GEOTECHNICAL PROCEDURES FOR OPEN-PIT COAL MINE DESIGN

Procédés géotechniques pour la conception des houillères à ciel ouvert

Geotechnische Verfahren für die Projektierung des Tagebergbaus von Kohle

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SYNOPSIS

In this paper a geotechnical procedure for the study of six open pit coal mines in Spain is presented. The experience gained in the methods of investigation, engineering geological surveys, in situ and laboratory testing as well as back analysis of the shale rock formations is included.

RESUME

Cette communication présente une méthode pour l'étude géotechnique de six houillères à ciel ouvert en Espagne. Elle traite notamment des méthodes de reconnaissance de site, des essais in situ et en laboratoire et de l'analyse en retour des formations de schistes argileux.

ZUSAMMENFASSUNG

Die Arbeit beschreibt die geotechnischen Methoden für die Projektierung von 6 Tagbergbauen von Kohle in Spanien. Es werden die Erfahrungen dargelegt, die bei in-situ Untersuchungen, Ingenieurgeologie, Laboratoriums-Versuchen, Rückanalysen und Scherversuch in Diskontinuitäten von Felschiefer gemacht wurden.

1. INTRODUCTION

The energy crisis of the early 70's due to the increase of the oil prices has given rise to a reactivation of the open pit coal mining in Spain. Other contributory factors were the modern excavation techniques with highly mechanicised systems, as well as the substantial financial support by the Spanish Government. New coal basins have been explored since them mainly are composed by low grade coals.

This circumstances have developped a new situation for the spanish coal mining which has had to face the explotation of low quality coals under unfavorable geological conditions. Feasible economic ratios has reached so high values as much as 15 to 1 and up to 20 to 1 (cubic meters of overburden to Tn of coal).

Before the last decade few attention has been paid to the geotechnical aspects related with the open pit coal mining in Spain, but due to the reasons previously described, particulary the high ratios values, geotechnical input because one of the fundamental factors considered for coal mining feasibility and development. The main geotechnical problems which have had to cope could be summarized as follows:

- Geotechnical investigations over large areas ranging from 2 to 12 Km long and 150 to 300 m in depth.
- Specific geotechnical problems derived from the great depths to be reached over highly fractures rocks, of weak matrix and low durability.
- Incidence of environmental problems, hydrogeological constraints and old underground mining works.
- Critical geotechnical conditions to be reached in order to optimised the economic feasibility of the mines.
- Relationships between geotechnical recommendations for mining design and other related factors, e.g. geometry, explotaition development, ripability, drainage, spoil mining recovery, etc.

In this paper spanish experiences on six large open pit coal mines: Lloseta (Majorca), Juliana-Albardado (Cordoba), Cervantes Este (Cordoba), San Ricardo (Cordoba), La Castellana (Cordoba) and Puertollano, are discussed. Methods of investigations and geotechnical problems, and its solutions, are presented, pointing out those aspects of more generalized nature where general conclusions can be applied for any of the studied cases.

2. METHODOLOGY

The large excavations to be faced needed to develop new working procedures according with the geotechnical pro-

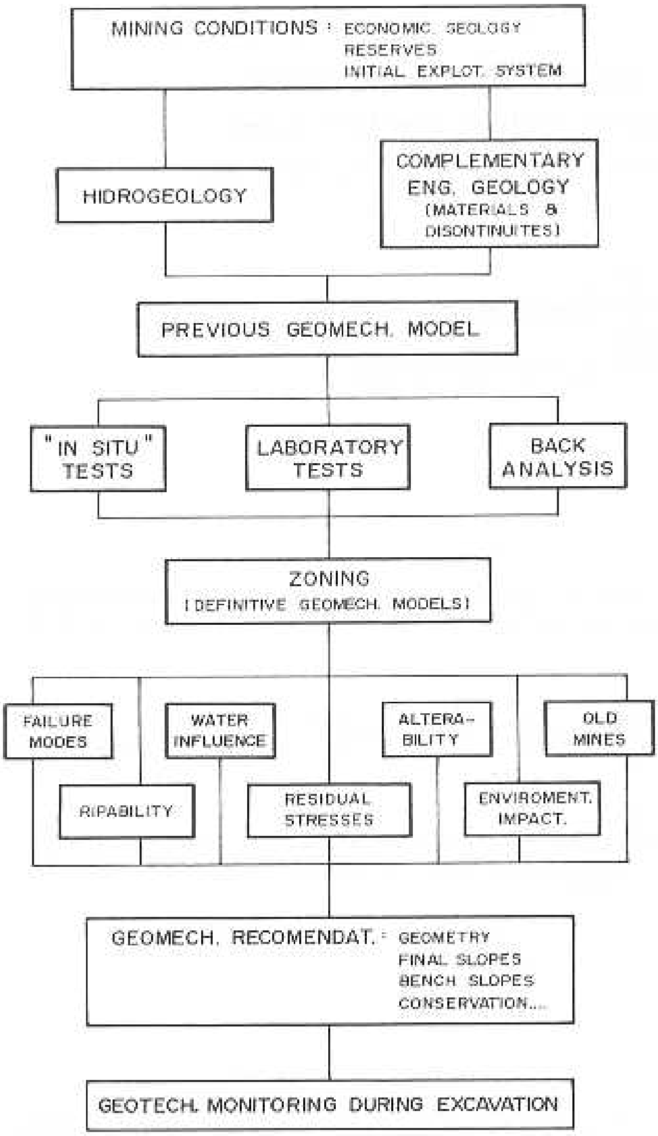

Fig. 1.- Organigram of work method

blems described in Section 1. Very deep excavations over great lengths as well as other related geomechanical and environmental factors contributed to such new working procedures. The last objective was to stablish the final slopes angles, drainage conditions, geometry of the open pit and reccomendations for the explotaition and recovery.

A working compromise between theoretical principles and practical engineering has had to be achieved. Thus, it has been tried to get the maximum geomechanical information from economic geological and mining studies. For this purpose a good coordination among that fields and geotechnical works is needed. After some previous experiences it has been possible to establish a working methodology which has been applied to 6 Spanish mines (Section 1). Such methodology is synthesised in fig. 1. The procedures has the following three major stages:

1 St. Stage: Once Economic and mining geological investigations are carried out Engineering geology and Hydrogeology works are proceeded. The main objective of these studies is to establish the previous Geomechanical Model (P.G.M.) as described in Section 3.

	ENG. GEOLOGY	HIDROGEOLOGY	GEOMECH. MODELS	ZONING	FAILURE TYPES	WATER INFLUENCE	ALTERABILITY	RESID. STRESSES
"DE VISU" INVEST	●	● ●	●	●	●	● ●	●	●
GEOLOGICAL CARTOGRAPHY	●	●	●	●	●	●	● ●	● ●
MECHANICAL BORINGS	●	●	●	●	●	●	● ●	∴
TRENCHES	● ●	∴	● ●	● ●	● ●	● ●	●	—
GEOPHYSICS	● ●	∴	● ●	● ●	● ●	● ●	∴	—
HIDROGEOLOGYCAL TESTS	∴	●	∴	∴	∴	●	∴	—
GEOMECH. "IN SITU" TESTS & BACK ANALYSIS	—	—	●	●	●	∴	∴	●
LABORATORY TESTS	—	∴	●	●	●	● ●	●	●
DATA TREATEMENT	—	—	—	●	●	●	●	●

● NECESARY ● ● RECOMENDABLE ∴ COMPLEMENTARY

Fig. 2.- Geomechanical procedures used in open pit mines

2nd Stage: Once the P.G.M. in established, a full site investigation program is carried ont based on in situ and laboratorory testing. Back analysis of failed slopes also performed. Special attention is paid to groundwater flow, discontinuities and the three physical properties coming into stability calculations: Specific gravity (γ), angle of internal friction (φ) and cohesion (c). Finally the open pit is divided in different sectors accordingly with its own geomechanical properties defining in such away the Definitive Geomechanical Model (D.G.M.).

3rd Stage: On each DGM following factors are analysed: a) Possible modes of slope failures; b) Influence of the groundwater conditions; c) Influence of the residual stresses; d) Weatherability; e) Influence of the old undergroundmining works; f) Explotaition aspects including mine geometry and ripability; g) Spoil Piles; h) Environmental impacts e.g. induced seismicity, mining recoveryand, land reclamation, etc; i) Geotechnical monitoring during the excavation.

This procedure has been carried out accordingly with the works described in fig. 2 where ranking values have been applied to point out the relationships between the procedure and their objectives. This figure is based on the experience gained on the mines mentioned in Section 1.

3. GEOLOGICAL STUDIES

Geotechnical studies must be based on detailed geological investigations of the future mined area. In most of the cases and Economic Geological Study is available before the geotechnical surveys are carried out. This Economic Geological Study provides information on the coal reserves, geometry of the deposits and properties of steam coals for calorific power. However, many geological aspects relevant for engineering purposes are not induced. On the other hand, the major emphasis is devoted on the

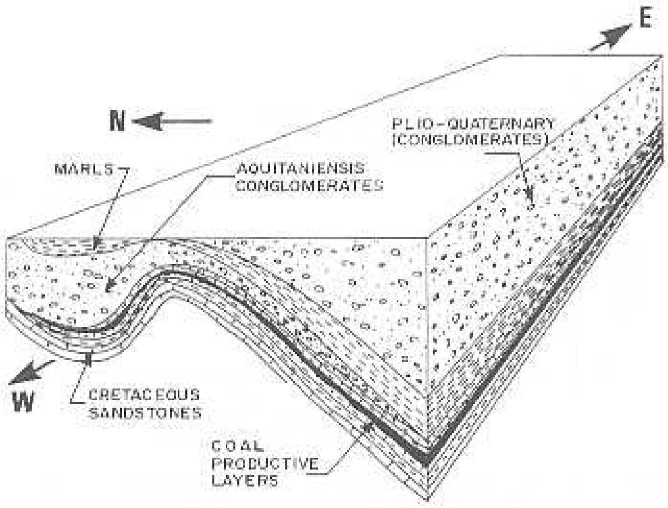

Fig. 3.- Geologycal scheme of Lloseta open pit mine (not scale)

area closer to the coal deposits, being unsufficiently studied the upper zones of the basin where most of the excavation processes should be taken place. Besides, a large number of borehole logs are generally available although few geotechnical data can be obtained from these boreholes which have been drilled only for mining economic evaluation.

From the geological studies the stratigraphy and tectonic of the area, as well as Geological maps and cross sections, are obtained. Isopacs and isohipses of the coal deposits are also included in these studies which are important to define the coal thickness and the Overburden materials, and therefore the depths of the slopes.

An example of the general structure of a coal basin in Lloseta (Majorca Island) is shown in figure 3. Engineering geological studies start from these previous economics geological works. Photogeological and structural analysis of discontinuities are proceeded as one of the most important stages of the investigation. Detailed structural surveys and logging of boreholes and open pits are carried out. Sistematic analysis of discontinuities in terms of orientation, spacing, continuity, rugosity, filling materials, etc, are described. Stereographic projections are extensively used to represent orientation and genetic studies of discontinuities. An example of the main discontinuities present in Lloseta coal basin is shown in fig. 4. As it can be seen these studies are complementary of the general structure showing fig. 3. The Lloseta case provided a good example of complex geological structure -asociated with synclinoriums- where extensive structural studies were needed to carried out cinematic analysis for slope stability calculations.

During this stage new borehole drilling and open pits are carried out. Usually they are made accompassing mining engineering geology and hidrogeology. This is due to the high cost of these boreholes where great depths are reached. From the point of view of the engineering geology, a detailed logging are proceded. Core orientation, RQD determination, and representative samples are obtained.

Besides that boreholes can be ready for further tests, e.g. well logging, seismic geophysics, permeability tests, etc, as they are described later (fig. 2). Geomorphological surveys of natural and certificial slopes are carried out studying the lithology, structure slope angles and slope heights, as well as their relationships.

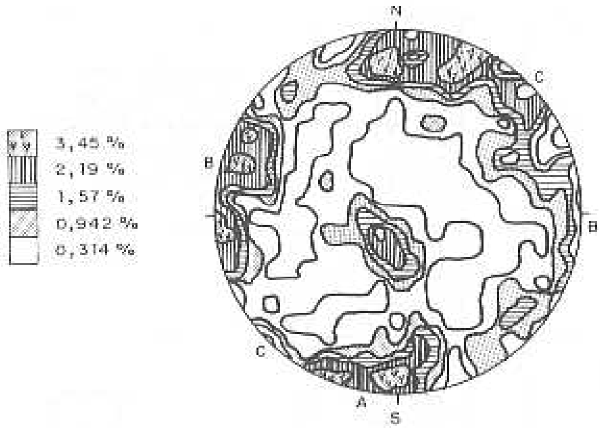

Fig. 4. Schmidt's stereographic representation of discontinuities at Lloseta open pit mine

Engineering hydrogeological studies range from groundwater and hydrological surveys, permeability and pumping tests in boreholes or wells, to the investigation of the groundwater flow nets before and during the excavation. These studies are conduced to assess the discharge, seepage forces on the slopes and to provide drainage measures.

From the Engineering Geology and Hydrogeology a Previous Geomechanical Model is obtained (The main objetive of these studies). Such a model represents a selective synthesis of the those geological aspects relevant for engineering purposes. The model should includes: the main lithological units, principal discontinuities and weakness zones, boundary conditions of seepage and an assessmant of the possible failures types related to natural and artificial slopes. Graphical representation of the model should included cross profiles, block diagrams and plans, as different means to explain a three dimension engineering geological model.

4. GEOMECHANICAL CHARACTERITATION

One of the most important steps during the geotechnical investigations is to find the representative geomechanics properties of the materials. For this purposes three types of works are generally carried out.

- Field testing including any "in situ" test which allows to find information on the rock mass strength and deformability.
- Laboratory tests: Detail identifications and classification of rock specimens is carried out as well as strength and deformability properties of cores and small discontinuities.
- Back analysis of failed slopes. Theoretical analysis on natural and artificial slopes are carried out in order to find $c-\varphi$ relationships and to compare them with Laboratory results.

Besides of engineering geological logging described in Section 3 the following tests are carried out inside the boreholes and trenches:

a) Well logging techniques, density log, sonic velocity, gamma-gamma, neutron, etc.

b) Down-hole or up-hole seismic geophysics to assess V_p and V_s velocities.

c) Permeability Tests, packer tests and Lugeon test.

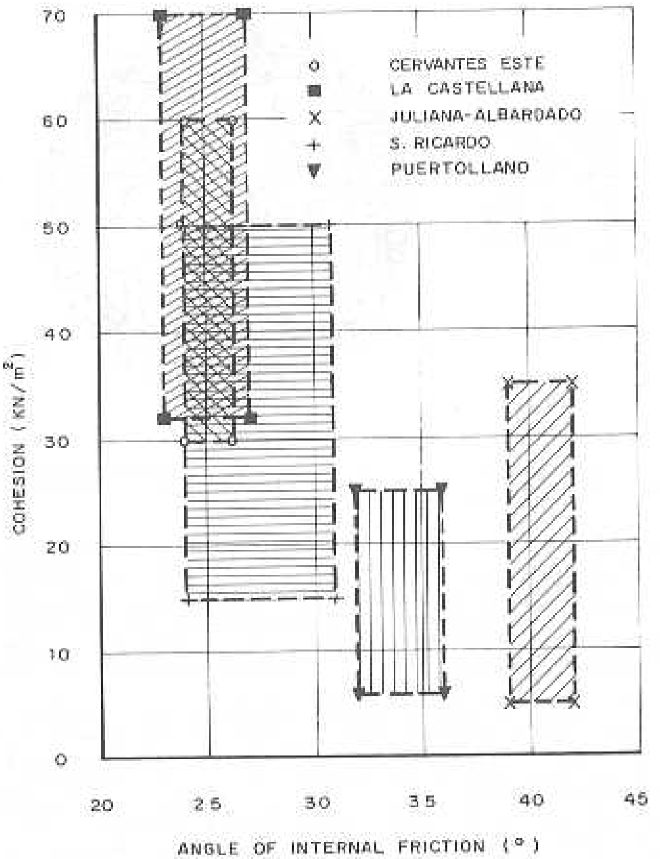

Fig. 5. Relationship between the apparent cohesion and the internal friction angle in the discontinuities of some Spanish shale rocks

d) Core orientations

e) In situ shear strength test in trenches.

Laboratory test are mainly carried out on core samples and block samples of maximum size about 40 x 40 cm. Typical classification tests consists in unconfined compressive strength, point load tests, Brazilian test, density, porosity, sonic velocity, etc. This tests trie to identify and classify posible zones of different rock qualities.

Mineralogical identification as well as fabric analysis both determined by optical and electronic scanning microscopes and X-Ray analysis have proved to be an important way to study the influence of shales and coal seams on geotechnical properties such as durability and shear strength. Durability is also studied using the slake durability test and other cyclic tests.

Small and large box shear strength tests on discontinuities are extensively used. Shear strength values in terms of cohesion (c) and internal friction (φ) are determined on natural and induced discontinuities. Results from a large number of tests are presented in figure 5. All the tested material came from 5 open pit mines where the overburden were shales with intercalations of coal seams. As it can be seen from fig. 5 some relationship could be suggested between c-φ values. Generally the highest φ values correspond to shales with a sandy matrix. Besides them rocks have an RQD ranging from 60 to 80. Low φ

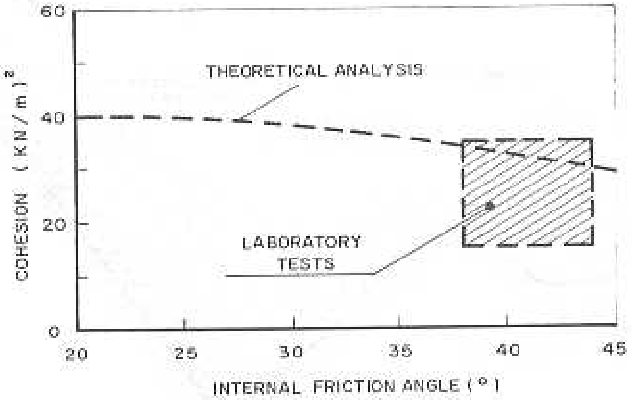

Fig. 6.- Back analysis carried out at Juliana-Albardado open pit mine

values correspond to shales with large quantities of clays in its composition and less than 40 RQD values.

From the actual studied cases a clear relationship between c-φ values and other properties, such as weathering or RQD, can not be establised although the results obtained in the present investigations are promising for future studies on this field.

Back analysis calculation of failed slopes are fundamental to determine c-φ relations on in situ large discontinuities. In most of the cases back analysis results and those c-φ values measured in the laboratories shown a acceptable aggreement (fig. 6). Other important application of back analysis investigations is to observe modes of failures. In this way a buckling failure could be identify in ones of the studied open pit mines (San Ricardo).

5. GEOMECHANICAL ZONING

All the open pit mines mentioned in Section 1 where located over a wide range of geological and geomechanical properties, extended on several Kms. of length and up to 300 m of depth. These circunstances obviously affected the geotechnical behaviour of the rock masses which were remarkable different from one sector to another of the open pit mines. Therefore a rock mass classification of the diferent sectors were carried out interms of a so called Geomechanical zoning (D.G.M.). The main criteria followed were based on the following aspects:

- The P.G.M., including Hidrogeology.
- Fracturing of the rock masses
- Rock mass quality evaluation
- Assigment of appropiate geotechnical properties to each sector.

The P.G.M. described in Section 3 was complemented with an assessment of the state of fracturing of the different rock masses affected by the open pit mine. A three dimensional model in developed using the data of Section 3, RQD values, relationship between seismic waves velocity (V_p) obtained in down-hole or seismic geophysics, and V_p obtained from sonic tests in rock cores, as well as other possible relationship between them.

Any other fators than could affect the state of fracturation such as old underground mining works was also taken into account. From this data, a rock mass classification was developed getting together zones with the

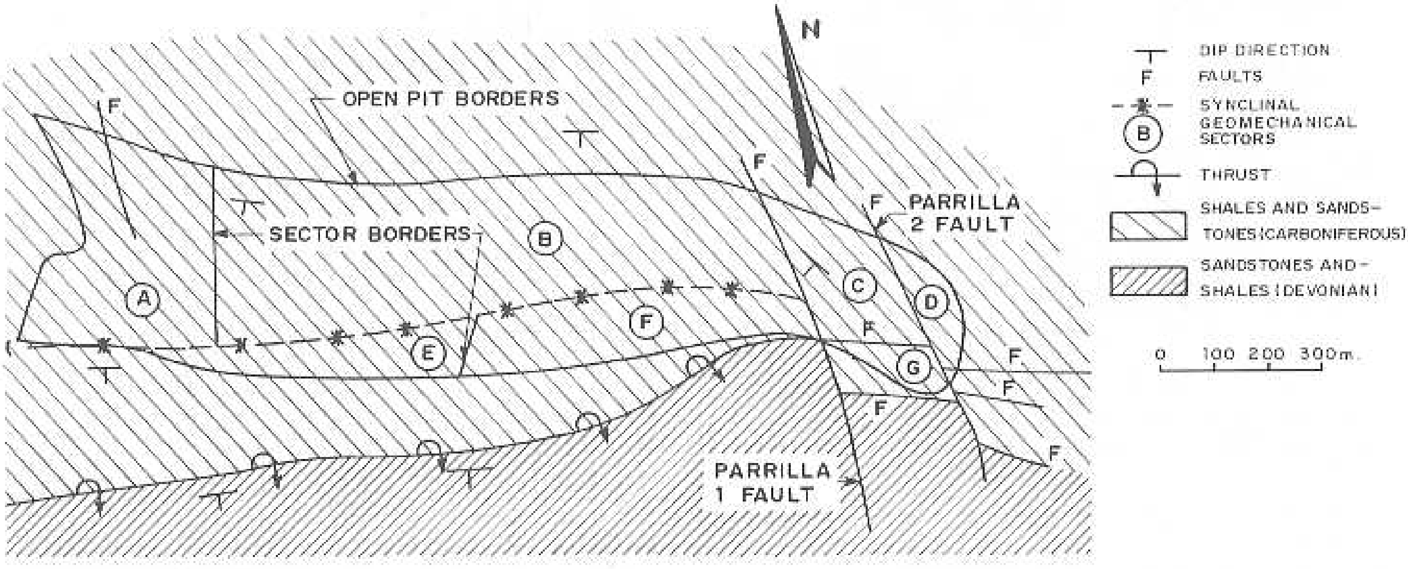

Fig. 7.- Zoning of La Castellana area

same range of rock mass values.

The Geotechnical properties described in Section 4 were assigned to the different zones defined by the rock mass values unconfined compressive strength values (σ_c) and its changes with depth were used as well as in situ deformation moduli (E) evaluated by geophysics , or the ratio E/σ_c . Shear strength values or ranges of them were also assigned to each sector. It is important to point out that for these exercises a significant amount of subjective criteria is used. Obviously as much as the geomechanical data is available as better matching can be done between sectors described in terms of rock mass classification and its strength properties.

Other useful properties such as average density values, durability or weathering grades and ripability indices were provided for each geomechanical sector. The geomechanical zoning concept constitute an essential criteria for slope stability calculations and mining geometry design. The type of zoning carried out in the open pit mine of La Castellana (Peñarroya, Córdoba) is shown in fig. 7.

6. FAILURE MODES

The definition of the possible failure slope modes is one of the essential stages in the previously described procedure. Some of the aspects that has to be considered are the following:

a) Block failures, in terms of planes, and wedges mainly. Graphycal analysis using K. John and Hoek and Bray's methods have been applied. Probabilistic analysis have been also used in some cases following the Castillo and Serrano (1973) method.

b) Total slope failure are assessed using plane failure analysis with or without tension cracks in the slope top. When the upper part of the slope is severely wathered at and its behavies as a soil-like a circular or poligonal analysis in carried out.

c) Specific problems arised from the productive wall slope where coal seams are in contact or very close to it. In this case the possible models shown in fig.8 should be taken into account. The height of the benches strongly influence the final slope angle.

d) Specific problems avised from the highwall slope. The geological structure of the studied cases consisted on a more or less complex folded structure (fig. 3), where the toppling was the most characteristic type of slope failure. This type of failure influences the width of the berms as well the angle of the benches in this highwall slope.

Typical safety factors used were 1.3 for final slopes and 1.1 to 1.2 for working slopes. To reach this coefficients an efficient drainage of the slopes were needed.

7. FINAL CONSIDERATIONS AND CONCLUSIONS

The previously described procedure has been proved to be efficient to achive the following objectives:

- Final slopes design in terms of slope angle, and geometry of berms and benches. Fig. 9 presented an example of the La Castellana open pit mine. The geomechanical sectors of this mine were described in fig. 7.

- The final slope should be ajusted using not only the results of a complete investigation but also the experienced obtained from similar cases especially if great depth has to be reached. Relationships between slope angle and slope height is presented in fig. 10 from spanish and elsewhere open pit mines.

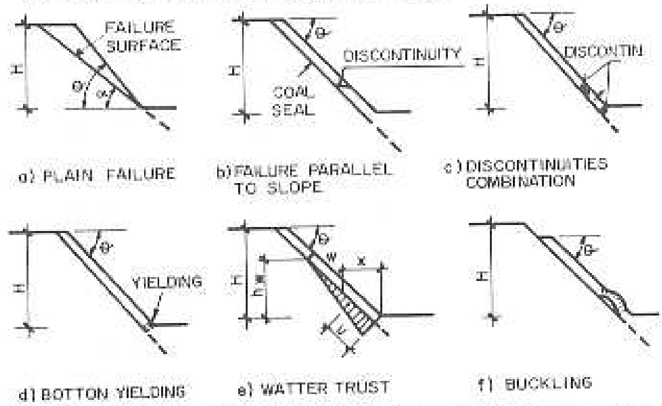

Fig. 8.- Failure types wen a coal seal is near the slope (Piteau and Martin, 1981)

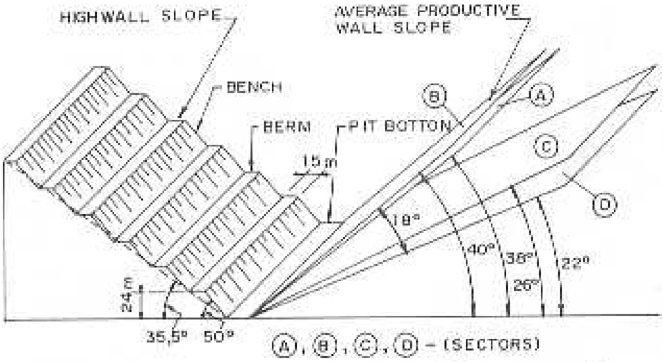

Fig. 9.- Slopes recommended at La Castellana open pit

- Working slopes and its geometrical conditions must to be fixed taking into account the excavation techniques used.

- Plan view geometry and its influence on convexities and concavities shapes.

- Excavation techniques, and drainage works

- Environmental impacts, induced seismicity, influence of waste piles, land reclamation, pollution, etc.

- Because the length and depth of studied mines the design must be checked and complemented during the explotation trhough out a geotechnical monitoring program mainly consisting in field instrumentation of the slopes and systematic surveying.

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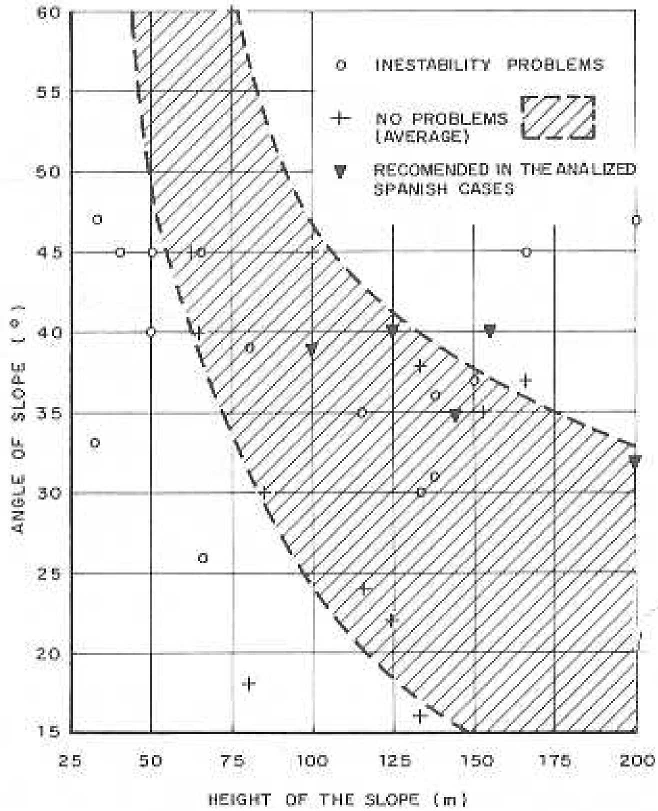

Fig. 10.- Relationship between the height and the angle of slope in shale materials (Data of Kley and Lutton)

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