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Stress and Strain Analysis in a Plate Composed of Ore by using Finite Element Method

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Abstract: In this paper is analyzed the plate structure in an underground mining operation, crown plate or plate composed of ore, plays an important role of stability of underground structure design. Is know that the stresses and strains are occurred by external forces which act on the surface of the solid body. Stress concentration and distribution in a plate composed of ore is occurred by continual loading of the rock mass block from the surface up to an analyzing point and is defined as vertical stress component also in the instability of the plates exploitation techniques have to be into consideration. Such stability analysis solution can not be obtained by closed form, common numerical methods are applied to such cases. Finite element method in a successful manner is applied in the solution of these problems of linear and nonlinear analysis. In this paper is analyzed a crown plate by rectangular geometry.

Key words: *Plate, mine structure, stress distribution, Finite element method.*

Introduction

A Solution of any underground structure problem refers to determine displacement at each node and the stress within each element. Analytical mathematical solutions are not appropriate to solve problems dealing with complicated geometry, loading, and mechanical-material properties. It is known that the elements of the plate structure are subjected to different types of loads, in our problem during an interval load is taken to be static. Loading conditions can cause such stress state in which element of the plate structure can not properly perform their functions. To perform safety evaluation of the plate structure it is necessary to know the geometry and the stress concentratin and/or distribution which depends on the geometry of the plate composed of ore and the static load condition.

For acceptable solutions FEM analysis is used. Numerical methods yield approximate values of the unknowns at discrete numbers of points in the continuum. The Modern development of FEM has began in the 1940s in the field of structural engineering. The first treatment of two dimensional elements was by Turner *et al*. in 1956. They derived stiffness matrices for truss elements, beam elements and two dimensional triangular and rectangular elements in plane stress. The first term finite element was introduced by Clough in 1960 when both triangular and rectangular elements were used for plane stress analysis. From the early 1950s to the present enormous advances have been made in the application of the FEM to solve complicated engineering problems.

Finite Element Analysis formulation

Most engineering problems in the Theory of Elasticity are described with partial differential equations with appropriate boundary conditions and/or variational methods. Differential equations which describe the state of stress and strain for complex geometry shapes and complicated boundaries often can not be solved in an analytical way, so for such problems approximate solutions may be found by application of numerical methods. FEM analysis is one of the most applied methods in solving many engineering problems in the mining industry. For crown plate modeling of the continuum in the plane condition of stress and strain, finite elements are used.

In plane condition of strain the material is deformed in idenctical way in all planes parallel to *x,y* plane. Internal distribution of displacement in the finite element itself is defined by interpolation functions. By using the FEM analysis method it enables approximation of the displacement field, must have nodes laying in the x and y plane with displacements having components in the x and y axis. Displacement vector $\{u\}$ in a particular node has two components for such 2D problem. To be able to determine the stress and deformation field of an element, deformation $\{\varepsilon\}$ and displacement $\{u\}$ of particular node of an element can be expressed as following,

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$$\{\varepsilon\} = [L]\{u\}$$

Where, $[L]$ is the operator matrix.

Relation between displacement and deformation are neccesary to understand two dimensional problem in x,y axis. The relationship between stresses and deformations for izotropic material known as general form of constitutive equations, knowing that for plane stress $(\sigma_{zz} = \tau_{xz} = \tau_{yz} = 0)$, and $(\gamma_{xz} = \gamma_{yz} = 0)$ but $(\varepsilon_z \neq 0)$ based on these conditions the relation between the stress and deformation components for an elastic material could be expressed as following,

$$\{\sigma\} = [D]\{\varepsilon\}$$

Where; $[D]$ is matrix of elastic constants.

For strain plane suppose that $(\varepsilon_z = \gamma_{xz} = \gamma_{yz} = 0)$ and $(\tau_{xz} = \tau_{yz} = 0)$ but $(\sigma_z \neq 0)$, then the matrix of elastic constants can be expressed as,

$$[D] = \frac{E}{(1+\nu)(1-2\nu)}\begin{bmatrix} 1-\nu & \nu & 0 \\ \nu & 1-\nu & 0 \\ 0 & 0 & \dfrac{1-2\nu}{2} \end{bmatrix}$$

Where; E - is the modulus of elasticity, ν - Poisson's ratio.

If we ignoer temperature stresses, the basic equation of FEM analysis is obtained and it expresses the relation between the nodal displacements and forces for the finite element,

$$\{F\} = [K^e]\{S\}$$

Or,

$$\{F\} = [K]\{S\}$$

Where; $[K]$ - is stifness matrix, $\{F\}$ - is the matrix of components of the generalized of nodal forces, $\{S\}$ -is the matrix of components of the nodal displacement vectors.

Numerical Analysis

The goal of plate structure analysis in this study is the influence of various geometry of the plate composed of ore in regard to **L** (length), **W** (width) and **H** (height). The geomechanical properties of the rock formation have been determined by experimental studies.

Table 1. Mechanical properties of intact rock from the three representative rock formations.

Location	Rock Type	Density	Uniaxial compressive test			Brazilian test	Triaxial test	
		$[t/m^3]$	σ_c $[MPa]$	E $[GPa]$	ν	$\sigma_t[MPa]$	c $[MPa]$	ϕ [°]
	Schist	2.76	44.10	48.71	0.17	6.60	8.60	44.39
Hanging wall	Volcanic Breccia	2.90	60.90	49.90	0.17	6.40	10.90	51.38
Orebody	Sulphide Mineralization	3.70	82.10	63.70	0.19	7.40	13.60	56.26
Footwall	Limestone	2.80	49.50	40.23	0.17	5.0	8.8	51.14

Table 2. Plate structure geometry.

Plate no.	Length [m]	Width [m]	Height [m]
#1	25.00	9.50	6
#2	25.00	9.50	4

The plate composed of ore is uniaxially loaded by unit of stress with intensity of $\sigma_z = 31$ $[MPa]$. The geometry of the plate is presented in table 2. The plate is made of minerals with mechanical properties as determined in table 1. The goal of our analysis in this study is the influence of the rock mass block on stress distribution and failure at the isotropic plane in the plate structure. The plate is subjected 31MN/m^2 pressure from the surrouding above rocks. The geometry of the plate are variable due to height of the plate as presented in table 2. The plate is made of mineral with modulus elasticity 63000 Mpa and Poisson's ratio 0.19. Figures 1 and 6 are shown the generated mesh of crown plate, whereas in figures 2,3 and 7,8 are presented deformations of the CP and principal stresses. In order to compare the obtained results of distribution of stress, Table 3 shows the σ_{max} and σ_{min} values and also the stress concentration factor *k*.

Table 3. Principal stresses and stress concentration values.

	h = 4.00 [m]	**h = 6.00 [m]**
$\sigma_{max}\ [MN/m^2]$	374.844	198.059
$\sigma_{min}\ [MN/m^2]$	80.322	36.0385
$k = \sigma_{max}/\sigma_{min}$	4.666	5.495

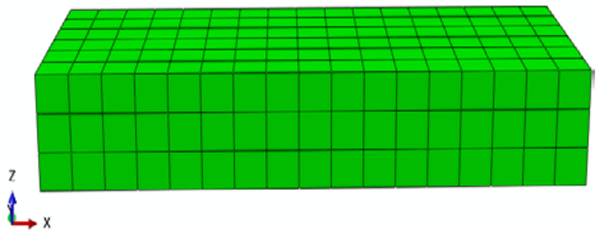

Figure 1. Finite element mesh (FEM model) for *h= 4m*

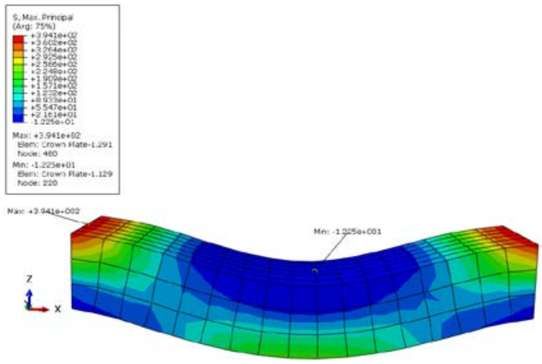

Figure 2. Distribution of maximum principal stress (FEM model) for *h = 4m*

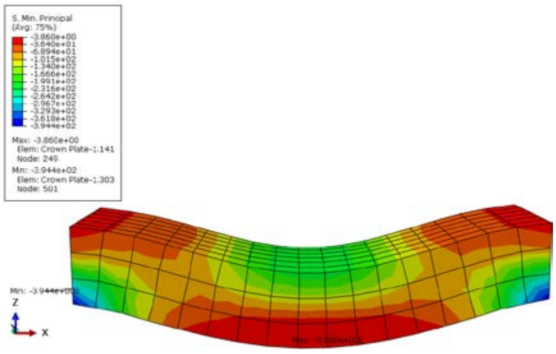

Figure 3. Distribution of minimum principal stress (FEM model) for *h = 4m*

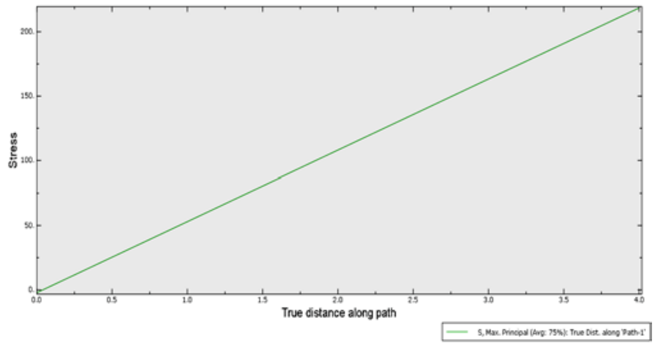

Figure 4. Stress vs. true distance along path (FEM model) for *h = 4m*

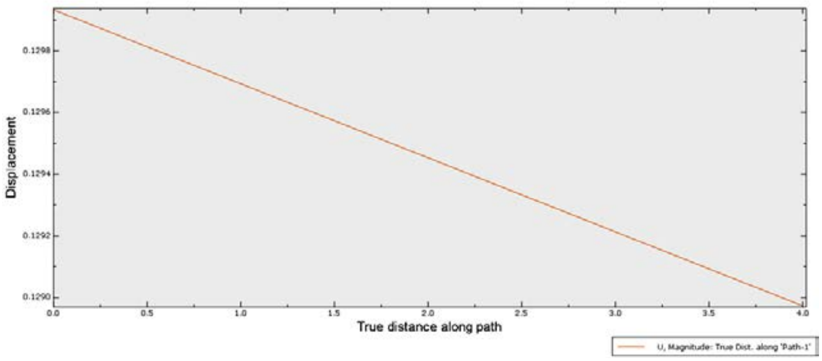

Figure 5. Displacement vs. true distance along path (FEM model) for *h = 4m*

Conclusion

In this paper we have analyzed two plates composed of ore which are left for stability of underground mines, results obtained by FEM analysis confirm that the plate with 4 m thickness is instable and risk the general stability of the underground workshop in an underground mine. Based on this paper, results show that stresses are decresed by increasing the thickness of the plate with rectangulare geometry and vice-verse.

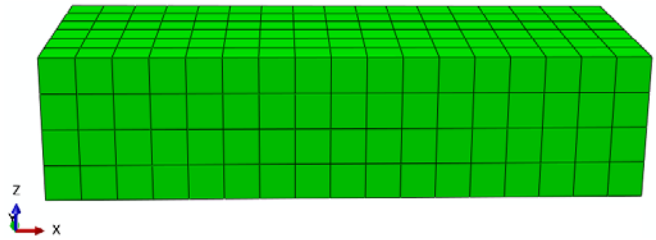

Figure 6. Finite element mesh (FEM model)= *6m*

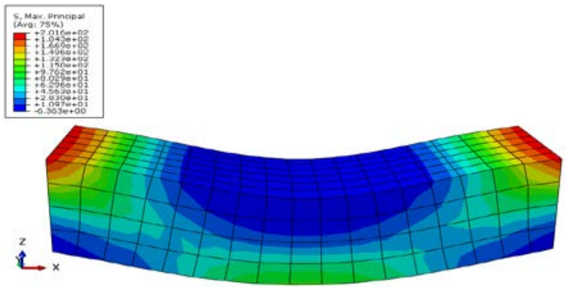

Figure 7. Distribution of maximum principal stress for *h* (FEM model) for *h* = *6m*

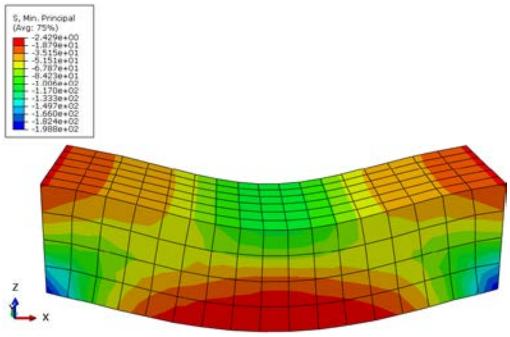

Figure 8. Distribution of minimum principal stress (FEM model) for *h* = *6m*

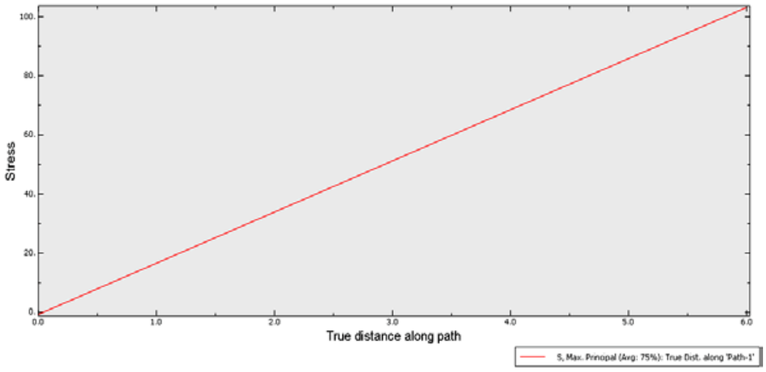

Figure 9. Stress vs. true distance along path (FEM model) for *h=6m*

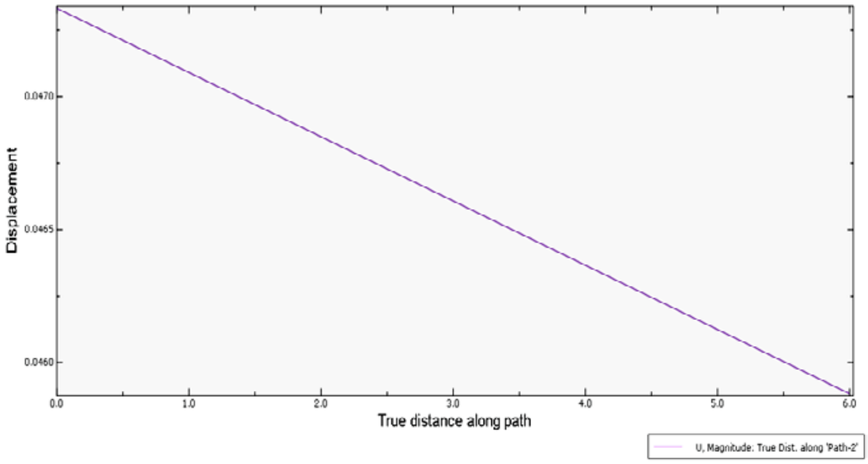

Figure 10. Displacement vs. true distance along path (FEM model) for *h* = *6m*

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