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Design of Support System for Shaft at Hutti Gold Mines Using Stress Analysis

R. Venugopala Rao*, M.N. Reddy†, S. Jakki‡ and R.N. Gupta§

Introduction

The Hutti Gold Mining Company (HGML) is mining gold at the Hutti in Raichur district of Karnataka state, India. The mine is accessed by three shafts namely Central Shaft, Mallappa Shaft and Village Shaft. They are mining between 20th and 25th levels. Mallappa shaft which is 6 m 2 m (finished) rectangular shape was sunk up to 25th level up to depth of 814 MRL. Gold reserves exist much below the 25th level. Therefore, it is required to deepen the shaft by keeping the future in view. The HGML is planning to deepen this shaft up to 1015 MRL and in the future they do not plan to deepen this shaft further. However another auxiliary shaft will be sunk nearby Mallappa shaft to mine the reserves which are at more than 1000 meters depth. Two dimensional continuum and discontinuum models were used to estimate stresses around the shaft and in the support systems. The various parameters required for modeling are summarized in the following sections.

* Scientists, National Institute of Rock Mechanics, Kolar Gold Fields, Karnataka-563117, India. E-mail: v-ravu@yahoo.com

† Scientists, National Institute of Rock Mechanics, Kolar Gold Fields, Karnataka-563117, India.

‡ Scientists, National Institute of Rock Mechanics, Kolar Gold Fields, Karnataka-563117, India.

§ Director, National Institute of Rock Mechanics, Kolar Gold Fields, Karnataka-563117, India.

TABLE 1 : Physico-Mechanical Properties of the Rock Mass and the Joints

Property	For Q = 2
Young's Modulus	12.5 GPa
Poisson's Ratio	0.2
Density	2700 kg/m^3
Cohesion	5.29 MPa
Friction	45°
Joint normal Stiffness	100 GPa/m
Joint Shear Stiffness	1 GPa/m
Joint Friction angle	25°

Input Parameters

Intact rock samples of various rock types such as metabasalt, acid volcanic rocks, chlorite biotite schist and various reef rocks found in the mine were tested in the laboratory. The uni-axial compressive strength values varied from 110 MPa to 305 MPa for various rock types. The shaft is located in the middle reef where the predominant rock type is Chlorite-bioitite schist. The unconfined compressive strength of 110 MPa and Hoek and Brown parameter m_i of 26 reported in Reddy and Gupta (2003) was used for the estimation of equivalent Mohr-Coulomb rock mass parameters of cohesion and friction angle (Hoek, 1990). The joint stiffness values were estimated from values obtained in similar rock types. These parameters were reported in Table 1.

Rock Mass Rating

National Institute of Rock Mechanics has assessed the rock mass quality in all the reefs of Hutti gold mine (Venkateswarlu, 2000). The rock mass quality found in four reefs has been summarized in Table 2. Q value was determined for all the reefs between 18th and 20th levels. The RMR was calculated from the correlation given by Bieniawski (1979).

TABLE 2 : Rock Mass Quality of Various Reefs

Ore Body	Rock Mass Quality (Q)	RMR
Strike Reef	2 to 9	54 to 62
Zone-I Reef	4 to 8	56 to 63
Oakley's Reef	8	63
Middle Reef	3	55 to 62

$$RMR = 9\ln Q + 44$$

The RMR value varied from 54 to 62. The minimum value of 54 was used in the stability analysis.

Insitu Stresses

Hydraulic-fracturing test was done to determine the insitu stress in Hutti Gold Mine (Sengupta, 1999). The major principal stress was found to be horizontal and it was in the direction of N20°E. The following stresses were estimated and applied on the cross section analyzed at 1050 MRL.

Stress parallel to the length of the shaft	: 24.33 MPa
Stress perpendicular to the length of the shaft	: 28.16 MPa
Stress parallel to the depth of the shaft	: 27.40 MPa

Computational Model

A large two-dimensional model to represent the horizontal section with boundaries placed at sufficiently large distance from the excavations was used for simulation. Strata pressure equivalent to 1050 m was imposed on the model. The deformation modulus was estimated from the Rock Mass Rating (lowest Q value of 2). Two sets of joints were simulated in the discontinuum model. The analysis was carried out without support system first and then it was repeated for the shotcrete thickness of 0.3 m with a bolt spacing of 1.5 m all along the periphery of the shaft.

The results of stress analysis in terms of deformations and stresses around the excavation and deformations of joints in terms of separation and slip were carefully examined. The support system for each case was estimated from the results of stress analysis with out supports and same was incorporated and the analysis was repeated. The adequacy of the support system was verified in terms of reduced deformations in the rock mass and the forces/stresses induced in the support system. The support systems were designed such that stresses and forces induced in them are within the permissible limits.

Analysis

Continuum and discontinuum analysis was performed to analyze the stability of different shapes at 1050 m depth. The results in terms of displacement vectors, joint deformations, forces induced in the support system were discussed in the following sections with and without support system for all the three shapes. The vector scale indicates the scale for measuring the stress magnitude in MPa. The maximum stress or displacement observed over the cross section is shown at the bottom of the figures. The joint slip and separation are shown in thick lines along the joints.

Continuum Analysis

The deformations and stresses obtained from the stress analysis considering the rock mass as continuum are described in the following sections. The summary of the results of continuum analysis are given in Table 3.

Rectangular Shaft

The maximum principle stress of 76 MPa was observed and it was confined to one or two zones. In continuum models the movement of rock is due to deformation of rock mass only. Therefore the model showed a small movement of 6.6 mm at only two zones. Corners were found to be in a yielding state. This analysis was performed for the rock quality 'Q' value of 2 and uniaxial compressive strength value of 110 MPa. This rock mass quality exists nearby middle reef only and in other places rock mass quality was better.

Elliptical Shaft

The maximum principal stress value of 65 MPa is observed. Maximum tensile stress value of 1.14 MPa was also observed around the elliptical shaft. Maximum displacement of only 4.78 mm observed. No yielding can be found around elliptical shaft. Very small area on the edge was found to be in a failure state (i.e. Hoek Brown strength/stress ratio less than one).

Circular Shaft

Maximum compressive stress magnitude of 58 MPa and 0.4 MPa of tensile stress were observed around the shaft. Stresses around circular shaft

TABLE 3 : Summary of Stress Analysis Results using Continuum Model for Different Shapes

Maximum Value	Rectangular Shaft	Elliptical Shaft	Circular Shaft
Displacement (mm)	6.64	4.78	4.04
Maximum Compressive Stress (MPa)	−76	−65	−58

were significantly less than those for rectangular and elliptical shafts. No yielding was observed and factor of safety contours less than two were not found.

Discontinuum Analysis

Continuum analysis demonstrates that all the three shapes are stable. In the following section discontinuum models along with supports were simulated. The shotcrete was simulated as a liner (beam element) and the rock bolts were simulated having axial and shear stiffness. 3 m long bolts were used in all the cases with 1.5 m spacing. The properties of support element are given in Table 4. The results of stress analysis for different shapes are summarized in Table 5.

Rectangular Shaft

The discontinuum analysis was performed for all the shapes of the shaft. The orientation and spacing of the joints was changing with depth. There are four sets of joints were found around the Mallappa shaft including foliation. In the present simulation one set of joints parallel and another set perpendicular to major axis were considered. The displacement vectors for rectangular shaft were 17.1 mm (Fig.1). When supports were provided the

TABLE 4 : Properties of Shotcrete Lining and Bolts

Shotcrete	
Thickness	0.3m
Density	2500kg/m^3
Young's modulus	25GPa
Poisson's ratio	0.2
Residual yield strength	5MPa
Compressive yield strength	20MPa

Rock/Shotcrete interface	
Normal stiffness	10GPa/m
Shear stiffness	0.7GPa/m
Friction	25^0

Reinforcement	
Axial stiffness	6.363GN/m
Shear stiffness	1.5GN/m
1/2 "Active" length	0.11m
Ultimate axial capacity	0.2MN

TABLE 5 : Summary of Stress Analysis Results using Discontinuum Model for Different Shapes

Maximum Value	Rectangular Shaft		Elliptical Shaft		Circular Shaft	
	No Supports	With Supports	No Supports	With Supports	No Supports	With Supports
Displacement (mm)	17.51	15.41	15.16	11.41	20.32	13.69
Joint Separation (mm)	1.99	1.381	1.458	0.467	0.812	0.377
Joint Slip (mm)	6.56	5.53	8.44	6.92	9.68	6.949
Principal Stresses (MPa)	-44.85	-54.35	-47.27	-50.43	-53.56	-69.42
	0.0008	0.0003	0.0028	0	0.01565	0.001
Shear Force on Shotcrete (MN)		1.841		0.541		0.8772
Moment on Shotcrete (MN-m)		0.643		0.256		0.2334
Axial Force on Shotcrete (MN)		3.93		5.280		5.982
Bolt Load (MN)		0.20		0.20		0.20
% of Bolts yielded		10%		41%		46%

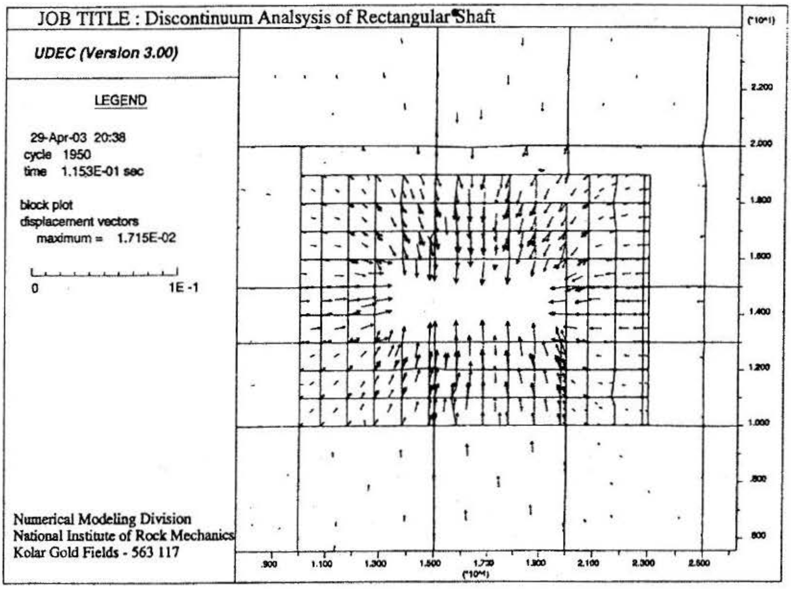

FIGURE 1 : Displacement Vectors Without Supports around Rectangular Shaft

magnitude of displacement has been reduced to 15.4 mm. The joint separation and joint slip around the rectangular shaft was 1.99 mm and 6.55 mm respectively before providing supports. Shotcrete thickness of 0.3 m (300 mm) and rock bolts of 3 m length were installed at 1.5 m spacing. These supports were effective and they reduced the joint opening to 1.381 mm and joint slip to 5.53 mm. The principal stress magnitude before the support was 44.85 MPa (compressive) but it increased to 54.35 MPa (compressive). The maximum value of axial force in the shotcrete element was 3.930 MN as shown in Figure 2. Similarly shear force and bending moment are 1.84 MN and 0.64 MN-m respectively. Maximum bolt load was observed to be 0.20 MN as shown in Figure 3.

Elliptical Shaft

The maximum displacement around the elliptical shaft was found to be 15.16 mm when no supports were provided. The displacement around the elliptical shaft was less than what it was observed around rectangular shaft. When the 0.3 mm thick shotcrete along with 3 m long rock bolts were installed, displacement magnitude was reduced to 11.41 mm. The joint opening and joint slip were 1.458 mm and 8.44 mm respectively. When support was provided the magnitude of separation and slip was reduced to 0.468 mm and 6.92 mm (Fig.4) respectively. The maximum compressive stress magnitude increased from 47.27 MPa to 50.43 MPa. The axial force

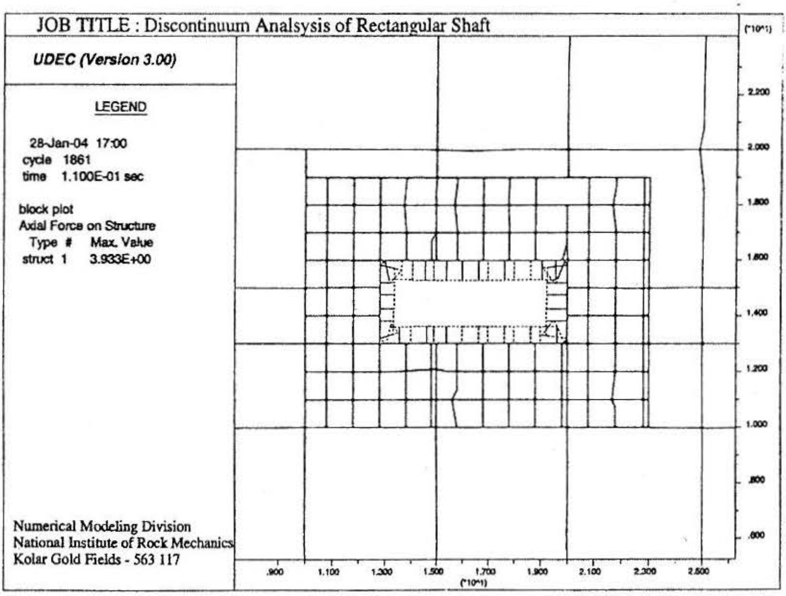

FIGURE 2 : Axial Force in Shotcrete around Rectangular Shaft

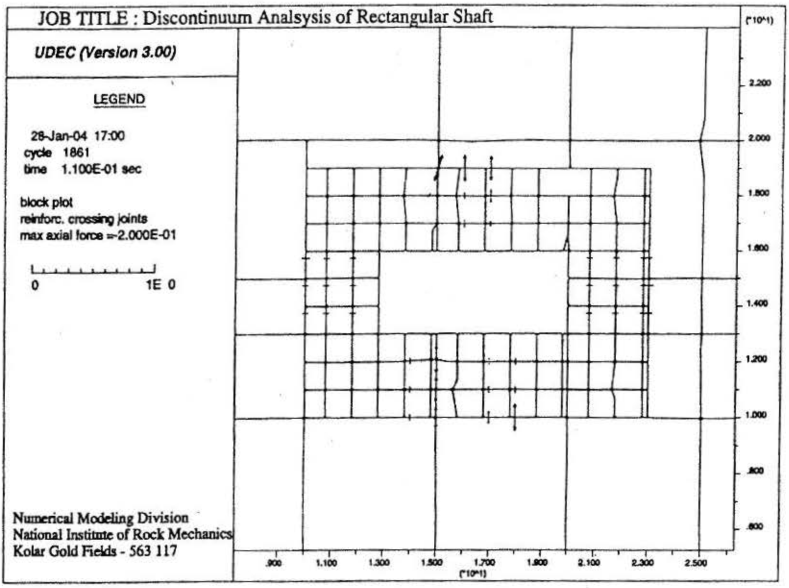

FIGURE 3 : Axial Force in Rock-Bolts around Rectangular Shaft

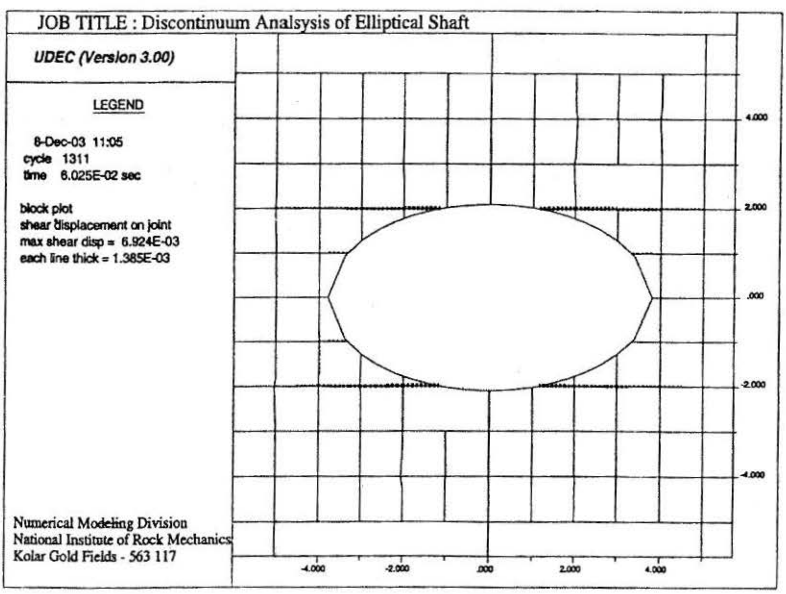

FIGURE 4 : Joint Slip With Supports around Elliptical Shaft

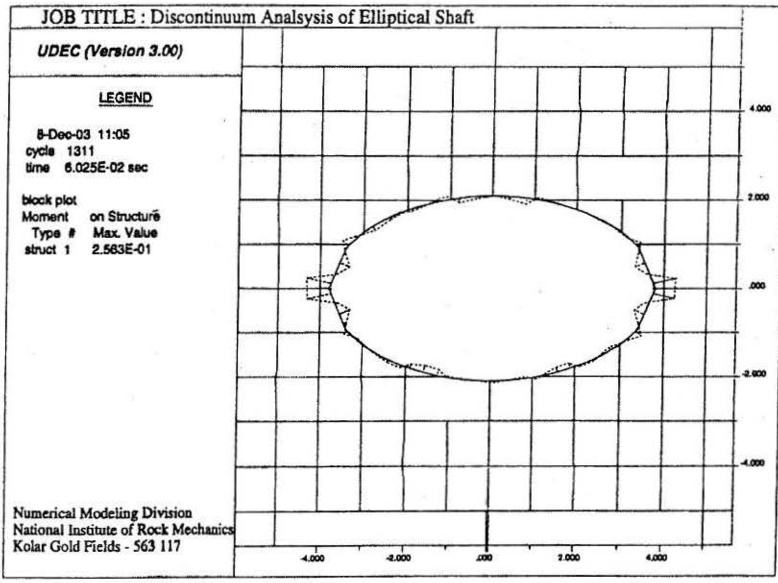

FIGURE 5 : Bending Moment on Shotcrete Support around Elliptical Shaft

on shotcrete was found to be 5.280 MN as shown in Fig.4. Bending moment on shotcrete was 0.256 MN-m (Fig.5) and shear force on shotcrete was 0.541 MN only. Maximum bolt load was found to be only 0.20 MN and it was less than what it was observed in rectangular shaft.

Circular Shaft

The maximum displacement around the circular shaft was found to be 20 mm when no support was provided. When rock bolts of 3.0 m length were provided at 2.1 m spacing along the periphery the maximum displacement was reduced to 13.96 mm. The joint separation and joint slip was 0.8 mm and 9.68 mm (Fig.6) respectively. In this case shotcrete of 0.3 m thick was provided. The maximum compressive stress magnitude of 53.56 MPa was observed prior to the supporting of shaft. It increased to 69 MPa when supports were put in place. Tensile stresses reduced by 15 times after erection of the support. The maximum axial force of 5.98 MN (Fig.7) was observed in the shotcrete elements. The maximum value of bending moment and shear force were found to be 0.23 MN-m and 0.87 MN respectively. The axial load of 0.2 MN (Fig.8) was observed in the bolts.

Conclusions and Discussions

- The continuum analysis showed lower displacements and stresses for

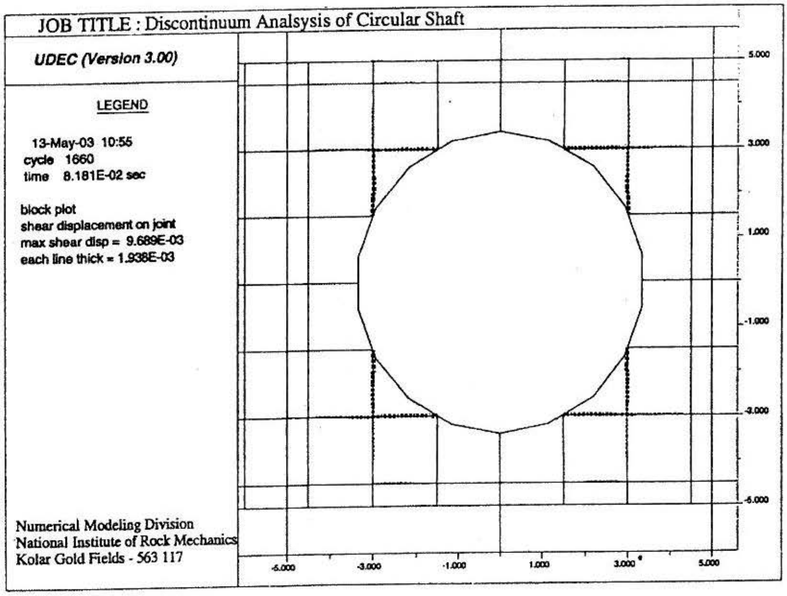

FIGURE 6 : Shear Displacement Without Supports around Circular Shaft

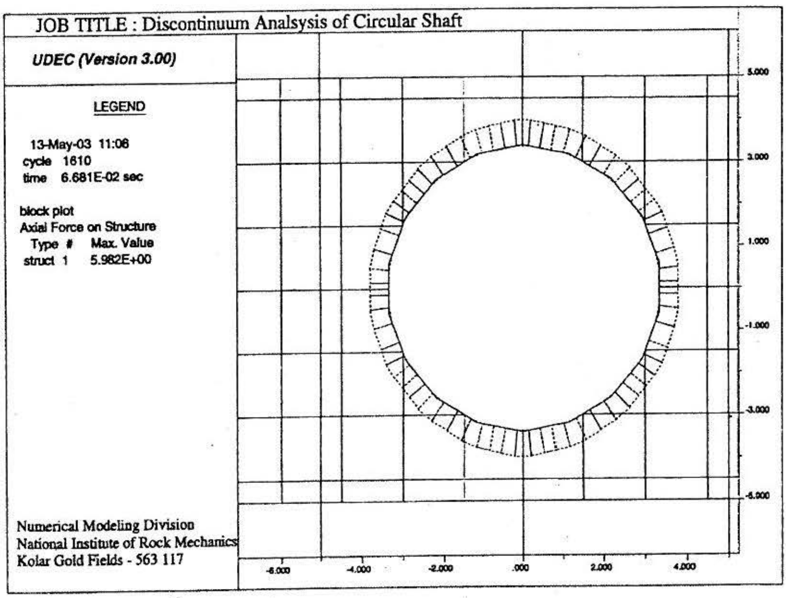

FIGURE 7 : Axial Force on Shotcrete Support around Circular Shaft

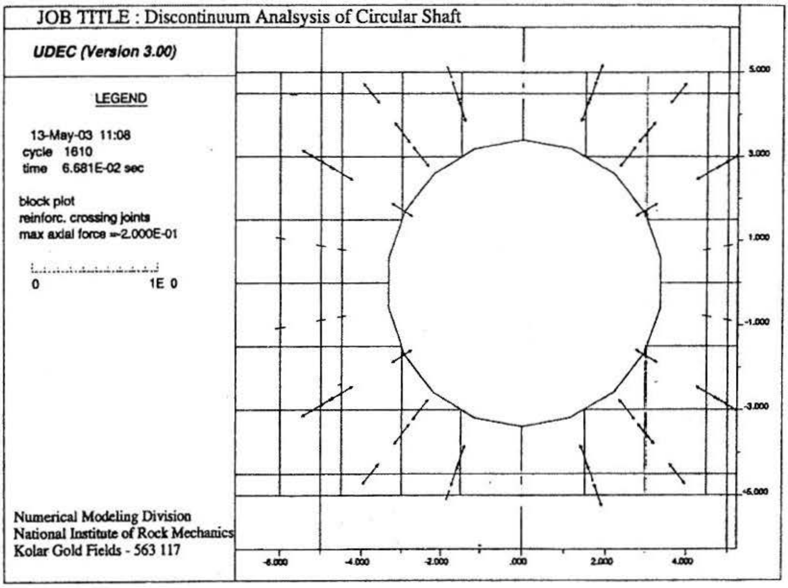

FIGURE 8 : Axial Force in Rock Bolts around Circular Shaft

elliptical and circular shafts as compared to rectangular which was expected. The results of continuum analysis could be misleading.

- In discontinuum analysis (which is the realistic approach), rectangular shaft exhibited larger displacements and stresses compared circular and elliptical shafts. This is due to the formation of small blocks in the case of elliptical and circular geometries cutting the foliation joints.

- The rectangular shaft would also withstand the strata pressure due to increase in depth. The performance of support system consisting of 0.3 m thick shotcrete and 3 m long bolts at 1.5 m spacing on either would serve the purpose. The rectangular shaft exhibited a total deformation of 15 mm, out of which more than 50% would occur during construction itself.

- The support system in each of the case could control the deformations in the rock mass as well as the joint deformations. It can also be seen from the forces induced in the rock bolts and the shotcrete, that the support systems considered were adequate for rectangular shape.

- The present rectangular shape of the Mallappa shaft could survive the strata pressure up to 1050 m horizon with the support system as indicated above.

- The maximum axial force induced in the shotcrete was lowest for rectangular shaft. Similarly, the number of bolts yielded were only 10% for rectangular shaft where as for circular shaft these were 46%. Closer bolt spacing is required for circular shaft.

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