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Research Article

Application of Partial Stress Release Method by Parallel Drilling to Determine the Initial Plane Stress State of Rock Mass Using Hole Diameter Variation Method

HyonHyok Ri[1], Myong-Nam Sin[1], Dae-Song Kim[2,*]

[1]Faculty of Mining Engineering, Kim Chaek University of Technology, Pyongyang, DPR of Korea
[2]Faculty of Earth Science and Technology, Kim Chaek University of Technology, Pyongyang, DPR of Korea

Abstract

To use the hole diameter variation method using the partial stress release method by parallel drilling in determining the initial plane stress state of the rock mass, the stress state change surrounding the main measuring hole by parallel drilling is derived and the results are verified by numerical simulations. In the partial stress relief method based on parallel drilling method, firstly, the main measurement hole is drilled to appropriate depth, and then the sensor which is designed and developed to measure the diametrical deformations in three different directions (in general they are apart 120° from each other) is installed in the main hole to sense the hole diametrical change, and then multiple parallel stress relief holes (approximately four at 90°) are drilled at regular intervals next to the core without drilling a larger hole which has coincident center with the main hole as in the complete stress relief method. The diametrical change due to the release of stress surrounding the main measuring hole is then measured using the diametrical deformation gage and through them the initial plane stress state of the rock mass is determined. The numerical simulation results of this method show that the reliability of the partial stress release method compared to the full stress release method can reach more than 99%.

Keywords

In-situ Stress, Deformation of Diameter, Strain

1. Introduction

There are several methods for determining the initial stress state of rock mass, including hydraulic fracturing and stress release, but the method currently accepted as the most accurate method is the stress release method [1-6].

Several researchers have developed sensors that can accurately determine the initial stress state even in deep or water-filled holes, and the following measurement procedures and application methods have been developed and introduced [7-9].

The stress release method also can be classified as hole diameter variation method, hole wall variation method, and hole bottom deformation method, depending on the measured quantity. Among them the most widely used method is the hole diameter variation method, in order to determine the initial stress state of the rock mass by the hole diameter variation method, first the main measuring hole with a diameter of approximately 36 mm is drilled at the measurement site and then

*Correspondence: Dae-Song Kim (kds93413@star-co.net.kp)

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the stress relief hole with a diameter of 76 mm which has coincident center is drilled, and then finally, completely separating the core from the rock mass containing the sensors installed in the main measuring hole.

The diameter of the main measuring hole is changed due to the release of stresses, and this variation of diameter is measured to determine the initial state of stress in the rock [10-14].

Sensors for sensing these changes of diameter in the main measurement hole have been developed in different forms by many researchers [15-23].

All calculations are then carried out under the assumption that the rock is homogeneous, isotropic, and elastic, and in the case of complete stress release, the equations determining the initial state of stress in the rock mass from the measured diameter variations are presented [13, 14].

The present study has shown that the method of determining the initial stress state of rock mass is widely used, mainly by the method of hole change by stress release, and the sensors for this are widely used and developed to have high accuracy, data management and adaptability to the surrounding environment, and the above methods are widely applied worldwide.

However, in some cases, it is difficult to apply the method of hole change by such a complete stress release.

In the case of relatively soft rock, the large hole drilling often results in failure of the core, including the main measuring hole, and consequently failure of the measurement.

Therefore, for objects where relatively soft rock or drilling equipment is not available, a more appropriate stress relief method should be used, and a partial stress relief method by parallel drilling is considered appropriate.

The study determined by numerical simulation the amount of diameter variation occurring in the main measuring hole when the stress in the main measuring hole is partially released by the method of parallel drilling, and established a methodology for applying the partial stress release method by parallel drilling.

Consequently, the same calculation method can be applied for the case of partial stress release, only considering the stress release rate factor, while the similarity of the full stress release method and the partial stress release method is more than 99%, which is quite acceptable for a particular object.

After the acrylic resin emulsion resin adhesive was prepared by the process and method of powder-sprayed adhesive interlining production, the resin adhesive was dotted at regular intervals on the substrate through a cylindrical screen and the polyester resin powder was sprayed over the surface. Then, through a vibrating screen and a vacuum cleaner, the resin powder sprayed on the unpainted part of the resin adhesive is recycled and the powder that falls on the resin adhesive is adhered to the resin adhesive, so it is heated and melted to the substrate through heat treatment to produce an adhesive interlining.

However, resin adhesives prepared from acrylic resin emulsions DR501 and DR402 were gelatinized and cured at room temperature after a certain period of time, during the process of production, by filling the fine pores of cylindrical screens to stop production and frequent washing of the screens with organic solvents, as well as their ability to trap and fix the resin powder due to the short duration of retention, resulting in poor quality of the adhesive interlining produced and very low adhesive strength.

Therefore, we developed new adhesives to improve the quality of products and put their production on a normal footing and applied them to various fields of the interlining cloth production and textile industry, thus making it possible to diversify textile products, reduce the cost of various kinds of fabrics including interlining cloth, raise their quality and put production on a normal basis.

2. Method

2.1. Analytical Consideration on the Full Stress Relief Method

In the case of applying the full stress relief method, the diameter variation in the main measuring hole was analyzed by analytical and numerical simulation.

Equations (1) and (2) show the relationship between the diameter change in the hole and the initial stress state, i.e., σ_1, σ_2 and θ, when applying the full stress release method.

$$u = \frac{d}{E}\left[\left(\sigma_1+\sigma_2\right)+2\left(\sigma_1-\sigma_2\right)\cos 2\theta\right] \tag{1}$$

$$u = \frac{\left(1-\nu^2\right)d}{E}\left[\left(\sigma_1+\sigma_2\right)+2\left(\sigma_1-\sigma_2\right)\cos 2\theta\right] \tag{2}$$

Where u -diametric deformation, d -diameter of hole, E -elastic modules of rock, ν -poisson coefficient, σ_1, σ_2 -maximum and minimum principle stress, θ -the angle of the direction of maximum principle stress to the direction of the diameter.

Eq. (1) is the expression used to determine the stress state in plane stress problems, and Eq. (2) is the expression used to measure the change in the hole diameter in plane strain problems.

From the above equation, to determine the stress state, three unknown parameters, i.e., a, b, and b, are determined, and the stress state is determined by determining the change in the hole diameter in three different directions.

In this case, to achieve stress release, the core around the hole must be completely isolated from the rock mass, which requires special equipment.

2.2. Numerical Simulation of Full Stress Relief Method

The factors that affect the diameter change when releasing stress around the measuring hole by the stress release method are, in addition to the mechanical properties of the rock, the diameter of the releasing hole, the orientation of the hole, and the distance between the releasing hole and measuring hole, and the magnitude and direction of the principal stresses.

However, it is difficult to obtain analytically the relationship between the above factors and the hole diameter variation.

Hence, we clarified the relationship between the variation of hole diameter and the influencing factors by means of partial stress release through numerical simulations using finite element method (COMSOL MULTI-PHYSICS, 2019).

To this end, we first observed the variation of the hole diameter by drilling one hole in the model and applying different forces.

For this purpose, the model is constructed assuming the material to be homogeneous, isotropic, and linear, and the geometric and mechanical properties of the model are listed in the table below.

Table 1. *Characteristics of numerical model.*

Index	Characteristics
Dimensions	700×500×100 mm
Elastic modules	2.1×10^{5} MPa
Poisson coefficient	0.28
density	7700 kg/m^3

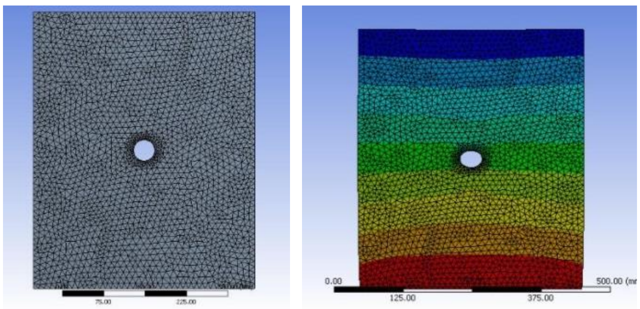

Figure 1. *Numerical model.*

For the above model, the diameter variation of the holes in different directions was simulated when the lower surface was fixed and the upper surface was loaded with 10, 20, 30, 40, 70, 120 and 200.

In the following Figure 2, the simulated diametrical strains in different directions under different loading conditions are presented.

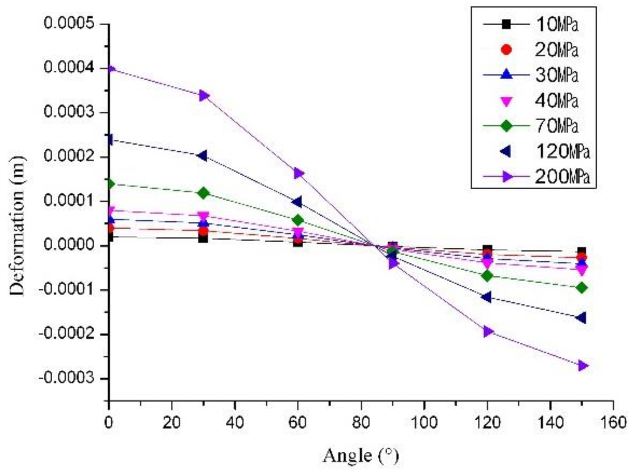

Figure 2. *DD under the diverse loading and directions.*

In the above figure, the positive sign of the diameter change means that the diameter of the hole decreases, and negative means that the diameter increases.

From the above figure, it can be seen that the variation of the hole diameter depends primarily on the magnitude and the diameter direction of the applied force.

It is also found that the diameter variation is periodic with the angle of orientation to the force axis.

Figure 3 shows the variation of diameter according to the measuring direction under different loading conditions.

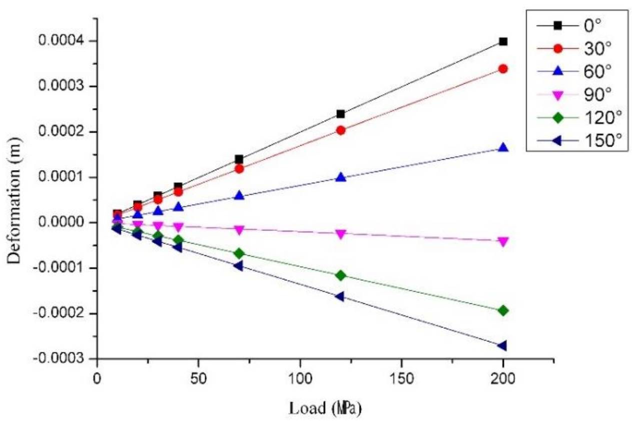

Figure 3. *DD for diverse direction with the increase of load.*

As can be seen from the above figure, the diameter variation is proportional to the magnitude of the applied load.

From the above simulation results, we conclude that the variation in the diameter of the hole depends on the mechanical properties of the material, including the elastic modulus, Poisson's ratio, and in addition on the magnitude and the direction of the applied load, and the relationship can be expressed analytically as follows.

$$\Delta d = p \times \cos\alpha \times f(E, \nu, \ldots) \tag{3}$$

2.3. Numerical Simulation on the Partial Stress Relief Method

First, the variation of the diameter of the measuring hole under uniaxial stress and the diameter of the stress relief hole was simulated by varying the magnitude of the stress and the spacing of the hole.

The simulation results are shown in Figure 4.

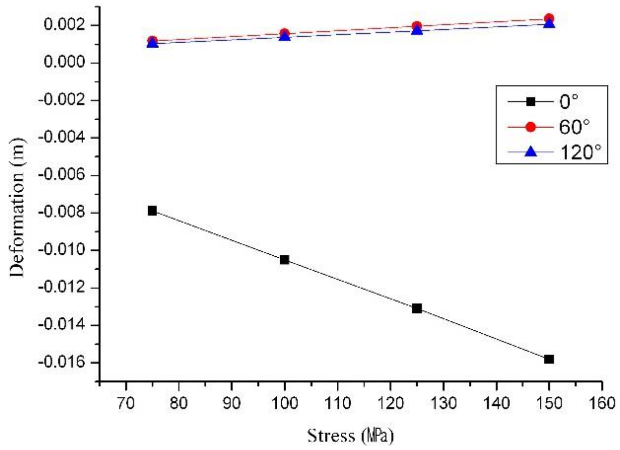

Figure 4. *Relationship of DD with the magnitude of loading.*

As can be seen from the above figure, the variation in the direction of the diameter due to the initial stress and the release of stress in the object is linearly related to each other.

Also, the relationship between the dislocation spacing of the stress relief hole and the change in the diameter of the hole for a constant stress magnitude is a power function as shown in Figure 5.

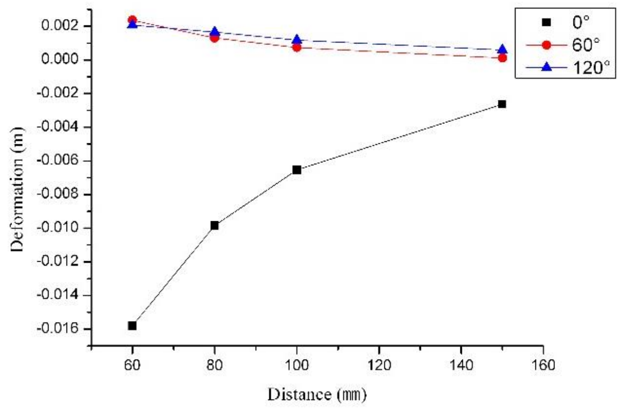

Figure 5. *Relationship of DD with the distance of holes.*

From this, the diameter variation is inversely proportional to the square of the spacing of the holes and proportional to the magnitude of the applied stress, and can be written as

$$u = k \cdot \sigma \cdot \frac{1}{l^2} \tag{4}$$

2.4. Partial Stress Relief Method

The method and procedure to simulate the variation of diameter in the main measuring hole when partially relieved the stress through four parallel holes are as follows.

First, a model with one hole (measuring hole) is created and the amount of diametrical displacement of the hole is obtained when different stress states are created in different ways in this model.

Next, a model with one main hole and four release holes is created and the amount of diametrical displacement of the hole under different stress states is obtained in the same manner as above.

Next, the difference in the diameter direction changes obtained in both cases is the diameter change that occurs in the measurement hole when drilling a real measuring hole, inserting a sensor into it, and drilling four stress relief holes.

To this end, we first created a model that only exists the main measurement hole.

The geometry of the model was 10 m × 10 m × 1 m.

And a perforation hole of 40 mm in diameter was created at the center of the element.

The diameter of the hole was determined by referring to the diameter of the drilling of the drilling instruments used in the field.

The following figure shows the model and mesh state created.

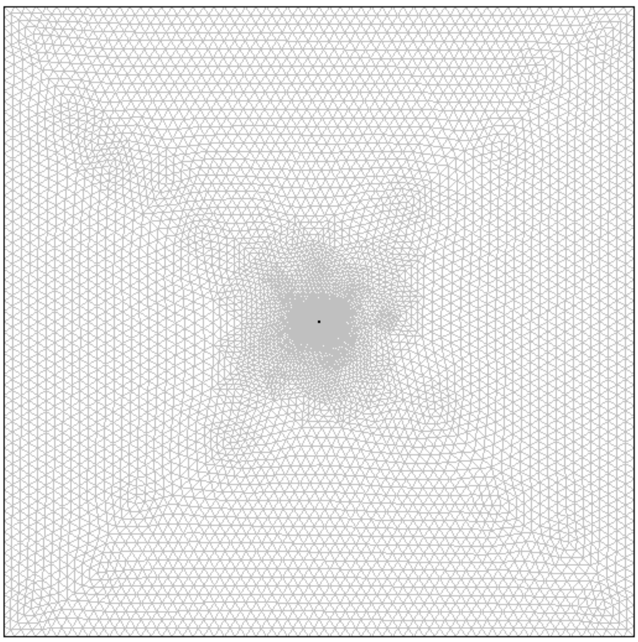

Figure 6. *Meshing diagram of model.*

For the above model, the boundary conditions are set as follows:

First, both sides are given free ends, the lower surface is completely constrained and the upper surface is subjected to a uniform load distribution.

In this case, the diametrical strain was simulated by varying the magnitude of the distributed load, in which the diametrical direction was determined in three directions: the direction of the applied load (vertical direction) and the diametrical variation in the direction of the distribution loading (vertical direction) at angles of 60° and 120°, respectively.

The following figure shows the reduced stress distribution and diameter variation around the hole during the simulation under the above boundary conditions.

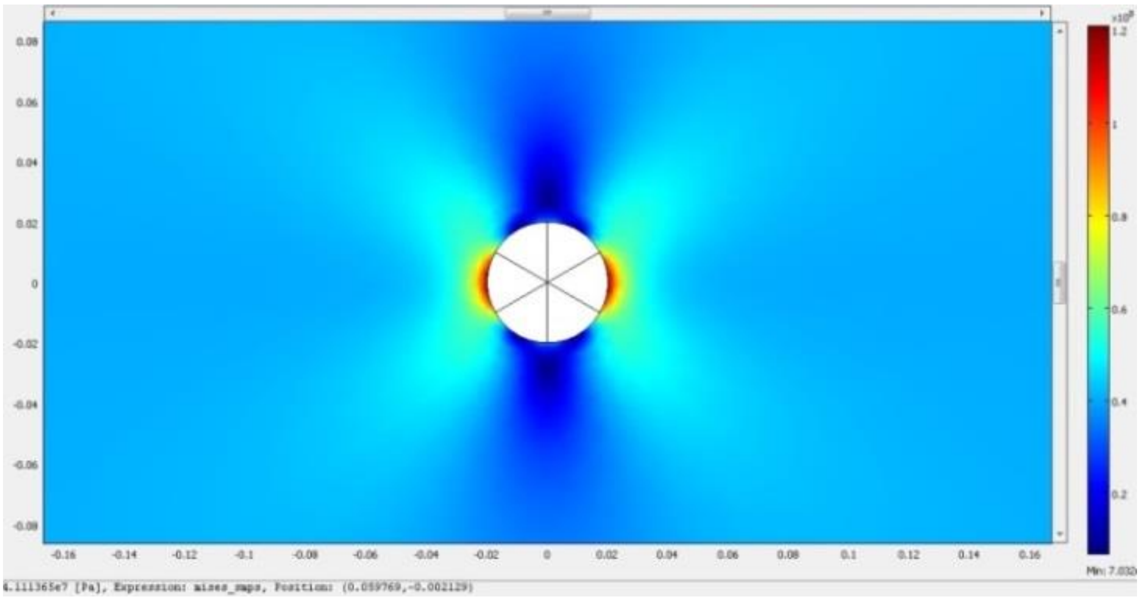

Figure 7. *Von-misses stress around the main hole.*

The von Mises stress distribution shows that the stress near the point where the diameter displacement in the direction of the maximum principal stress around the hole must be measured decreases by 70% of the applied stress.

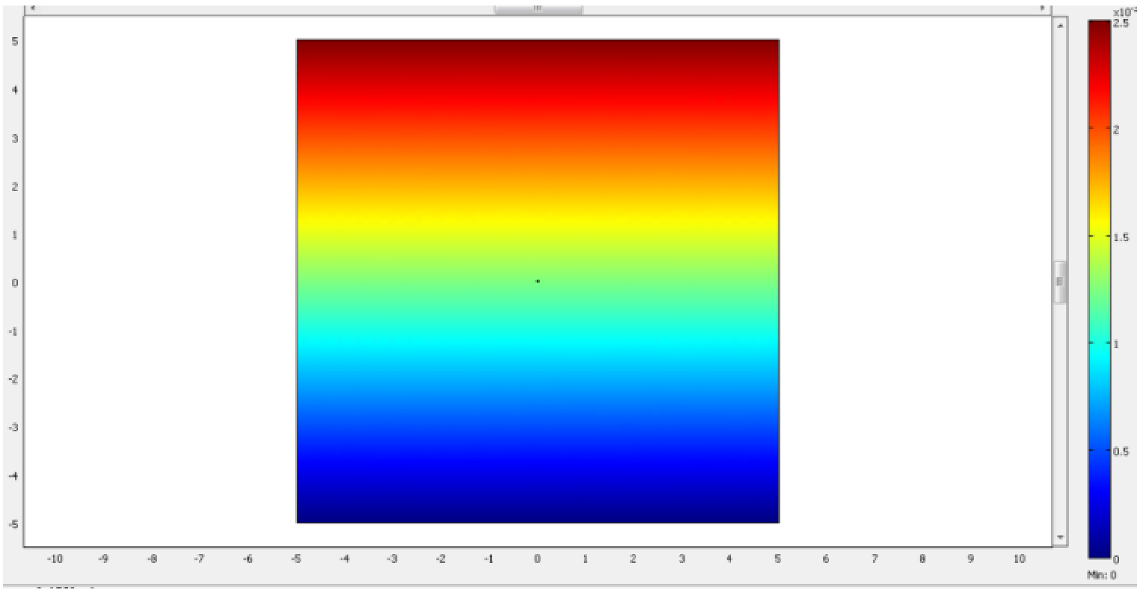

Figure 8. *The simulation result of vertical deformation.*

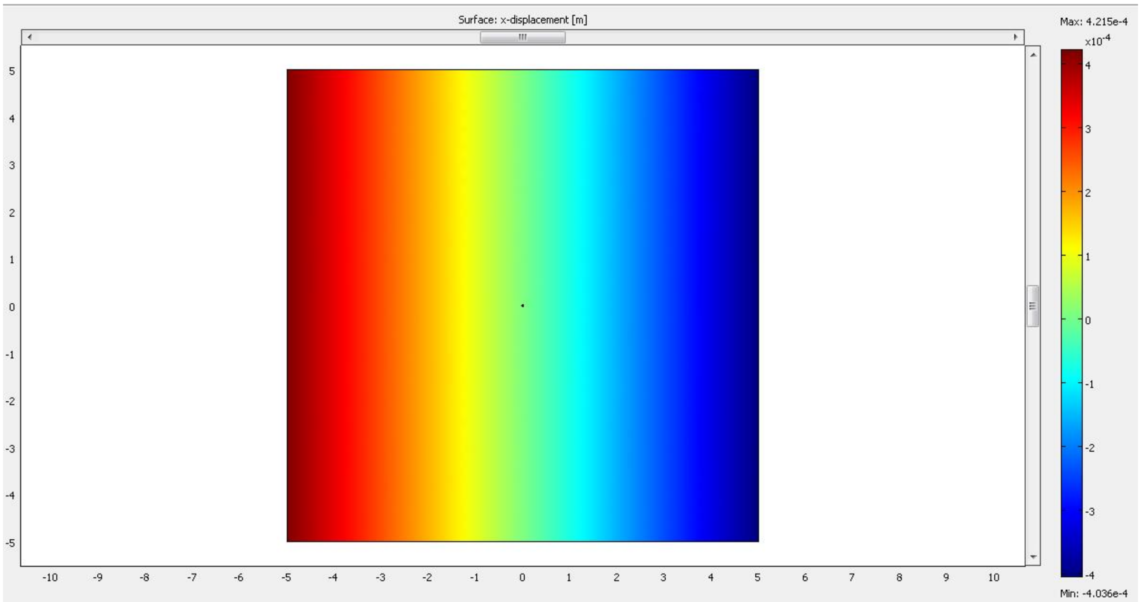

Figure 9. *Simulation result of horizontal deformation.*

As a result of the above simulations, we obtained the same results as the table below.

Table 2. *DD according to the increase of load in each direction in the case of the complete releasing method.*

Stress (MPa)	DD, µm		
	1	**2**	**3**
10	-6	-2.2	-2.2
20	-12	-5.7	-5.7
30	-18	-8.8	-8.8
40	-24	-11.7	-11.7
50	-31	-14.6	-14.6

The results of the above simulation are compared with the results of the calculations of the previously presented expressions, as shown in the table below.

Table 3. *Comparison of the calculated and simulated results.*

Stress (MPa)	Simulated value, µm			Calculated value, µm		
	1	**1**	**3**	**1 (0°)**	**2 (60°)**	**3 (120°)**
10	-6	-6	-2.2	-5.97	-2.2	-2.2
20	-12	-12	-5.7	-11.9	-5.7	-5.7
30	-18	-18	-8.8	-17.9	-8.8	-8.8
40	-24	-24	-11.7	-23.8	-11.7	-11.7
50	-31	-31	-14.6	-29.8	-14.6	-14.6

As can be seen from the above table, the proposed calculation and simulation results are in very good agreement for the full stress release case, so we can conclude that the model creation and boundary conditions are entered correctly.

Next, we simulated the diameter variation in the situation of drilling four local stress relief holes around the measurement hole, assuming that the local stress relief hole is drilled, and the results are as follows.

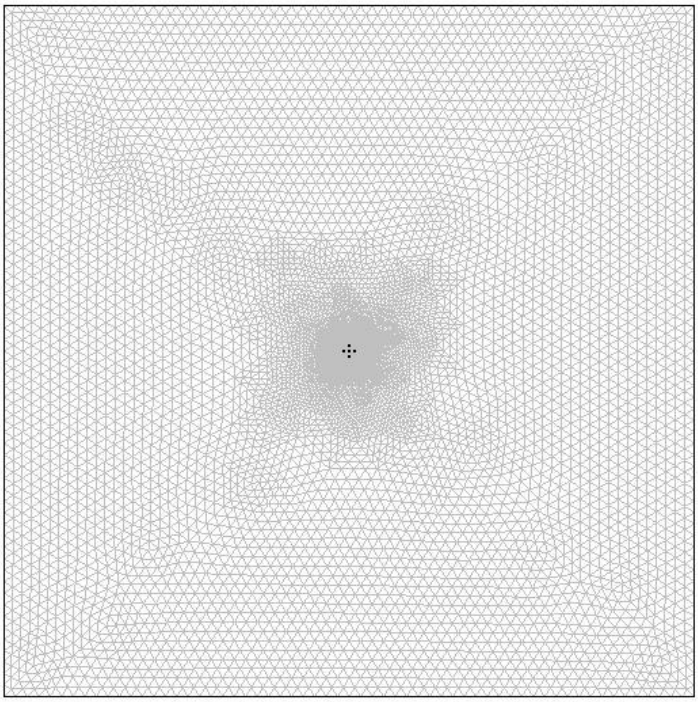

Figure 10. Meshing diagram of model.

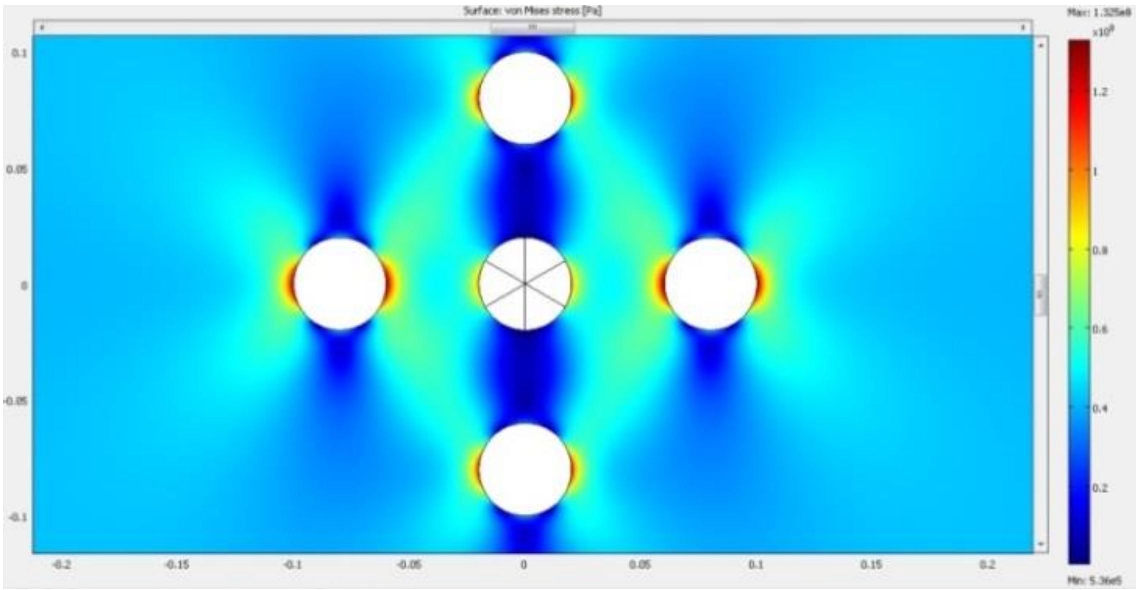

Figure 11. Equivalent stress distribution diagram.

The von-Mises stress distribution shows that the stress near the point where the diameter displacement in the direction of the maximum principal stress around the hole must be measured decreases by 12.5% of the applied stress.

Thus, the local stress release method can lead to a stress change of 58% of the applied stress.

Table 4. DD according to the increase of load in each direction in the case of partial stress relief method.

Stress (MPa)	**DD, μm**		
	1	**2**	**3**
10	-4.50	-1.44	-1.44
20	-8.99	-2.87	-2.88
30	-13.48	-4.30	-4.31
40	-17.98	-5.71	-5.73
50	-22.46	-7.12	-7.12

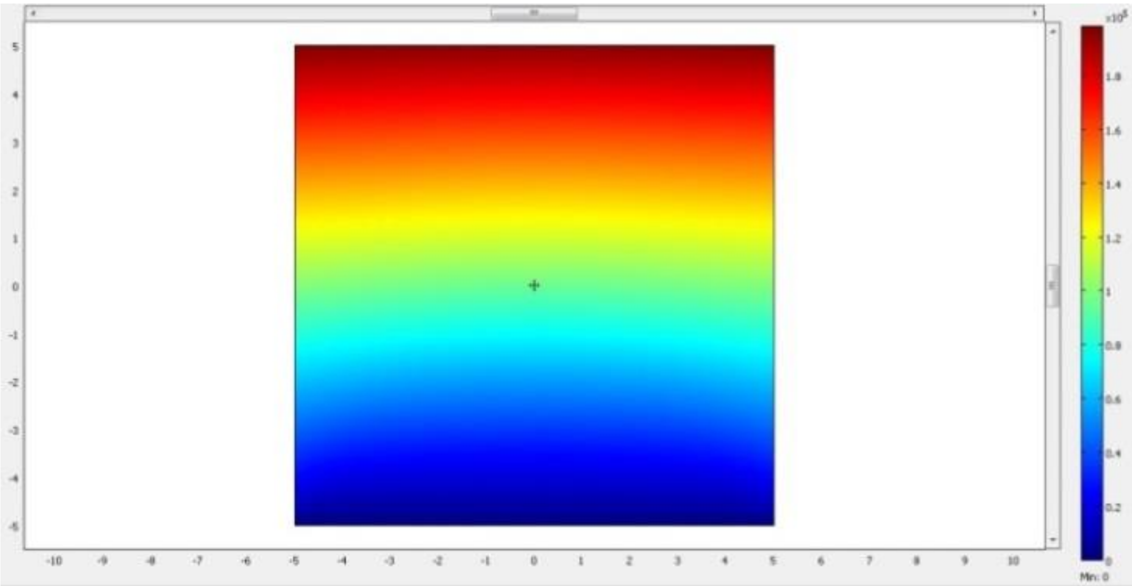

Figure 12. Vertical deformation distribution.

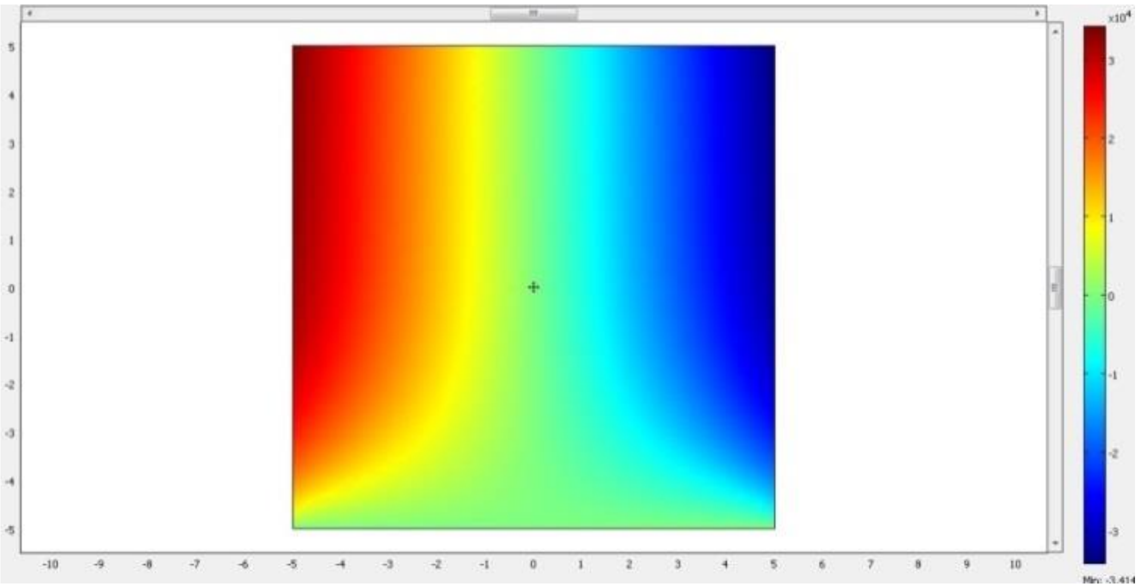

Figure 13. Horizontal deformation distribution.

Table 5. *DD in each direction according to the increase of load in the case of before and after stress releasing.*

Stress (MPa)	Befor releasing, µm			After releasing, µm		
	1	1	3	1 (0°)	2 (60°)	3 (120°)
10	-6	-2.2	-2.2	-4.50	-1.44	-1.44
20	-12	-5.7	-5.7	-8.99	-2.87	-2.88
30	-18	-8.8	-8.8	-13.48	-4.30	-4.31
40	-24	-11.7	-11.7	-17.98	-5.71	-5.73
50	-31	-14.6	-14.6	-22.46	-7.12	-7.12

Therefore, the diametrical displacement quantities that will occur when drilling the measuring hole, inserting the hole strain gauge, and then drilling the local stress relief holes are shown in the table below.

Table 6. *DD according to the increase of load in each direction in the case of partial stress relief method.*

Stress (MPa)	DD, µm		
	1	2	3
10	1.50	0.78	0.78
20	3.01	2.82	2.82
30	4.52	4.49	4.49
40	6.02	5.97	5.97
50	7.54	7.48	7.48

From the above table, it can be seen that the diameter variation due to local stress release is about 25% of the case of full stress release.

Thus, we can determine the stress state of the object by measuring the diameter change during local stress release.

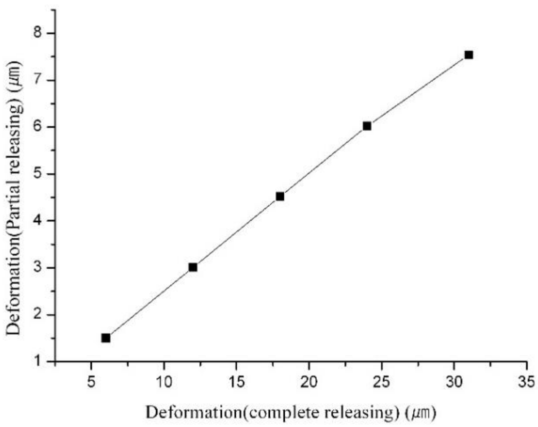

Figure 14. *Comparing of the DD in the case of partial and complete stress relief method.*

3. Conclusion

The application of the stress measurement method by the release of the total stress requires special test measurement equipment, especially the failure of the core frequently during the test, which does not result in a high success rate in the measurement.

This paper proposes a partial stress release method by parallel drilling to determine the initial stress state of rock mass without special test measurement equipment by applying the partial stress release method.

In the partial stress relief method by parallel drilling, the main measuring hole with a diameter of 36 mm is first drilled and there is a sensor to measure the change in hole diameter.

Then, after recording the initial value of the hole diameter strain gauge, four parallel holes with an orientation angle of 90° each other are drilled at locations about 70 mm from the main measuring hole.

At that time, the depth of the parallel holes should be drilled deep enough to release the stress around the main measuring hole.

During drilling of parallel holes, stress release around the main measurement hole occurs and consequently the diameter in the main measurement hole changes.

Therefore, all four release holes are drilled and then a constant time (usually 10 min) is used to record the diameter change.

With the three measured diameters, the initial stress state of the rock mass can be determined.

Abbreviations

DD Deformation of Diameter

Author Contributions

HyonHyok Ri: Conceptualization, Methodology, Project administration, Software

Myong-Nam Sin: Data curation, Resources, Visualization

Dae-Song Kim: Formal Analysis, Investigation, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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