17th International Mining Congress and Exhibition of Turkey- IMCET2001, © 2001, ISBN 975-395-417-4

Estimation of Lining Thickness Around Circular Shafts

H.Öztürk & E.Ünal
Department of Mining Engineering, Middle East Technical University, Ankara, Turkey

ABSTRACT: In this paper, the broken zone developing, around a circular mine shafts and lining pressure is estimated by integrating the results of numerical analysis and the "cock-load height" equation derived from empirical analysis. During numerical modelling studies, the computer program $FLAC^{2D}$ was utilized. In order to estimate equivalent Mohr failure Envelope from the generalised Hoek Brown failure criterion, a new FISH function was written within $FLAC^{2D}$. Parametric studies were carried out by considering mRMR (modified Rock Mass Rating) values, depth from surface, shaft diameter, ratio of horizontal principal-stresses and uniaxial compressive strength of intact rock. Finally, the computer program, "SHAFT" was also introduced. This program simplifies the lengthy and complex process of shaft-lining design.

1 INTRODUCTION

In literature, the lining thickness calculation for circular shaft is based on the assumption that the pressure on the rock-lining contact is known. This pressure is calculated analytically assuming hydrostatic state of stress, considering a failure criterion, and by determining the internal support pressure that will prevent the broken zone developing around the shaft. Consequently, wim the help of this value, the lining thickness is calculated from the thick-wall cylinder meory of elasticity. In this study, firstly, the broken zone developing around circular shafts were calculated, for different ratios of horizontal principal stresses, based on numerical studies. Secondly, considering these results and based on statistical analyses, Unal's (1983;1992) empirical rock-load height equation was calibrated, allowing for the effect of stress. Thirdly, the lining pressures was estimated. Lastly, by using the analytical thick-wall cylinder equation, the lining thickness was calculated.

2 ESTIMATION OF THE DISTURBED ZONE

Information on the extent of disturbed zones is one of the main required parameters in the design of shaft support system. This parameter can be estimated according to the induced stresses and an appropriate rock mass strength criterion. In this study, the numerical stress anaysis program $FLAC^{2D}$ (Fast Lagrangian Analysis of Continua) (Itasca, 1993) and the empirical rock-load height equation derived by Unal (1983,1992,1999) were used.

2.1 *Numerical Studies*

In order to determine the extent of the failure zones developing around shafts, a two-dimensional finite difference program, $FLAC^{2D}$, was used. Parametric studies were carried out considering the ratios of horizontal principal stresses, uniaxial compressive strength of intact rock, mRMR (modified rock mass rating) (Unal, 1996), shaft diameter and depth from the surface. The unit weight of material was assumed to be $27 kN/m^3$. A total of 288 models were analysed. During modelling, only one-quarter of the cross-section of the circular shaft is modelled due to symmetry. As a failure criterion, Generalised Hoek-Brown Equation (Hoek and Brown, 1997), presented through Equations 1-4, was used. With the help of a new FISH function, an equivalent Mohr Envelope was derived and the tensile strength, cohesion and internal friction .angle were calculated. The Generalised Hoek-Brown criterion is presented in Equation (1).

$$\sigma'_1 = \sigma_3 + \sigma_{ci}\left(m_b \frac{\sigma_3}{\sigma_{ci}} + s\right)^a \quad (1)$$

where
σ'_1= maximum effective stress at failure

σ'_3= minimum effective stress at failure
σ_{ci} = uniaxial compressive strength of the intact rock
mb,s,a = Hoek-Brown constants which depend on charecteristics of rock mass.

The material constant mb can be determined by Equation (2).

$$m_b = m_i \exp\left(\frac{GSI - 100}{28}\right) \quad (2)$$

where, GSI *is the* geological strength index and m_i is the intact rock constant.

For GSI >= 25 the original Hoek-Brown criterion is applicable with

$$s = \exp\left(\frac{GSI - 100}{9}\right)$$

and a=0.5 (3)

For GSI < 25

$$a = 0.65 - \frac{GSI}{200}$$

and s=0 (4)

For better quality rock masses(GSI>=25), the value of the GSI can be estimated directly from the 1976 version of Beniawski's Rock Mass Rating, with the ground water rating set to 10 (dry) and the adjustment for joint orientation set to 0 (very favourable). For very poor quality rock masses the value of RMR is very difficult to estimate and the balance between the ratings no longer gives a reliable basis for estimating rock mass strength. Consequently, Bieniawski's RMR classification should not be used for estimating GSI values for poor quality rock masses. If the 1989 version of Bieniawski's RMR classification is used, then GSI=RMRg9-5 where RMRgg has the groundwater rating set to 15 and the adjustment for joint orientation is set to zero (Hoek and Brown, 1997).

It should be noted, however that in order to provide a more quantitative basis for evaluating GSI values, the modifications were suggested by Sönmez and Ulusay (1999) should be considered. These modification include easily measurable parameters with their ratings and/or intervals which define the blockiness and surface condition of discontinuities. An example of a failure zone developing around a circular opening is presented in Figure 1. In this example, the input parameters used are as follows: the depth is 300m, P_v=Ph2=8.1MPa uniaxial compressive strength of intact rock is 50 MPa, shaft radius is 3 meters, ratio of horizontal principal-stresses is k=0.75 and mRMR is 60.

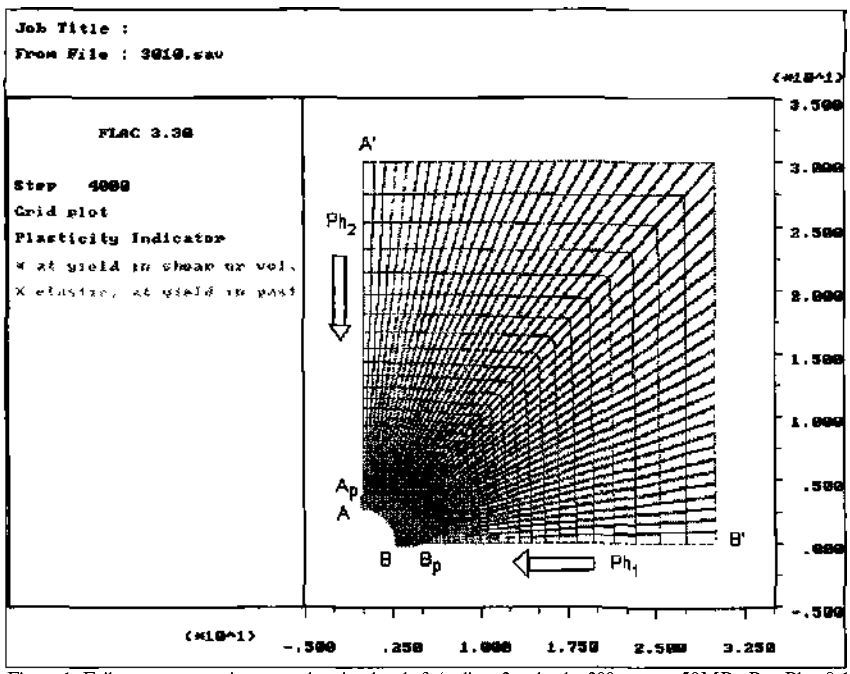

Figure 1. Failure zone occuring around a circular shaft (radius=3m,depth=300m, σ_{ci}= 50MPa,Pv=Ph,=8.1 MPa,k= Ph(/Ph2=0.75, mRMR=60, m,=4) (Öztürk, 2000).

In order to check the validity of the model and to investigate the extent of the broken zone, the stress distribution presented in Figure 2 was analysed. This figure İs the result of a model having a principal horizontal-stress ratio of 0.75 and vertical in-situ stress of 8.1 MPa. As can be seen from this figure, at the roof and wall (when the shaft cross-section İs taken into account, the right side is called the wall) of the opening, the tangential stress jumps provides information about the extent of the disturbed zone. Another point that should be be mentioned is that as one goes away from the opening, stresses converge to in-situ stresses. In this study,the maximum extent of the broken zone was taken as the broken zone thickness.

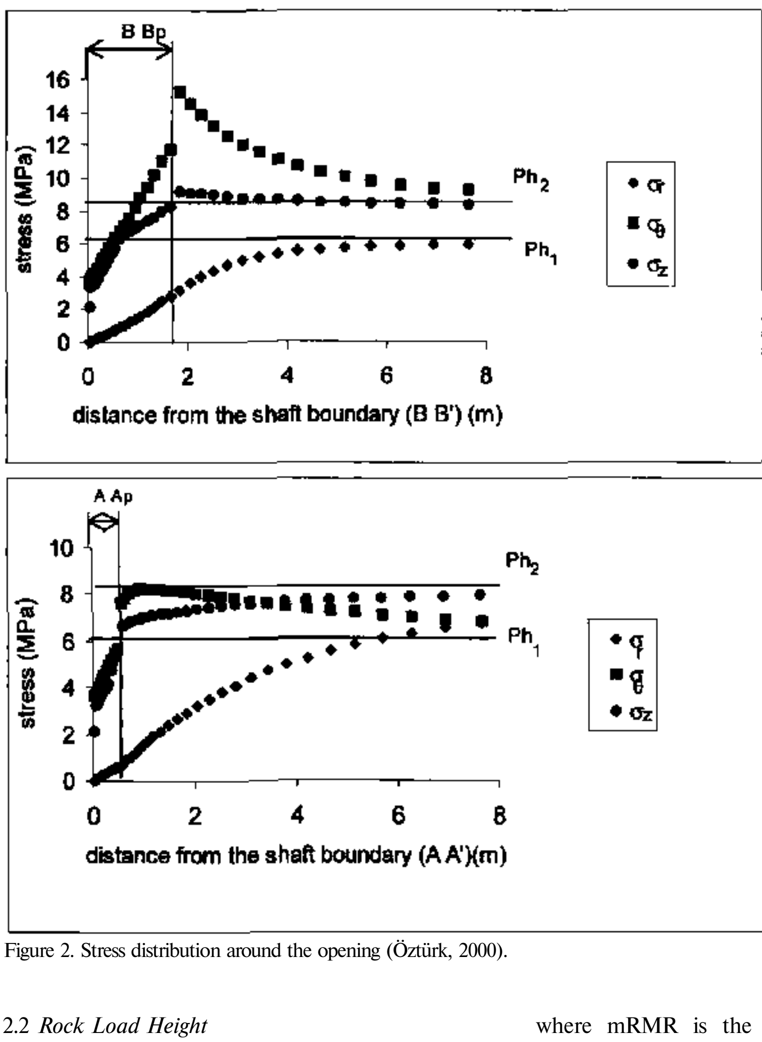

Figure 2. Stress distribution around the opening (Öztürk, 2000).

2.2 *Rock Load Height*

The rock-load height in underground openings can be calculated by using Equation (5), developed by Unal(1983; 1992).

$$ht = S * \left[\frac{100 - mRMR}{100}\right] * B \qquad (5)$$

where mRMR is the modified rock mass rating defined by the modified-RMR system developed on the basis of Bieniawski's RMR-system (Unal, 1989; 1996),B is the span, and S is the stress factor that should be determined by means of numerical studies.

Unal (1999) defines the rock-load height as the height of the potential instability zone around the opening which will exert pressure on the support.

This parameter is used, by the author, in the support design of roadways excavated at depuis of 50-500 meters.

3 COMPARISON OF THE ORIGINAL ROCK LOAD HEIGHTS AND FAILURE ZONES

In this study, the failure height {hfj is defined as the maximum extent of the failure zones around the circular shaft openings. During analyses, the failure heights were compared with the rock load heights (ht) obtained from the mRMR system. A typical plot obtained from the results of the empirical and numerical analyses is shown in Figure 3.

In Figure 3, the rock quality is kept constant (mRMR=60), while the broken zones are plotted as a function of various ratios of horizontal-principal-stresses (k) and shaft diameter. For h, calculations, "S" is taken as I. As can be seen in Figure 3, rock-load height is not sensitive to stress. Therefore, a stress factor (S) is necessary to calibrate the rock-load height. This process was realized by regression analyses, explained in Section 4.

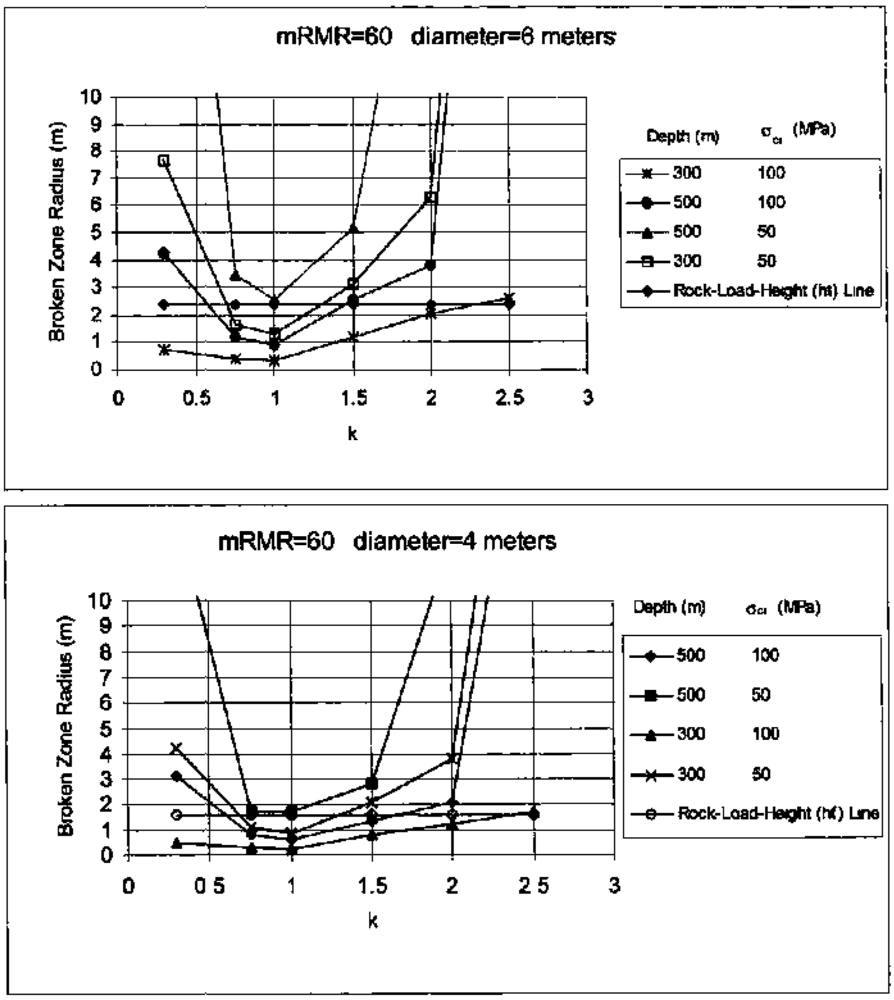

Figure3 Variation of broken zone radius with the ratio of horizontal-principal stresses (k) (Öztürk, 2000).

4 REGRESSION ANALYSES

Regression analyses were carried out by taking 288 models into account. These models were derived from combinations of ratio of horizontal-principal stresses with (0.3, 0.75, 1, 1.5, 2, 2.5), mRMR values (26, 35, 45, 60, 75, 85), depths of 300 and 500 meters and uniaxial compressive strength of intact rocks of 50 and lOOMPa and spans of 4 and 6 meters. Regression Equation (6) relates the numerical broken zone radius to empirical rock-load height (Öztürk, 2000).

$$S = Ae^{Bk} + Ck + D\frac{\sigma_{ci}}{P_v} \quad (6)$$

where,
k = ratio of horizontal principal-stresses
σ_{ci} = uniaxial compressive strength of intact rock (MPa)
P_v = vertical in-situ stress (MPa)
A.B.C.D = regression constants which are presented in Table 1.

Table 1. Regression constants

RMR	A	B	C	D	R*
26	19.772	0.605	-24.727	-1.438	0.73
35	14.882	0.588	-17.814	-1.106	0.76
45	11933	0.59	-14.25	0.928	0.74
60	8.584	0.58	-10.042	-0.661	0-67
75	4.89	0.564	-5.79	-0.335	0.68
85	1.693	0-52S	-1.615	-0.078	0-5

For circular shafts, the rock-load height equation can be presented as shown in Equation (7).

$$ht = S * \left[\frac{100 - mRMR}{100}\right] * 2R_i \quad (7)$$

ht = 5*
where, *Ri* = inner shaft radius

5 DETERMINATION OF LINING PRESSURE AND THICKNESS

For determination of tiie pressure exerted on die rock-lining contact, Equation (8), suggested by Unal (1999), can be used.

$$P_{ri} = ht * \gamma * TS \quad (8)$$

where,
ht = rock-load height
y = unit weight of rock material
TS = support constant changes between 1 and 2.25 (Unal, 1999)

A comparison of Pressure Equation (8) with values reported in die literature is presented in Figure 4.

As can be seen from Figure 4, there is a good agreement witii observed values. The modified equation forms the upper limit for die values of mRMR smaller than 30; for other values of mRMR, the associated graphs are between die upper and lower bounds.

After finding the pressure, for the calculation of lining thickness, Lamé's thickwall cylinder theory (Timoshenko, 1976) can be used as shown in Figure 5 and Equation (9).

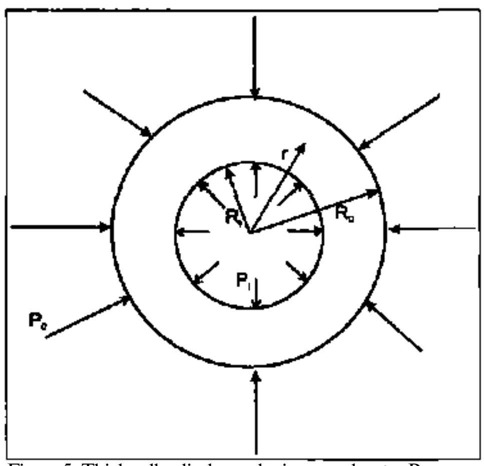

Figure 5. Thickwall cylinder under inner and outer Pressure (Timoshenko, 1976).

$$t = R_i\left(\left(\frac{\sigma_{\theta\max}/SF}{\sigma_{\theta\max}/SF - 2P_{ri}}\right) - 1\right) \quad (9)$$

where,
R =shaft radius
t =lining thickness
SF =safety factor applied to the ultimate compressive strength of the concrete
$\sigma_{\theta max}$ =tangential stress at the inside face of the lining prior to failure inside lining radius
Po =uniformly distributed hydrostatic pressure at the rear of the lining.

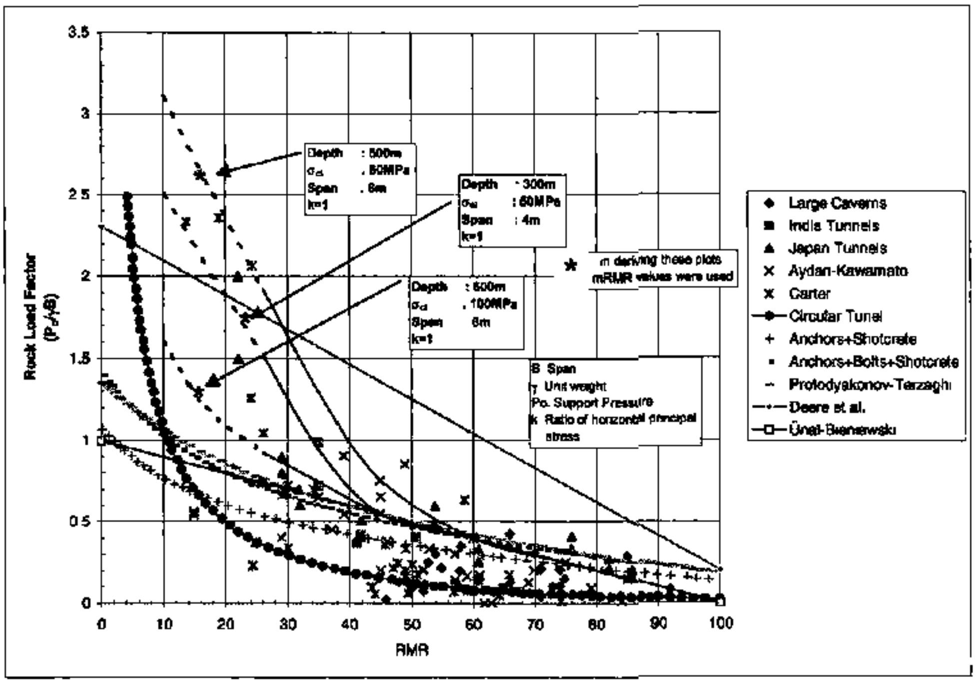

Figure 4. Comparison of pressure equation with reported values (modified after Aydan, 1999).

6 COMPUTER PROGRAM SHAFT

The computer program SHAFT (Öztürk, 2000) has been developed by the authors for determination of shaft support requirements. The program is written in Quick-Basic and consists of several sub-programs.

The required data to be provided by die user are listed below.

1. Radius of the shaft.
2. The number of regions (each region is a section of me rock mass which may respond to the shaft excavation in the same manner).

For each region the required data are:

3. RMR value or GSI value.

NOTE: RMR can be used considering the RMR classification system of Bieniawski 1989. However,the ground water index should be taken as IS and the joint orientation index should be taken as 0. If the RMR value is less than 40, which is usually the case for weak stratifying and clay-bearing rock, then it is suggested that Unal's mRMR index value be used.

4. The depth of each region from the surface (bottom depth of each region).
5. Uniaxial compressive strength of intact rock material.
6. Unit weight of rock material.
7. Ratio of horizontal principal stresses.
8. Compressive strength of the concrete.
9. Required minimum factor of safety.
10. Compressive strength of steel (when required).
11. Required minimum factor of safety for steel.

The program provides the design outputs in graphical form. The total depth of the shaft is drawn on the screen. The cursor can be moved vertically along the shaft langth to obtain information for the required location. Moving this cursor to the desired point and progressing "ENTER" key will open a window on the screen. The design requirements for that particular point can be seen on the screen and can be printed if desired.

Example output data are shown in Figure 6. The following parameters were used for this example.

Shaft diameter :3m

Number of zones having the same properties: 2

For zone number 1

mRMR	:26
Depth	:200m
Unit Weight	:27kN/m^3
Uniaxial Compressive Strength	:25 MPa
Ratio of horizontal principal-stresses	:3

For zone number 2

mRMR or GSI	:85
Depth	:500m
Unit Weight	:27 kN/m^3

Uniaxial Compressive Strength :50 MPa
Ratio of horizontal principal-stresses :1

Concrete Properties:

Strength 50 MPa
Safety Factor : 1

Steel Properties:

Strength : 200 MPa
Safety Factor : 1

Outputs:

Sample outputs are presented in Figure 6.

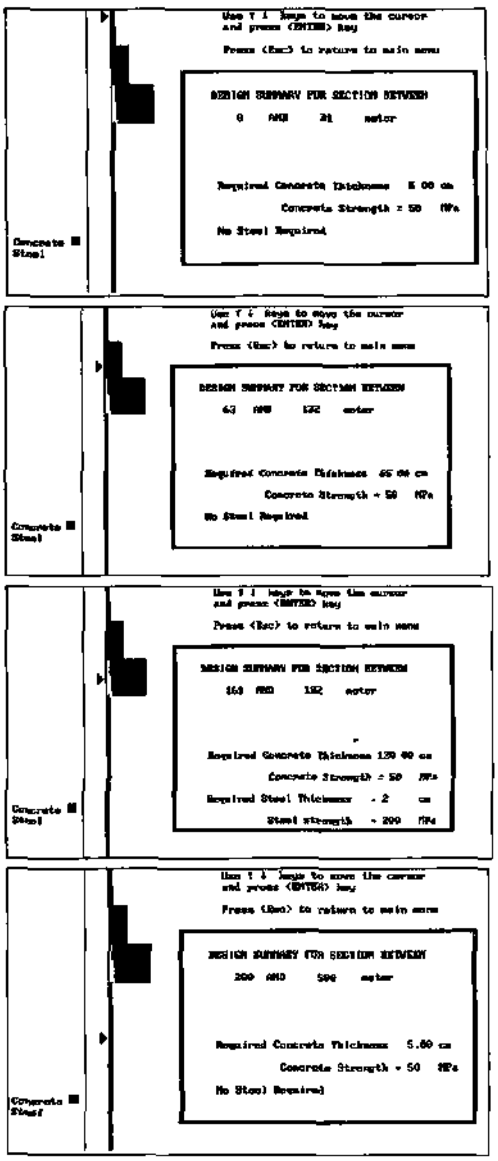

Figure 6. Sample outputs of SHAFT program.

7 CONCLUSIONS

According to the results of this study, the following conclusions were drawn.

1. The preliminary requirement for a support design in a shaft is knowledge of the extension of the broken zone. This parameter can be obtained from numerical analysis or simply from the following equation proposed in this study:

$$ht = S * \left[\frac{100 - mRMR}{100}\right] * 2R_t$$

where

ht =rock-load height representing broken zone radius
R, = shaft radius
mRMR = modified Rock-Mass Rating
S = stress factor

2. It was observed from the regression analysis that die stress factor "S" is a function of the uniaxial compressive strength of intact rock, ratio of horizontal stresses and vertical stress in the form of:

$$S = Ae^{Bk} + Ck + D\frac{\sigma_{cf}}{P_v}$$

where:

k = ratio of horizontal principal-stresses
c_c, = uniaxial compressive strength of intact rock
P_v = vertical in-situ stress
A,B,C,D = regression constants

3. The pressure on the support can be found simply by multiplication of ht with the unit weight of the material and the support constant.
4. With the help of the computer program SHAFT, complex shaft lining design calculations were simplified. By providing information on the geometry and the properties *of* material through the shaft-driven zones, detailed information on lining requirements throughout the pre-entered successive zones of a driven depth can be obtained.

REFERENCES

Aydan, Ö. 1999. Support System of Large Underground Openings According to RMR Classification System *Yeraltı Yapılarında Mühendislik Jeolojisi Kollokyumu,* s. 103-110.

Bieniawski, Z.T 1989 *Engineering Rock Mass Classification.* Me Graw Hill, New York

Hoefc, E. and Brown, E.T 1997. Practical Estimates of Rock Mass Strength. *Int J. Rock Meek Min. Sei.* Vol.34 No.8. pp. 1165-1186

Itasca, 1993. FLAC Code, 3 Vol, Minneapolis, USA

Öztörk, H. 2000. *Prediction of Broken Zone Radius and Lining Thickness Around Circular Mine Shafts* M. Sc. Thesis, 136 pages, METU, Turkey.

Sönmez, H., Ulusay, R. 1999. Modifications to the geological strength index (GS!) and then" applicability to stability of slopes. *International Journal Of Rock Mechanics And Mining Sciences.* Vol. 36: (6) pp. 743-760.

Timoshenko, S. 1976. *Strength of Materials, Part II, Advance Theory and Problem.* 3rd Edn. Van Nostrand Reinhold^ New York.

Unal, E. 1983. *Development of Design Guidelines and Roof-control Standards for Coal Mine Roofs,* **Ph.D.** Thesis, Penn State Univ., USA.

Unal, E. 1992. Rock Reinforcement Design and Its Application m Mining. *Proceedings of the International* Symposium on *Rock Support, Canada,* pp. 541-547.

Unal, E. 1996. Modified Rock Mass Rating M-RMR System. *Milestones in Rock Engineering: A Jubilee Collection; Z. T. Bieniawski, Editor,* A.ABalkema,pp, 203-223.

Unal, E. 1999. Personal Communication