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A preliminary study on the structural stability of room-and-pillar underground structures

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ABSTRACT: In a view of stability of the room-and-pillar underground structure, a series of preliminary numerical analyses were performed. With assumed material properties, size ratios of room and pillar were mainly considered then failure mode and yielding initiation were investigated. It was found from the result that relationship between the ratio of pillar width to the roof span (w/s) and overburden pressure at failure initiation shows a relatively linear relation, and the effect of w/s ratio on structural stability is much more critical than the ratio of pillar width and height (w/H) which is a main consideration in design of the room-and-pillar mining. And failure modes and location at failure initiation were varied with respect to the ratio of room and pillar width.

1 INTRODUCTION

The room-and-pillar method is a very old method applied to horizontal or nearly horizontal deposits that has been adapted and refined over the years (Harman & Mutmansky 2002). When the deposit and method are both uniform, plan view of room-and-pillar mine looks like a chessboard or intersecting streets and avenues of a city. Because mining process can be conducted at several openings, it is known as a high productivity and efficiency method. And pillars are often exploited to increase productivity in the room-and-pillar mining. Recently, an abandoned limestone mine in the United State was developed as an underground space by room-and-pillar method for the office, distribution center or stores and etc. using natural rock pillars (Fig. 1).

However, the room-and-pillar method for an underground structure has different requirements from that for the mining industry. In the underground structure, a long-term structural stability is more required and design of both roof and pillar should be considered in connection with the structural stability while strength of pillar is mainly examined in mining. In other words, the room-and-pillar underground structure should have a long-term stability to the overburden pressure and each roof and pillar also has to maintain stability during the service period. In case of South Korea, the room-and-pillar method have not been adopted as an underground excavating method so far.

Many empirical methods for the strength of pillar (Fig. 2) have been studied in a conventional room-and-pillar design in mining because of difficulty to consider effects of discontinuity or crack in the pillar (Hedley & Grant 1972, Kimmelmann et al. 1984, Lunder & Pkalnis, 1997, Sheorey et al. 2000, Esterhuizen et al. 2011). In a view of stability of the room-and-pillar underground structure, preliminary numerical analyses were performed. Size ratios of room and pillar and failure modes at initiation of yielding were investigated.

Figure 1. Picture of the Subtroplis in Kansas city (Hunt Midwest, 2009).

2 NUMERICAL ANALYSIS

In this study, stability of room-and-pillar underground structure depending on overburden pressure was examined with a finite element method program (MIDAS GTX). Figure 3 shows a schematic diagram of a numerical model for 2-dimensinal room-and-pillar underground structure as a plane-strain condition.

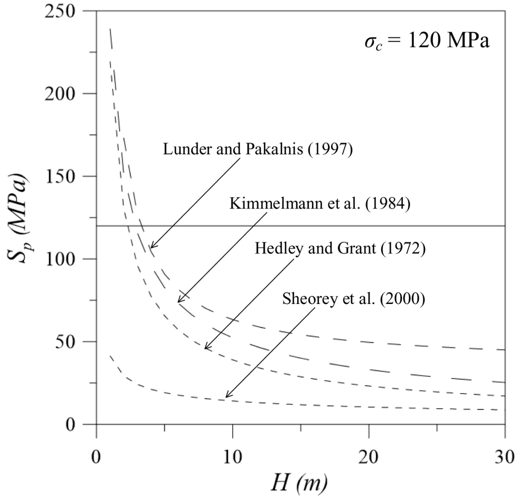


Figure 2. Comparison of the pillar strength by different empirical equations (Lee et al. 2013).

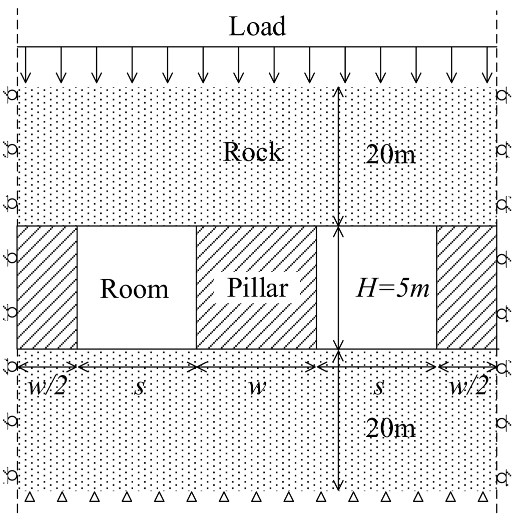


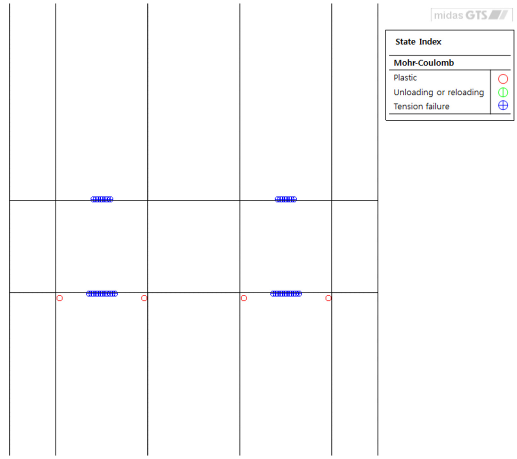
Figure 3. Schematic diagram of a numerical model.

Height of room and pillar (H) was determined to consider a size of equipment for excavation. And room span (s) were 5, 7.5 and 10 m to consider size of room span. Width of pillar (w) was 2.5, 5 and 7.5 m depends on 3 size ratios of pillar, i.e. w/H = 0.5, 1.0 and 1.5. Therefore, the size ratios in numerical analysis were 9. The rock property for the Mohr-Coulomb's failure criteria with the tension cut-off (T) is shown in Table 1. Rock property was adopted from the previous research (Lee et al. 2013).

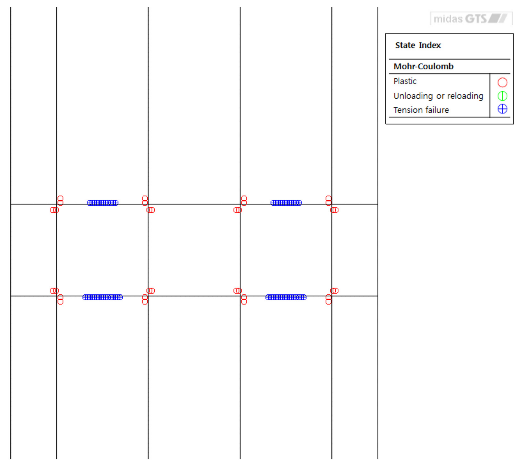
In this 2-dimentional analysis, rooms exist infinitely at lateral axis by the symmetric boundary condition. And the yielding initiation was mainly examined than the realistic failure of structure. Therefore, numerical analysis in this study was limited to the general observation of structure depending on shape and overburden pressure, not to the real behavior of structure. For convenience, displacement by the initial overburden pressure set to zero.

Table 1. Rock property.

γ (kN/m^3)	E (MPa)	ν	c (kPa)	ϕ (°)	T (kPa)
24.5	9,000	0.22	1,700	36	1,100



(a) 1800 kPa

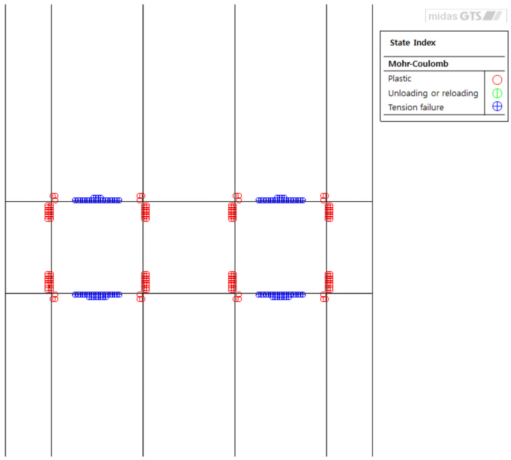


(b) 2000 kPa

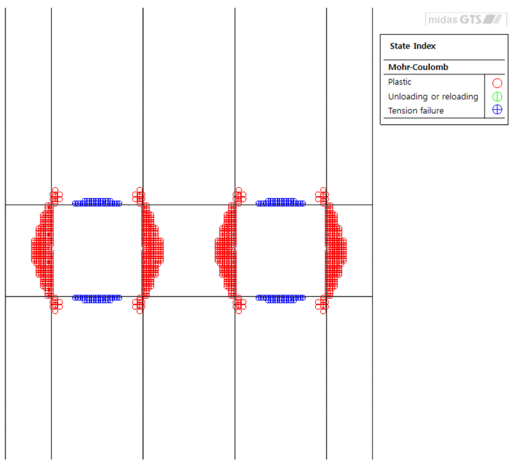
Figure 4. Tensile failure and plastic state of element at each stage of overburden pressure.

3 RESULTS

Figure 4 represents a yielding initiation at roof span and progress of tensile failure by increasing overburden pressure when ratio of pillar width to room span was 1.0 and ratio of width to height of pillar was 1.0.



(c) 2500 kPa



(d) 3000 kPa

Figure 4. Continued.

As shown in Figure 4, failure was initiated at the center of roof (Fig. 4a), then plastic state was developed at the corner of roof and pillar under the given conditions in this study. In case of pillar, shape of plastic state becomes a hyperbolic shape as overburden pressure increases.

In this analysis, case of ground property and coefficient of lateral pressure was only one case. Thus, location of the yielding initiation can be different depends on ground property, coefficient of lateral pressure and etc. For the real condition, properties and initial conditions including lateral pressure that is obtained by field tests are desirable.

Figure 5 shows a relationship between the overburden pressure which is normalized by an initial pressure and pillar width to roof span ratio (w/s) at different width to height ratio of pillar (w/H). From the result, plastic state was occurred at the pillar by a relatively lower state of overburden pressure when pillar width

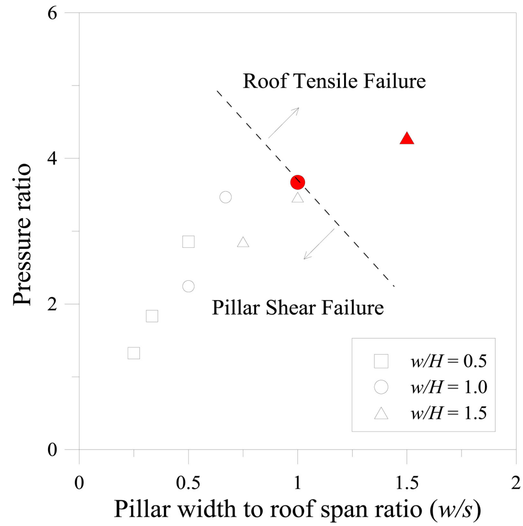


Figure 5. Overburden pressure at failure or plastic state.

to roof span ratio was low (length of roof span is longer than length of pillar width). And tensile failure at roof span was initiated by a relatively higher state of overburden pressure when pillar width to roof span ratio was relatively high. Tensile failure was occurred earlier when pillar width to roof span ratio was greater than 1.0 and plastic state was occurred earlier at corner of roof and pillar when pillar width to roof span ratio was smaller than 1.0.

Previous researches for the stability analysis of the room-and-pillar mine have been focused on strength of the pillar. Especially stress-strain behavior of pillar depends on overburden pressure was evaluated by numerical way for the strength of pillar (Murali et al. 2001, Esterhuizen 2006, Mortazavi et al. 2009, Wang et al. 2011). Generally rock bolts were empirically used as a support at the roof span and design of rock bolts were often from calculation of simple beam to the roof span.

However, in the room-and-pillar method for the underground space, because the natural rock pillar should be used as a structure, it is reasonable to minimize the damage at the pillar and use minimum support. Therefore, it is need to evaluate of safe factor of pillar with an expected overburden pressure after consideration of supports frequently. In other words, to obtain safety of pillar, it is needed to consider safety of roof with the given designing condition by literature review or numerical analysis before evaluating safety of rock pillar depends on the given overburden pressure.

It was found from results that relation between pillar width to roof span ratio and yielding initiation shows comparatively linear. But differences by pillar width to height ratio were not noticeable while pillar width to height ratio was mainly considered in the previous researches about designing rock pillar. It seems that effect of pillar width to roof span ratio is more important for the stability of the room-and-pillar underground structure due to the change of load distribution at roof and rock pillar. Tendency of failure mode can be changed by material property or condition of lateral pressure, however, care must be taken that failure at roof can be arisen at lower level of pillar strength evaluated from uniaxial compression strength of rock sample as previous researchers suggested.

4 CONCLUSIONS

In this study, preliminary study was carried out to estimate structural stability of room-and-pillar underground space. From the results, following findings are obtained by numerical analyses.

1) It is need to consider both stability of pillar and roof simultaneously. And instability at certain location should be treated as an instability of structure. Therefore, it is reasonable to examine stability of space and pillar in designing of underground space by room-and-pillar method at given conditions
2) Location of the yielding initiation was different depends on the pillar width to roof span ratio with the given material property and failure criteria which was used in this study. When length of roof span was relatively longer than width of rock pillar, shear failure at corner of roof and rock pillar occurred first. On the contrary to this, when length of roof span was relatively shorter than width of rock pillar, tensile failure occurred first at the center of roof span. It seems that the pillar width to roof span ratio is more sensitive than the width to height ratio of pillar.
3) When pillar width to roof span ratio is relatively small, plastic state at the pillar occurred at lower level of overburden pressure. When pillar width to roof span ratio is relatively big, tensile failure at the roof occurred at higher level of overburden pressure.

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