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Slope Stability at Gol-E-Gohar Iron Mine

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ABSTRACT: The progress of mining operations to deeper zones usually causes some changes in states of stresses. These changes have resulted some failures and instability problems in different parts of Gol-E-Gohar iron open pit mine. It seems that main parameters which effect the failure and instability of the mine slopes are high pressure of groundwater and system of discontinuities (faults, joins, and bedding planes), which intersect the pit walls. To overcome these problems, numerical analysis was carried out using a Fast Lagrangian Analysis of Continua (FLAC) software. To prepare the input parameters for modeling, field studies (include discontinuities mapping, point load index test, and Schmidt hammer test) and laboratory tests (to determine compressive, shear strengths, and elastic constants) were carried out. Then discontinuities orientation and laboratory tests data analysed to determine major structures, and shear strength parameters. Following pit walls modeling and safety factors have been determined. The results of analysis were in good agreement with the actual observations in the mine, and with analysis that carried out using other methods.

1 INTRODUCTION

The Gol-E-Gohar (GEG) Iron mine is located in 60 km southwest of Sirjan, in Kerman province of the Islamic Republic of Iran. The mine lies at a point approximately equidistant from the cities of Bandar Abbas, Shiraz and Kerman. each being approximately 280 km away. The Mine elevation is approximately 1750 meters above the sea level in an area of planar desert topography.

/./ *History*

Iron ore extraction in GEG goes back to at least 900 years ago, some historians believe that mining activity was carried on from 2500 years ago. the time of the great Persian Empire at Perspolisc. There was remnant of a large underground excavation and a small open pit in the central part of the mine (Figure 1); it is estimated from these old mining areas about 350,000 tones of ore had been extracted during that period. Most of these old mining areas have been destroyed by recent mining activities.

1.2 Exploration

In 1969 the Iran Barite Co. began exploration work at the site. Following the government policy of the day. responsibility of exploration was then delegated to the National Iranian Steel Industries Co. (NISIC),

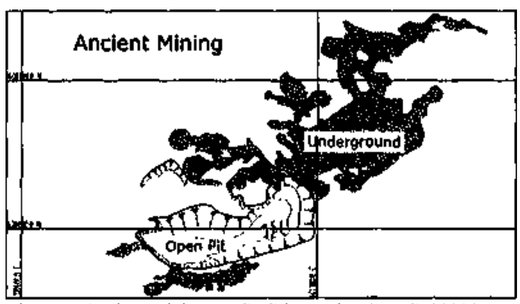
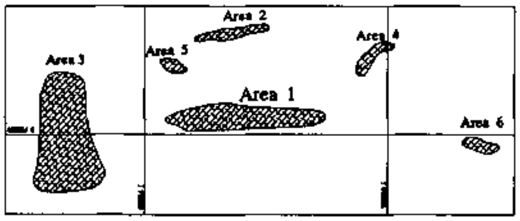


Figure I. Ancient mining on GEG iron mine (KMC. 2001)

a government corporation. After revolution its name was changed to National Iranian Steel Company (NISCO). NISIC in turn entered into a joint venture for development with Granges International Mining of Sweden (GIM). NISIC and GIM continued the various step of exploration and engineering planning, leading to development of an ore body, based on aerial and ground geophysical survey on an area *of* 75 km" at GEG in 1974. Following that, exploratory drilling began on six separate anomalies in the district in 1975 with a result of finding 6 anomalies (Figure 2), for estimating of ore quality and its reserves. Based on geophysical modeling, the total reserve in all anomalous zones was estimated about 1100 million tones (Table 1).

The detailed exploration of area I and 2 is finished and since 1994 the mine (Area I) is being extracted.



Fıguıe 2 Anomalies of GEG non oie complex

Semi detailed exploration of Area3, the largest iron oie anomaly at GEG, has been finished and the detailed exploration program for this anomaly is being prepaied. Due to the small size and high depth of the other anomalies, and more exploration on these deposits has not been planned yet.

2 GEOLOGY

The GEG complex (Area 1) is situated on the northeast margin of the Sanandaj-Sirjan tectonic-metamorphie belt, more precisely locally, the area is located in the marginal depression zone known as the Salt Lake of Kheirabad. The lithostaligraphy of the exposed rock units in the area comprises Paleozoic metamorphic rocks, Mesozoic and Cenozoic sedimentary rocks and Quaternary alluvial materials. The Paleozoic rocks form the basement of complex.

The ore body is generally lenticular form, greatly elongated in the east west direction, roughly parallel to the strike of the Sanandaj-Sirjan tectonic-metamorphic belt. The overall length of the ore body is 2600 m and the width at the widest section is 400 m (Figure 3).

2./ *Genesis of ore body and ore classification*

There are a number of alternatives and conflicting concepts on the genesis of the ore body, the first of these set out by Ljung (1976), who proposed a meta-sedimentary origin, the second is that of Muke and Golestaneh (1982-1991) who assumed a magmatic kiruna type genetic model, Hallaji (1992) has yielded a number of lines of evidence suggesting a metasomatic origin for deposits while Khalili (1993) has suggested a volcano sedimentary origin for GEG iron ore.

Iron ores at GEG are classified not on lithology but exclusively on their chemical characteristics in three types, Top Magnetite, oxidize ore and bottom Magnetite:

Top Magnetite: Magnetite ore with low sulfur and phosphor.

Oxidize ore: Magnetite and Hematite with low sulfur and a little high phosphor.

Bottom Magnetite: Magnetite ore with high sulfur and low phosphor.

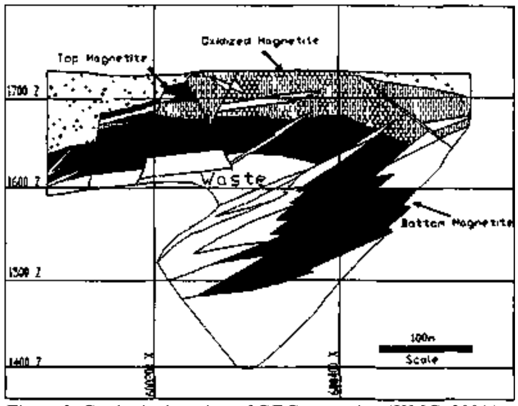


Figure 3. Geological section of GEG non mine (KMC, 2001)

2.2 *Structural geology*

The structural mapping includes all the structural features that its persistence is such that they affect at least one bench and/or those structures associated with bench-scale instabilities. The main joint systems determined using a detailed face mapping of exposure in the pit area has been summarized in Table 2, and shown in Figure 4.

It seems that faults existing in the pit area have the most effect on pit walls stability. The main orientations of faults are 203773°, 108772°, and 22762°.

Stereographic projection of the main fault systems is shown in Figure 5.

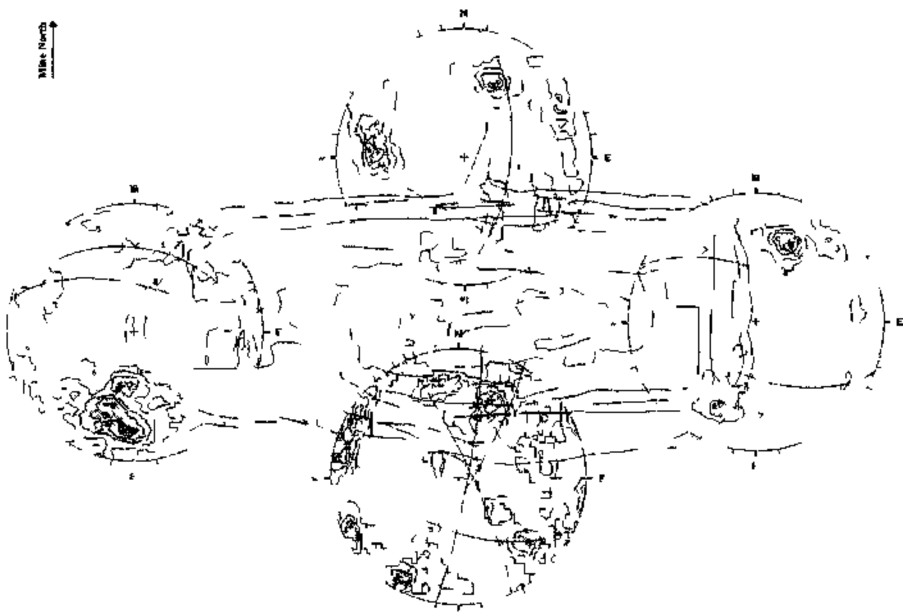
Table I Suinmaiv Pıopertıes ot GEG Iron Oie Complex Anomalies

Oie body	Exploration Dulling (m)	Reseives (in t) Pioved	Piobable	Dimension (m) Length	Width	O B Thickness (in) Min	Max	Giades(%) Ft	P	s
Ai e a l	26300	265	-	2600	400	0	310	55.5	0.152	1 521
Aıea2	7470	52	-	1100	200	41	199	53.1	0 146	2 308
Area 3	32340	608	-	2200	2200	84	545	53 6	0 121	1.784
Aiea4	580	-	12	'300	"100	95	N/A	53 1	0 150	2.030
Aıea 5	260	-	4.5	*100	'1 00	80	N/A			
Aıea 6	610	-	150	'1100	'2400	568	N/A	50	0 090	0 084

Based on geophysical study

Table 2 Chaıacteııstıcs ot the |oint sits at the GEG mini-

	Joint Sets (Dip / Dip Direction)				
Wall	**S-l**	**S-2**	**Ş^**	**Ş-4**	**S-S**
Noith	60'±87 % ± IS	54'±9/201 ± 12			
South	82 ± 8 / 120 ±5	85 ± 5 / 100 ±6	82 ±4/65 ±5	80 ± 8 / 10 ± 7	56 ± 6 / 202 ± 8
East	56 ±8/202 ±10	18 ±8/24 ±9			
West	15 ±6 / 11 ±7	60 ± 10 / IS ± 10			

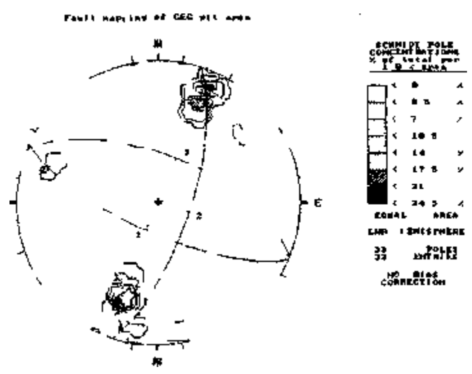


Figuie4 Steitogiaphic pıojectıon ot the main |oint systems on ditfeient wills at GEG mine (bagheiian 2001)

2 3 H\dlolo%

Study ot the tesponse ot groundwatet flow to mining activity has begun by characterizing the poiosity and permeability ot the ıock sequences Rock sequences including alluvial material, paleogravels, and weathered locks Because ot the high permeability ot the rock and/or intensity ot discontinuities within this sequence it ıs consıdeıed that the suıtace ıock mass would likely drain on pit

Gioundwatei table in GEG pit area is estimated at a depth ot 40 m below the giound surface Excavation ot the pit has created a diawdown ot the groundwater level It can be obseived that the majonty ot water inflow to the pit is through the oveiburden excavation, and faulted zone in oie body



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Fıguıe S Fault sets in GEG pıt aıea

1 MINE PLANNING

A numbei ot geotechmcal-based lecommendations have been given by different consulting gioups and agieed the GEG mine authorities which arc summaıızed as below

- The best bench height is 15 m
- The pit is appioximately 1600 m long and 750 m wide in final position
- The pit oveiall slope angles are 45 deg in ore and waste rock and 38 deg in soil overbuiden

- Roads are 20 to 25 m wide with a grade of 8%.
- A 10 m wide safety bench is left at every two bench (30 m height) in the final layout.
- The overall slope height of pit is 220 m.
- The bench face angle is 60 deg.

4 GEOTECHNICAL ASSESSMENT

The geotcchnical evaluation of rock-mass has been done by rock-mass classification, rock materials strength obtained from the laboratory tests, and field observations of weathering. The input parameters for numerical models were obtained from characteristics obtained from above mentioned sources.

4.1 Rock-mass classification

A detailed and comprehensive study was taken to determine rock-mass and structural propeities for GEG iron ores and enclosed rocks.

By using the parameters collected from the structural mapping and those obtained in the laboratory and field tests, rock-mass rating (RMR) was calculated.

The average values of the geotechnical parameters are summarized in Table 3.

4.2 Strength assessment

The material properties used in the analyses were derived from laboratory, field tests, and field rock-mass characterization.

- Intact rock strengths were derived from the laboratory and in pit point load tests.
- Values for the cohesion and friction angles were determined by triaxial testing in the laboratories.
- Joint strengths were determined lrom laboratory shear tests. Shear tests on natural joint surface, as well as on artificial saw cut surfaces, were evaluated.
- The GSI was used with the Hoek and Brown failure eri teri a-2002 edition (Hoek el al. 2002) to determine the instantaneous friction angle and cohesive strength for given normal stress values.

Parameters such as m and s in the Hoek-Brown criterion were calculated assuming disturbed rock-mass condition (disturbance factor =1), since recent work has shown this category to be more appropriate for large-scale rock slopes (Sjoberg 1999). By using m, s, GSI, and uniaxial compressive strength of intact rock (a_u). the corresponding Hoek-Brown failure envelope was calculated assuming disturbed rock-mass conditions. The curved Hoek-Brown failure envelope was then translated to a linear Mohr-Coulomb envelope, to be used as input into the numerical models. Cohesion and friction angle for the Mohr-Coulomb model were determined using linear regression over a representative stress range of the Hock-Brown envelope. The resulting strength values (c and ⌖) are summarized in Table 4, along with calculated compressive (o_{tm}) and tensile ($a_{,m}$) strength, and Young's modulus (E_m) of the rock mass. Since no stress ineasureinents have been carried out at GEG, the virgin stress state can only be estimated. For most models, a horizontal-to-vertical stress ratio (k) of 1.5 was suggested (Sjoberg et al. 2001). A more detailed study on the inlluence of the virgin stress is outside the scope of this work.

5 STABILITY EVALUATION

5. / Slope mass rating for GEG mine

For evaluating the stability of rock slopes, a classification system called Slope Mass Rating (SMR) system (Romana 1985) has been used by adding adjustment factors of joint-slope relationship and method of excavation to RMR,

$$SMR = RMR_{h,wt} - (F_,.F_,.F_,) + F_4 \quad (1)$$

Where $F_,$, F_2, and Fi are adjustment factors for joint orientation with respect to slope orientation and F_4 is the correction factor for method of excavation (Singh&GocI 1999).

The SMR values for pit walls, rock mass description, and stability classes are shown in Table 5. Final pit layout will locate at waste rocks.

Table 1 Avet age values of geotechnical parameter's for intact matenal.s

Rock Tvpe	Density (Kii/m-')	UCS (MPa)	PoLsson s Ratio	Young's Modulus (GPa)	ROD	RMR
Ore	4200-4400	85	0.20	**23**	**80**	**65**
waste	2600-2700	65	0.20	**23**	**50**	**56**

Notes'

UCS' Uniaxial Compressive Stiettgtli RQD: Rock-Quality Designation

Table 4 Estimated lock-mass stıeıgtlı lll GEG assuming disturbed lock mass toi a stiess lange ol Oi=()-6 MPa (Bagherian 2001)

	Ore				Waste			
Walk	North	South	East	West	North	South	East	West
ııı,	17	17	17	17	27	27	27	27
o_{ci} (MPa)	• 85	85	85	85	65	65	65	65
GSI	52	56	58	57	41	47	49	48
nil,	0 55]	0 714	0 846	0 788	0 460	0 611	0 707	0 658
s	0 0001	0 0007	0 0009	0 0008	0 0001	0 0001	0 0002	0 0002
a	0 505	0 504	0 501	0 504	0 509	0 507	0 506	0 507
$(degree)	11 6	14	15 1	14 7	27 8	101	11 9	10 9
C (MPa)	1 25	140	1 48	1 44	1 02	1 15	1 21	1 18
C„„ (MPa)	1 50	2 11	251	2 10	0 515	0 717	0 880	0 806
0„„ (MPa)	0 052	0 076	0 092	0 081	0 011	0 015	0 019	0 017
E„, (GPa)	5 171	6512	7 106	6 897	2 694	1 192	1806	1 591

Tahle 5 SMR values and stability classes toi GEG pits wall (Bagheuan 2001)

	Ore				Waste			
Walls	North	South	East	West	North	South	East	West
SMR Value	57	61	61	62	48	52	54	51
Rock Mass Description	Noimal	Good	Good	Good	Noi mal	Noi mal	Noi mal	Noi mal
Stability	Paıtıally Stable	Stable	Stable	Stable	Paıtıally Stable	Paıtıally Stable	Pailially Stable	Paıtıally Stable
1 allure	PI &MW	Some BF	Some BF	Some BF	PI AcMW	PJ&MW	PJ&MW	PI&MW
Probability of Failure	0 25	0 2	0 2	02	0 15	0 1	01	0 1

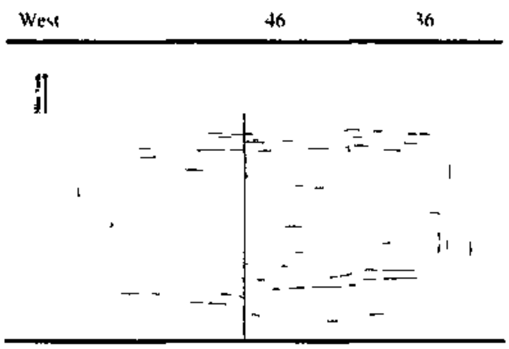
Notts PI Planai along some Joint MW Many Wedges BF Block Failine

5 2 Cut rem slope design

Initial slope design al GEG is done based on bore hole data It seems that because ot the lacking ol data on that time, slope angles ot pit considered vety cautiously Table 6 shows cut rent overall slope angle of GEG pit in different soil, and tock walls Cuttent pit geonietty shown on Fıguıe 6

T ıble 6 Cm lent oveiall slope angles ot pits walls

walls	Rock	Soil
North	47	32
South		41
East	48	39



Fıguıe 6 Houzontal map showing GEG ciment pıt geomeliy

5 3 Numerical modeling

Numerical modeling of the GEG pit slopes has been carried out on a number of occasions to develop a more comprehensive understanding of the slope-detormation behavior and to assess the potential for deep-seated slope-deformation mechanisms to adversely affect the current mine design.

In this paper, the south wall is analyzed, with a two-dimensional finite difference program Fast Lagrangian Analysis of Continua (FLAC) (Itasca 2001) A Mohr-Coulomb constitutive model was assigned as described to all zones with the following properties (Table 7)

Tahle 7 Input paiameieis foi nuniencal modeling

Materials	Soil	Ore	Waste
Density (Kg/in[1])	2 IM)	4100	2650
Poisson s Ratio	0 «	0 3	0 3
Φ (degree)	25	34	30 3
C (MPa)	0 0295	1 4	1 15
E,,, (GPa)	0 015	6 51	3.39

Fıguıe 7 shows the FLAC model for the south wall

5.4 Modeling results

The south wall was analyzed along section 1 at current and final pit layout. The factor of safety was obtained through successive FLAC model evaluations in which the rock-mass strength was decreased incrementally until overall slope failure occurred. The ratio of the estimated strength to the lailure strength defines the factor of safety in this context. By using strength parameters, a factor of safety 1.45 predicted for south wall.

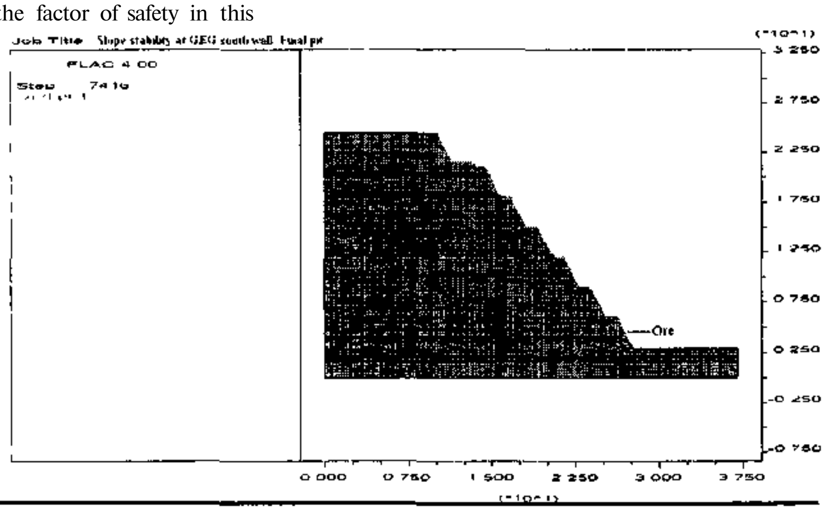
Based on the FLAC model evaluations (Figure 8 to 10), it is reasonable to expect the future south wall to remain stable.

Modeling for north, east, and west walls, yielded a factor of safety 1.40, 1.5, and 1.5 respectively (Bagherian 2003).

6 CONCLUSIONS

The following conclusions can be drawn, based on the stability analyses:

- The main parameters influencing the failure and instability of the mine walls are high pressure of groundwater and system of discontinuities, which intersect the pit walls.
- Based on the FLAC model evaluations, and results, it is evident that pit walls remain stable.
- FLAC model results shows that, with assuming a factor of safety of at least 1 3 against the circular-type failure the overall slope angles of pit walls could be increased.
- Because of economical importance of overall slope angles increasing, a more detailed program suggested to determine increased slope angles.
- Future analysis must consider discontinuities, using a distinct element code, like UDEC



Fıguıe 7 FLAC models used foi analysis of south wall stability

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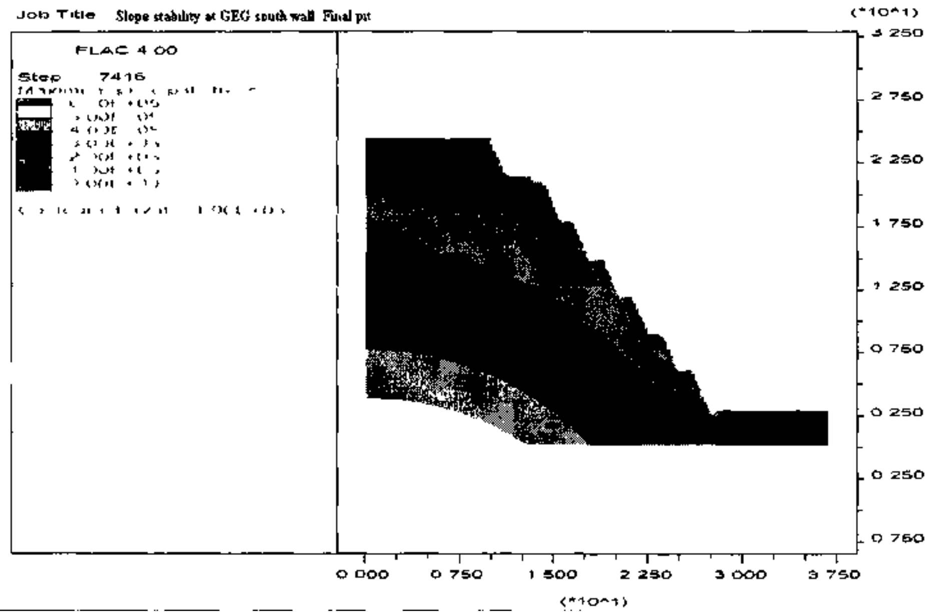
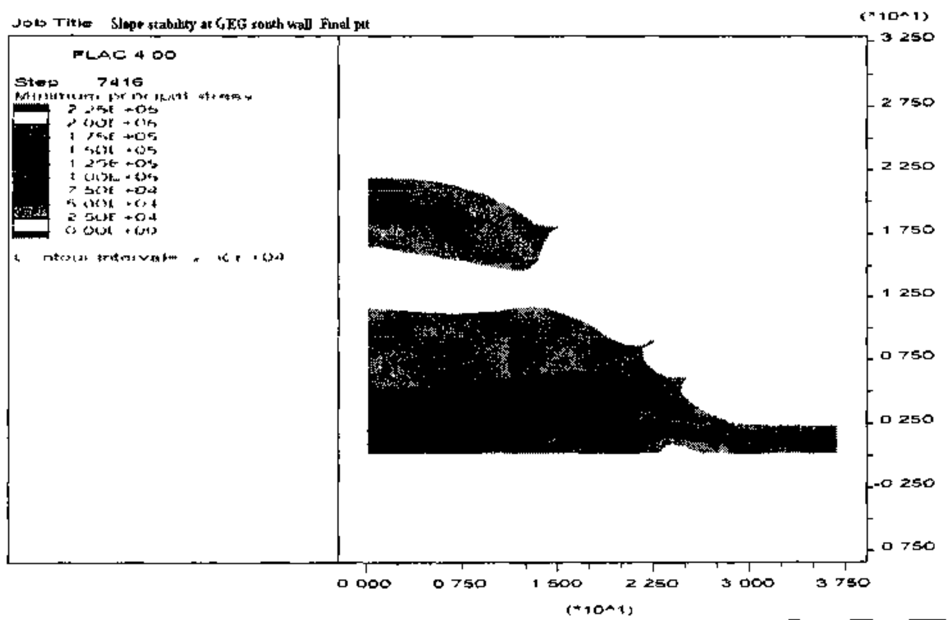
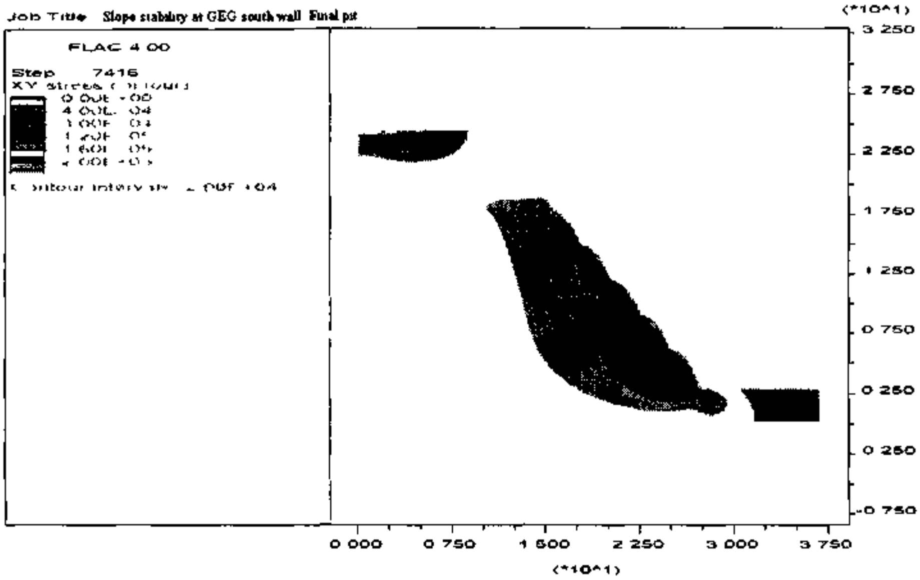


Heme 8 Result *of* FLAC analysis showing maximum principal stiess conioui lot *GhG south* wall



Fıguıe *9* Result ot FLAC analysis showing minimum pıncıpal stiess contoui toi GEG south wall



Fıguıe IÜ Result ot FLAC analysis showing slıeaı stiess tontoui toi GbG south wal

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