the surface.

Figure 4. Typical highly fractured core samples

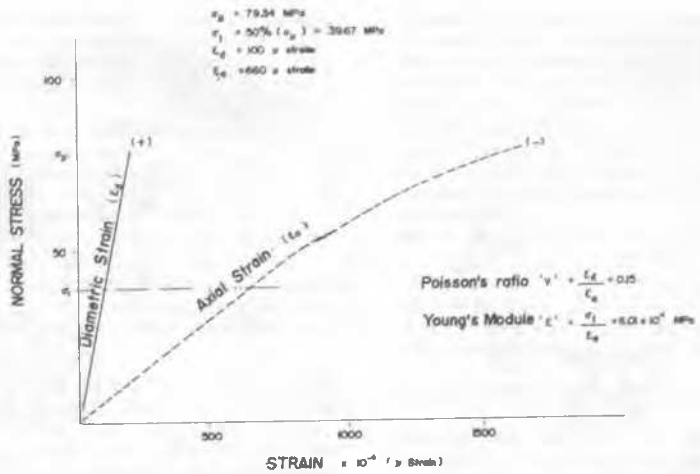
The fillings are also partly due to weathering of the rock itself. This weathering is prevalent along the lenghts of all the borings investigated. Also the effect of minor faulting can be inferred from the high degree of fracturing and jointing identified from the core samples.

The following mechanical properties have been assigned to the different rocks found in the zone of interest (Mayor, 1981) :

Cohesion	: 100-150 KPa for the rock of poor quality.
Angle of internal friction	: 30-35 degrees for the rock of poor quality
Angle of internal friction	: <30 degrees for the rock mass of very poor quality
Unconfine compresive strengh	: 0.43-1.37 MPa for the rock of poor quality <0.43 MPa for the rock of very very poor quality
Elastic Modulus	: Due to the quality of the rock, the elastic modulus is in the range of inelastic behaviour (Figure 5)

UNDERGROUND WATER CONDITIONS

The origin of underground water in the surroundings of the critical area are the seepage and the steady state phreatic line level corresponds to the most permeable aquifer or the better supplied within the rock.



(Mayor,1981)

Figure 5 Deformability of rock material in uniaxial compression

In some borings the phreathic surface has been detected to be at 29.20 meters below ground, in others 9.00 meters below the ground, and in the remaining borings the water level has not been detected. This shows the high level of anisotropy in the rock and the variability of its secondary permeability,this water levels are the results of the concentration of water from surface runoff and should represent a zone of high infiltration rate.

In the interior of the mine (ore bodies underneath the zone of interest), high seepage rates have been observed. Drainage pumped from access ramps in the mine adits are estimated at about 3,400 lts/minute, this gives an idea of the importance of water within the rock mass.

SUBSIDENCE MECHANISM

It has been established that in the most critical area the evidence of subsidence or increase of tensions produce important deformations with surface evidence or breakage of the rock while in less critical areas there is a certain upward movement resembling dome forces. These are a consecuence of nearness from this area to the principal faults already mention.

From the geotechnical analysis performed, the factors causing inestability can be defined. These factors are the underground mining , inadequate performances of the stabilizing system a main backfilling, and the influence of seepage water in the rock mass under study.

It has been established that the hidraulic fill does not fulfill the objective of supporting, in a general way, the excavated area;because, it does not fill totally the open space (in the adit), and there is a contraction and segregation problem in the fill once it has been placed

It is established that the downhill exploitation of the minerals in the veins and ore bodies originate subsidence to the low shear resistance of the rock and the up to 30 % reduction due to the effect of the seepage water. This seepage occurs continually increasing the deterioration on the quality of the fill and reducing its initial competence.

The failure mechanism of subsidence indicates that the geotechnical characteristics of the rock are poor, and that the geological faults are recurrents, beside the existance of an inadequate mining procedure and effects due to blasting and mining operation affect subsidence. Effects of residual regional tectonic movements should not been discarded. All of this is associated to the plastic behavior of the rock with mass settlements or alternating movements of bloks through the principal structural discontinuities.

SUBSIDENCE CONTROL PROGRAM

The control program was established. Firstly,to attack the factors that were producing subsidence in the critical areas, that is to temporarily suspend the underground mining operations, establishing apropiate conditions for mine backfilling, and implementing a good drainage system in order to control the flow water through the material in the critical areas this also included impermeabilizing select areas. Secondly, information and observation about the rock mass on the regional basis was gathered. Existing registers were organized and increase by geological mapping in the forward and rear directions of the critical area in order to establish or disregard residual tectonics traces on a regional basis. Thirdly, and in situ monitoring program has been establish to detect movements in the rock mass, both in the surface and in the interior of the mine. This will produce a quantitative measurements of movements.

On the other hand it has been recomended that wherever possible open cavities should be back filled. These cavities are located below the problem area, specially in those areas in the upper elevations on the mine tunnels. Only addits for access ventilation and necessary services should be left open. This is important because these cavities control the amount of settlement that occurs during subsidence. Mine backfilling is recomended with a ratio 1 : 25 to 1 : 30 of cement to tailings. Backfilling technics should be improved particularly in the way the mixture is discharged at the works, so that a more homogeneous mixture is placed and therefore, the backfill is stronger throughout.

With regard to seepege control due to water flow from the mine works and from surface water, and internal water paths due to the operation of the mill, it was found convenient to implement a surface drainage system and an underground drainage system in order to prevent the access of water to the rock mass in the critical area.

Cracks were filled with asphalt or products specially designed for this purposes. This was done in areas found inside and outside the plant. In the interior of the plant an aditional recomendation was made to the effect that an impermeable layer of asphalt or asphaltic emulsion be used to direct flow spill by mining equipment into drainage channels that has not been operating properly.

The rainwater for drainage from the hills and slopes adjacent to the plant shall be collected by means of subdrains. This should penetrate 0.50 meters into the rock. Hence they will be 3 meters long on the average and they will have the necessary slope to eliminate the water in the lower areas or to connect to the collection system in the mining camp.

On the other, it was found convenient to collect seepage water from the rock mass adjacent to the rear of the plant using a curtain or filtration gallery made by a line of borings trought the rock. The borings were performed starting at a convenient elevation in the slope. This curtain was connectec with existing addits at lower elevations. Thus, the seepage was cut off and collected directly to the natural drainage inside the mine. An aditional recomendation was to continously mantain the drainage ditches in the interior of the tunnels in order to avoid saturation of the rock in the critical area of the study.

CONCLUSIONS

Data gathered and the studies performed suggest that the main factors influencing the stability of the area are subsurface mining, inadequate performace of timber shoring and mine backfilling, and the infiltration of water into the rock mass.

Subsequent to the studies, short term emergency stabilization measures were recommended. These were directed to counteract the varius factors that affected the problem.

Surface mining in the critical areas was temporarily suspended, mine backfilling procedures with totally cemented mixtures were improved, cracks were slush grouted or sealed, and subsurface drainage systems were improved. Thus, ground movements have been controlled.

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