Consideration to evaluate maintenance process for utilization of non-supported underground quarries

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ABSTRACT: In this study, the authors focus on propose evaluation chart for checking stability and safety the underground quarries because of the underground quarries are unstable and worried about the corrupts. Additionally, it is necessary for those users, such as entrepreneurs to evaluate the stability of the underground spaces in case of utilizing those underground spaces in certain purpose. Field survey is very important and necessary to understand for the workers and entrepreneurs. Thus, the authors consider the stress distribution and deformation to simulate active and abandoned underground quarries. the authors will consider stability for individual structure of room and pillar type based on the numerical analysis with considering influence of adjacent underground spaces. Finally, the authors will discuss the maintenance process to utilize the underground quarries analysis.

Keywords: underground quarry, stability and utilization assessment, field survey, numerical analysis

1 INTRODUCTION

1.1 Background

The authors have considered the stability of Oya underground quarry (Seiki, et al.2016), which is quarrying Oya tuff in Utsunomiya city, Tochigi Prefecture, Japan, to evaluate easily by using table for engineers to check the stability. Oya tuff is classified into pumice tuff geologically and it is called Oya stone. And it is used as building materials for fences and decorating plate for houses. Those underground space structures are almost non-supported and locate in Oya area about 5 km in north-south and 4 km in east-south. It has said that there are over 200 underground spaces after quarrying Oya tuff. Almost of them has room and pillar type structures some of them has long-wall type structures. Some of them has been unstable and had corrupted (Memories of Natural Disasters 2023).

1.2 Objective for study

In this study, the authors focus on propose evaluation indexes for checking stability and safety the underground quarries because of the underground quarries are unstable and worried about the

Figure 1. Internal view of active underground quarry A.

Figure 2. Internal view of abandoned underground quarry

corrupts. Additionally, it is necessary for those users, such as entrepreneurs to evaluate the stability of the underground spaces in case of utilizing those underground spaces in certain purpose. Field survey is very important and necessary to understand for the workers and entrepreneurs. At first, the authors propose the way of field survey to consider the table. Secondly, the authors try to propose the evaluation chart including indexes for novice users, especially entrepreneur to check the structural safety for business continuation easily because of being aware of unstable state according to daily use. Thus, the authors consider the stress distribution and deformation to simulate some of underground quarries. As roughly those quarries have two kinds of structure, room and pillar and long wall type structures, the authors will consider stability for individual structure based on the numerical analysis with considering influence of neighbor underground spaces. Finally, the authors will propose the maintenance concept to utilize the underground quarries based on filed survey and numerical analysis.

2 FEATURE OF UNDEGROUND QUARRY

It has over 200 underground spaces quarried Oya tuff in Oya area, Utsunomiya City, Tochigi Prefecture, Japan. However almost of them have been abounded after terminating to quarry the stone materials and only 4 quarries are active now. In this study, the authors focused on some of those quarries. One is active and the others are ruined and only restricted person are able to access them now. Almost of them has quarried in room and pillar structure and some of them have been done by long wall type structure.

2.1 Active underground quarries

This underground quarry located in about 60 m below the ground surface and has largest vertical shaft to access the quarry and it is for carrying out the stone material of Oya tuff. Every weekday, mason excavate Oya tuff bricks for row materials. Periodically, the risk taker will check structural safety based on the check sheet provided by Oya stone cooperative association. As this is for only quarrying the Oya tuff. In this study the authors propose the check method to utilize those spaces as the check sheet should be blushed up to adopt the stability for the underground utilization and its maintenance.

2.2 Abandoned underground quarries

Almost of underground quarries have been abandoned after terminating to quarry the Oya tuff. Based on the quarrying law in Japan, the owner of the quarries should secure those stability at least two years. However, after that terms, those abandoned ones have been getting degradation. Now a days, over 70 % of abounded quarries are submerged because those are gradually filled by rain water and underground water after terminating quarrying.

3 FIELD SURVEY OF THE UNDERGROUND QUARRIES

3.1 Field Survey of an underground quarry

The research group of the authors have kept continuing the survey the underground quarries in Oya town. In this study, the authors focused on the one active underground and three abandoned ones. In this study, the authors surveyed an active underground quarry of room pillar type. Figure 1 will show the internal view of an active quarry. The bottom of the quarry has flat and almost area is dry and pillar was settled in regular interval by following the quarrying law in Japan. On the other hand, some part of the quarry is excavated deeper than bottom floor of the quarry. It was at less than 10 m. Those complex structure made quarrying and planning for utilizing it difficult as underground facilities. Base plane is stable.

3.2 Field survey of abounded underground quarries.

In this study, the authors have carried out the field survey of some of abounded quarries in Oya area. The authors visited three underground ruined quarries. Some of them are excavated for underground firm during World War II. It took over 70 years after that and it seemed that it still has been stable. Base plate was almost flat but the small bolder about 1 m^2 in cross section was caved in from the roof. We defined it was the first level in underground space B in this study. Figure 2 show the internal view of the abandoned space. Second underground space has complex passages and horse shore cross section. Groundwater inflow and retention were ubiquitous, making it relatively difficult to carry out the survey. It was observed that a part of roof was corrupted and the space connected the neighbor underground abandoned quarry. The third underground quarry was supported by pillars and no cave-in has happened. It becomes larger space than the original one and it becomes far-sighted space with breathable. Thus, it is more useful to utilize the underground quarry. And we could find traces of utilizing trial in the underground. Almost underground has been kept stable structurally however the safety condition was different on individual areas. The authors felt that the more neatly rooms of the underground space were, the more stable those rooms were. Although a part of the underground quarry was devasted, we think we are able to find out the virtue for utilization.

4 NUMERICAL ANALYSIS FOR STABILITY OF UNDERGROUND QUARRIES

4.1 Introduction of numerical study approach

This study focused on simulate to 3-dimensional structure of the stability of 2 underground quarry which is named underground quarry A and B by Flac3D ver5.0. Itasca Co. Ltd. At first, we apply the amount of gravity acceleration as $9.81 m/s^2$ along z-direction or vertical direction and carried out the first step of the analysis estimating the homogeneous elastic media. Excavation analysis has been carried out for consideration of the structural stability for quarrying Oya tuff from those underground quarries. It follows Mohr-Coulomb criteria for perfect elasto-plastic state. Parameters are general value of Oya tuff and shown in Table 1 (Cheng, C. 2020).

4.2 Modeling and numerical analysis of underground space with pillar

Figure 3 shows overview of underground space A of room and pillar type that still has been active to excavate and product Oya tuff for building material. It has 145.3 m in width, 75.3 m in length and about 40 m of overburden. In this study, the authors estimate the stability of the underground quarry

Table 1. Material properties of Oya tuff.

Density	Bulk moduls	Shear moduls
1730 kg/m^3	1.38×10^9 Pa	0.91×10^9 Pa
Cohesion	IFA*	Tensile strength
2.10×10^6 Pa	30 °	1.08×10^6 Pa
*IFA:Internal friction angle		

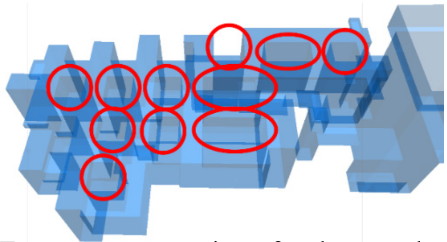

Figure 3. Transparency overview of underground space A for numerical analysis. Red circles indicate the pillars.

consider that the pillars may bear the overburden after degradation by weathering. At the first step, the authors deleted all pillars to simulate no pillar support situation of the underground quarry. The results show that no yield zone was shown on the other pillars, base plane and roof plane. It might show that underground A is stable even though it loses pillars. At the next step, a half value of strength parameters, i.e. cohesion, internal friction angle and tensile strength, was applied. And the authors make individual pillars collapse one by one. The authors also carried out the numerical analysis for collapsing several numbers of pillars by neglecting them in 6 steps. Those results show the roof plane tended to collapse in the 5th step. Those means that the underground quarry A which has a half value of strength parameters may collapse in certain numbers of pillar reduction. We also carried out the stability assessment of abandoned underground quarry B.

5 PROPOSAL OF STABILITY EVALUSATON OF UNDERGROUND QUARRIES

5.1 Process for the stability assessment

In this study, an attempt was made to propose a new evaluation index with reference to the Oya tuff underground quarry stability evaluation method that has been used up to now. The background to this is that, for example, in the previous evaluation methods, stability is evaluated on the assumption that each remaining pillar supports the overburden load. The stability of the quarry underground space is assumed to drop to an extreme level when the pillars yield, thereby ensuring a high level of safety. On the other hand, the possibility of the quarry basement space maintaining a certain degree of stability after the collapse of a pillar by the surrounding pillars sharing the overburden load that was previously supported by the pillars has not been considered (Oya tuff quarry site evaluation review committee 2001). In addition, as there are adjacent quarry underground spaces, it is also desirable to consider the state of interacting ground pressure and the effect of groundwater stored in the underground quarries, as many of the cavities are submerged due to rainwater and groundwater inflow. Furthermore, the old evaluation methods were focused on structural stability and did not include the factors necessary for the effective utilisation of underground space. For example, there are several factors such as “falls on sloping surfaces and wet floors” and 'inflow of groundwater', which can be hazardous to the behaviour of users due to the shape and condition of the underground quarry, and it is expected that these factors should be included in the study to clear the concerns of users. To be used for the effective utilisation of the space, this evaluation method is expected to include the viewpoint of users. In view of these points, the authors considered that a new assessment index for examining the structural safety of Oya underground quarries instead of those official stability assessment methodology for Oya underground quarry, incorporating modern technology, was necessary. Specifically, the authors carried out a study on the stability for underground quarries when the pillars stop to function and stresses are redistributed and a study on the influence of adjacent abandoned underground quarries and storage pressure on those quarries, and added other items that should be additionally considered, such as settlement of backfilled quarries, to provide evaluation indices to be considered. It was also considered that the safety of the quarries from the viewpoint of users should also be considered. The following indicators were considered the necessity to quantitatively evaluate hazards such as falls on sloping surfaces and wet floors' and 'inflow of groundwater'. Combining the viewpoints on the structural stability of the Oya underground quarry and the sense of security of effective use. It is applicable to consider maintenance process, the authors set following five evaluation stages in Figure 4.

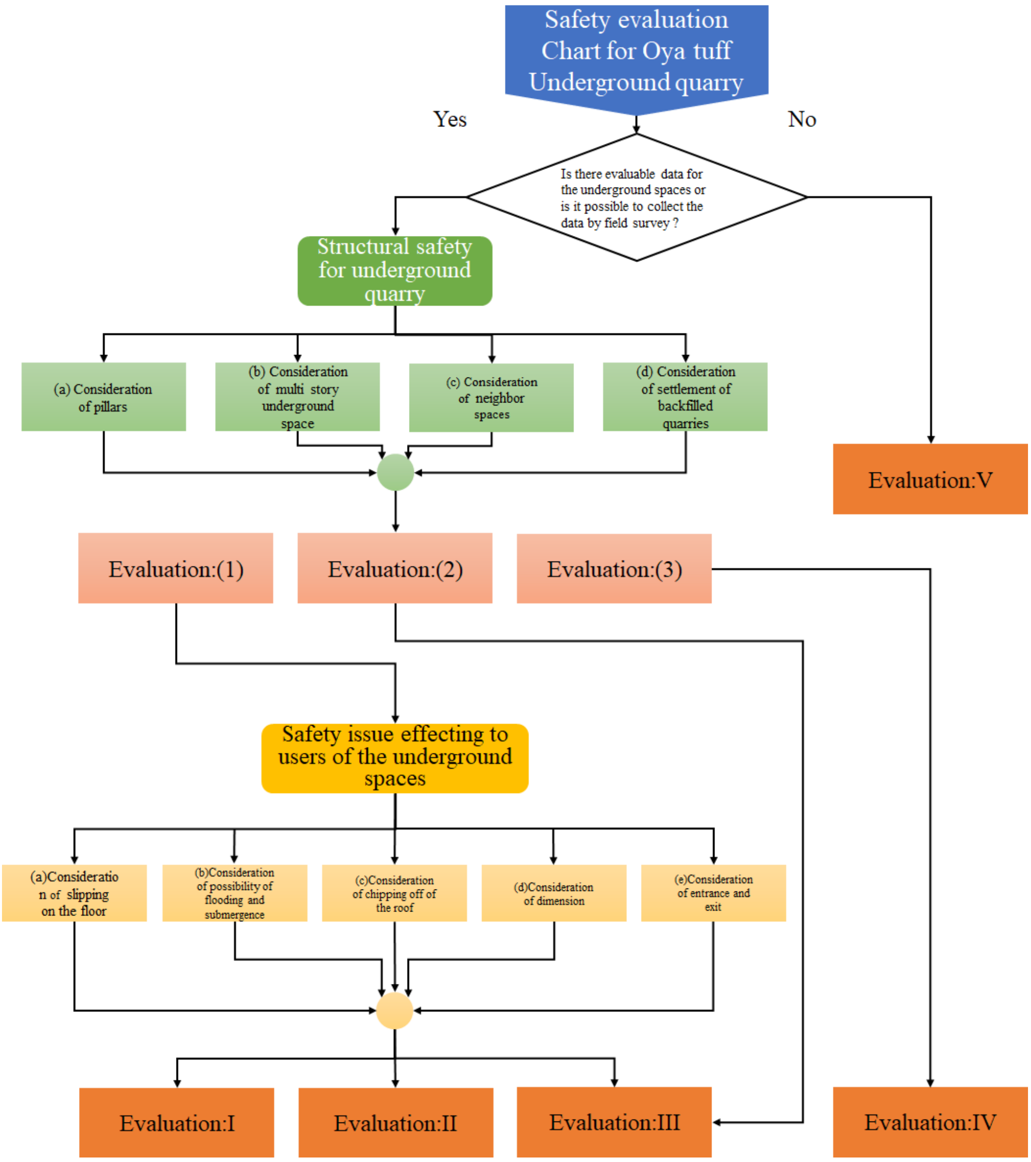

Figure 4. Flow chart of evaluation indexes.

I. Underground quarries that can be referred to as accessible to an unspecified number of people., II. Underground quarries that can be referred to as accessible to some interested parties if safety considerations such as wearing helmets and regular monitoring are considered., III. Underground quarries where users are likely to encounter hazards and entry needs to be restricted., IV. Underground quarries that are likely to collapse and need to be basically off-limits, V. Underground quarries that are inaccessible or whose hazards cannot be identified. It is for all underground quarries not falling into I-IV selected above.

The evaluation of the safety of the space in question is then divided into two phases, namely "Examination of the safety of the structure of the underground quarry" and "Examination of the safety of the impact of the underground quarry on the users".

5.2 Examination of the safety of the underground structure

The evaluation method was based on a point reduction system, with 10 points being the highest evaluation point, and the evaluation was carried out in three stages. The distribution of points was differentiated according to the priority of each item to be evaluated. The underground quarries with an evaluation score of 7 or more points are considered to have the best evaluation, and only these are subjected to a “safety study on the impact of the underground quarries on the users”. Underground quarries with an evaluation score of between 6 and 4 points are designated as evaluation III and those with an evaluation score of 3 points or less as IV.

6 APPLICATION AND SHARING OF SAFETY ASSESSMENT INDICATORS

In this study, the authors collected the data necessary for the evaluation of Underground quarry A and B from drawings and analyses of the underground spaces and conducted the actual evaluation. For the other two underground spaces, only the items that could be confirmed by on-site inspection were evaluated. As a result, the evaluation of cavity A, which is still in use today, was classified as Evaluation II, which can only be used by the operator. The results for the other underground spaces were generally close to the perception of safety by authors. On 24 December 2021 and 31 January 2022, the authors explained to staffs of Utsunomiya city hall, some evaluation indicators proposed and the status of the trial, and received general approval, as well as opinions on points to be improved.

7 SUMMARY

In this study, in order to promote the effective use of the Oya underground quarry by emphasising its safety, and to share information on its safety, measures to share risks among the parties concerned were studied using the concept of geological risk management (Anan 2021), and the safety reassessment index for the Oya underground quarry was simplified. The safety of the space was re-evaluated using a simplified version of the old safety reassessment index for the Oya underground quarry. For this purpose, numerical analysis and field inspections of the space were carried out, and based on the knowledge obtained, a new evaluation index was developed and the validity of the developed index was confirmed through actual trials. The developed evaluation indicators were also shared with the local authorities to apply the maintenance strategy. Further consideration should be given to the influence of multi-level and adjacent underground quarries like a underground quarry B and the order of priority of the evaluation in the "Investigation of the safety of the cavity structure".

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