CHAPTER 5 CONCLUSIONS

5.1 Conclusions

In this study, failure behaviors of rock mass surrounding the underground gas storage cavern under high pressure are numerically investigated. Two kinds of behaviors which are initial crack by stress analysis and fracture propagation by progressive failure analysis, have been conducted.

First, the conclusion of initial crack behaviors can be listed as followed.

1. Three parameters including the in-situ stress ratio (*k*), rock strength properties and the cavern depth, are investigated their effect on the crack initiation behaviors. The *k* and rock strength properties have a strong influence on the position and the transition of initial crack point around the cavern periphery, while the depth of the cavern has an insignificant effect on crack initiation.

2. By considering possible range of rock properties, especially the relationship between σ_t and C, it is seen that both tensile and shear failures can be taken place. This strongly depends on the relationship between the σ_t and C. By introducing the line of D/R=1, the distinct zones of tensile and shear failures can be obtained on C - σ_t space.

3. By considering the stress states in rock masses around the cavern, it was seen a difference of trajectories of principle planes between the rocks having low and high strength. Due to the level of cavern pressure, the principal planes are different. For low strength rocks, the level of cavern pressure which initiates a crack is low. In contrast, for high strength rock, it is required a high level of cavern pressure for initiating a crack. The trajectories of principle planes become similar when the *k* approaches 1 and the rock strength is high. The *k* has a strong effect on the location of initial crack when the rock has low strength, while the effect of *k* is decreasing in case of high strength rock. Moreover, for high strength rock and *k* close to 1, the location of initiation crack tends to be appeared at about 40 degree of failure angle.

Second, the FEA with contact-interface interaction were performed through a series of cases with careful selection to analyze the fracture propagation behaviors. Following conclusions can be drawn.

1. The distinction between tensile and shear fracture propagations can be seen from different relationship of σ_t and C. It was also seen that the concept of the line of D/R=1 can be used to separate the tensile and shear fractures. Such a pair of C - σ_t that is far from the line of D/R=1, the fracture continually propagates with the failure mode of which it is initiated.

2. For a relationship of σ_t and C that is closed to the line of D/R=1. The mode of fracture propagation would be changed. This issue was found only the pairs of C - σ_t situated under the line of D/R=1 of which the initial crack is satisfied with shear mode. On the other hand, for analyses with a pair of C - σ_t located on above the line of D/R=1, the fracture starts with tensile mode and it prolongs growing with tensile fracture.

3. At certain level of cavern pressure during crack propagation, a new fracture point can be occurred along the cavern periphery for both fracture modes. A new fracture point should be propagated under the same failure mode that the first fracture is initiated.

5.2 Application of developed charts in practical use

Two developed charts proposed in Chapter 4 which are the Chart D/R=1 and the Chart for initial crack point, can be altogether used to suggest the possible failure path of high pressurized gas storage cavern. This section presents the systematic procedures for obtaining the simple shear and tensile failure paths.

The flow of these procedures is illustrated in Figure 5.1. There are four rock parameters and cavern depth are required as input parameters. First, σ_t, and C are used to consider the fracture modes in rock masses by using Chart 1 (see in Figure 5.2). Second, after the failure mode has been known, the initial crack location, α, is then specified. By using Chart 2 (see in Figure 5.3), if tensile mode is satisfied, σ_t/σ_v and k are used to specify α. In contrast, if shear mode is satisfied, C/σ_v and k are used to obtain α. Finally, the simple characteristics for tensile and shear failure path can be applicable as shown in Figure 5.4. If tensile failure mode is satisfied, the simple tensile failure path can be obtained. It starts from the crack initiation point (see in Figure 5.3) and propagates with a vertical straight line to ground surface. In contrary, for shear mode, the simple shear failure path can be drawn as an inclined line in radial direction to ground surface.

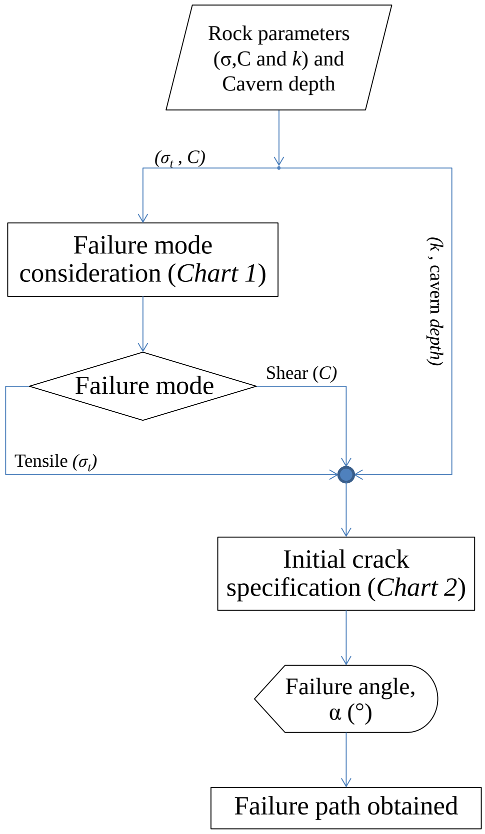

Figure 5.1 The procedure of simple failure path evaluation

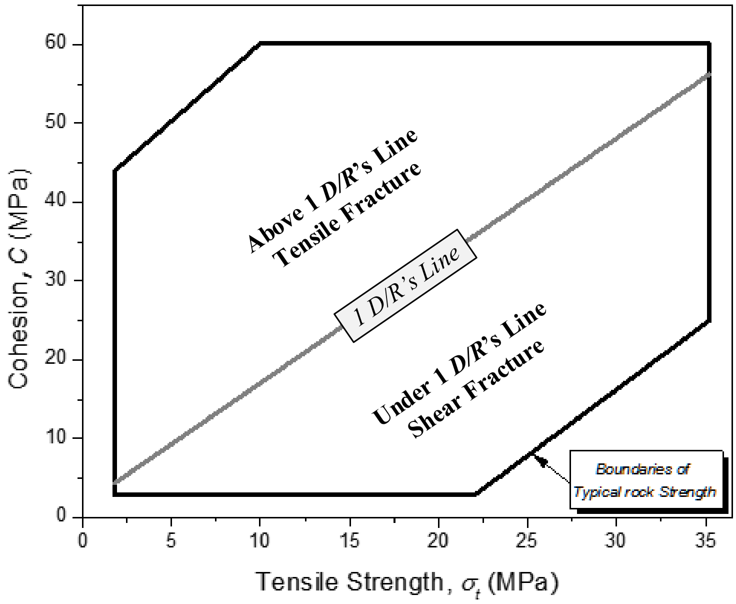

Figure 5.2 Chart 1 to determine the failure mode

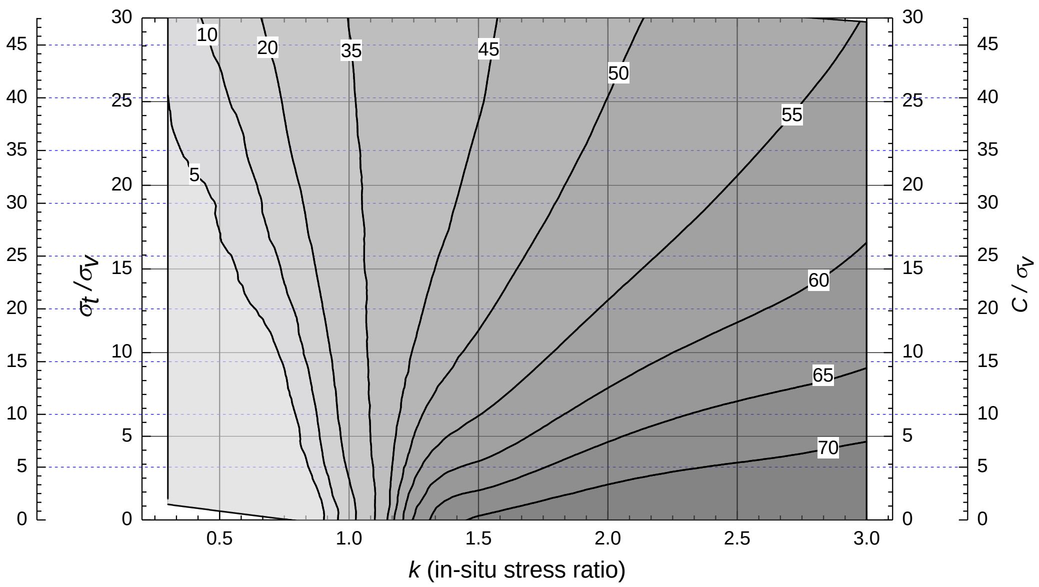

Figure 5.3 Chart 2 for specifying initial crack location

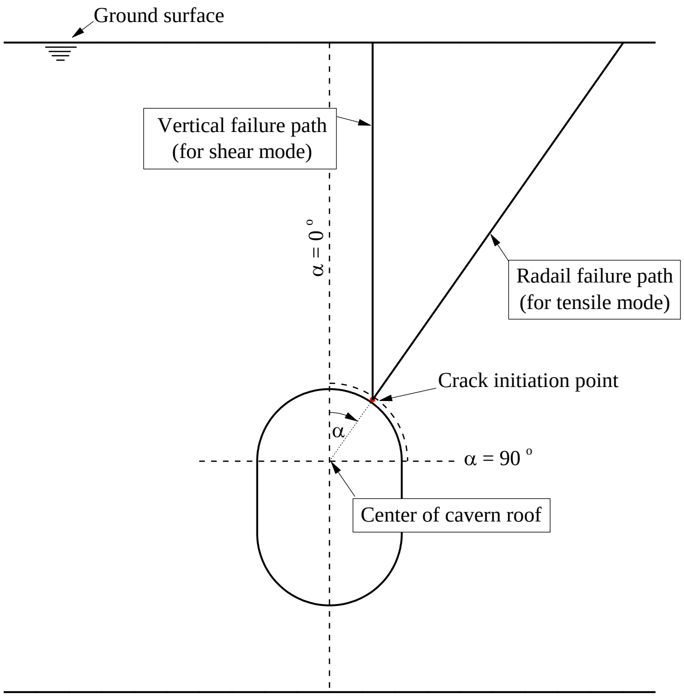

Figure 5.4 The characteristics of simple tensile and shear failure path

5.3 Recommendations for future studies

1. Such a tensile fracture was found in the previous research (Tunsakul et al., 2013) that performed through a series of physical model test with the artificial rock the rock properties, on above the line of D/R=1 which the relationship of σ_t and C is situated. In order to verify the concept of the line of D/R=1 that can be used to separate the tensile and shear fracture, a physical model test with an artificial rock having properties as located under the line of D/R=1 should be further investigated.

2. The occurrence of a new fracture should be extended in the future study.

3. Future study should be extended to analyze under anisotropic in-situ conditions.