論　文　要　旨

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論文題名　Failure characteristics of shaft lining in eastern Chinese coal mines and its treatment through the application of an underground continuous impervious curtain
(中国東部の坑内掘り石炭鉱山における立坑ライニング破壊挙動の解明および地中遮水連続壁を用いた破壊抑制方法に関する研究)

論　文　内　容　の　要　旨

Serious shaft lining failures have often occurred in the shafts constructed more than 10 years ago in the eastern part of China, such as Datun, Xuzhou, Huaibei, Huainan, Yanzhou, Yongxia, and so on, since 1987. All these shaft linings are constructed in similar geological conditions and they pass through the deep topsoil of Quaternary strata, about 100 ~ 200 m thick and more than 20 m thickness of aquifer composed at the bottom of deep topsoil. The serious deformation and failure in their shafts linings have occurred even though enough coal pillars have been left around their shafts. The main cause of these shaft lining failures is considered to be additional stress concentration induced by the drawdown of aquifer. The ground water level in aquifer had dropped due to the effects of mining operations, and then this phenomenon gave rise to the compaction of aquifer and the subsidence of the alluvium. The failure firstly occurs at the inner surface of the shaft lining, and then develops further on the inside. As for the counter measures for shaft lining failures, several treatments such as the set of wall method, stress-relief groove method, strata grouting method, and so on, have been applied so far. However, these treatments effects were temporary and/or limited due to the complex and unique geological conditions. In serious cases, some shafts experienced a second failure, even after the first treatments.

From these backgrounds, this study develops and suggests a new treatment method for preventing shaft lining failure using an underground continuous impervious curtain around the shaft lining, which uses a chain conveyor cutter based on the results of an investigation of shaft lining failures that have occurred in eastern Chinese underground coal mines and its mechanism. Then, this study also discusses the method by which to apply and its applicability in order to establish a guideline of its application.

Chapter 1 introduces the background and conditions of the shaft lining failures that have occurred in eastern Chinese coal mines. The research conducted on the shaft lining failures so far and the current treatment methods are reviewed. The objectives of the study are described in this chapter.

Chapter 2 investigates the mechanism by which the shaft lining failures have occurred in eastern Chinese coal mines, based on the results of site investigation conducted at one coal mine and numerical analyses. Namely, the ground behavior induced by the drop in ground water level in aquifer and its effect on the stability of the shaft lining were discussed. From the results, the mechanism of the shaft lining failures can be made clear: the lowering of the water level causes the subsidence of the upper layer. Then, the stress concentration which happens in the shaft lining is caused by the subsidence of the layer of the surrounding shaft. As the

subsidence occurs in the aquifer and the upper layer, a large stress concentration appears in the shaft lining near the interface between the aquifer and bedrock and the risk of shaft lining failure is high in both boundaries of the aquifer. Therefore, shaft lining failure is considered to occur around these parts. Moreover, it can also be clearly understood that the thicker the aquifer is, the larger the magnitude of stress concentration is. When the thickness ratio of the upper layer and aquifer is greater than 9.0, the lowest strength factor appears near the upper boundary. Many treatment methods for improving the stability of shaft lining have to be adopted in order to prevent shaft lining failures. Moreover, based on the results of a series of numerical analyses, it can be thought that the set of wall methods only reinforce the shaft lining and it cannot control the influence of the water level decline in aquifer. Moreover, as the average settlement of the ground surface was about 0.024 m/year, the stress-relief groove method just plays a temporary role in preventing shaft lining failure due to the constant compression and the decline of their effects. The strata grouting method is meant to change the property of the aquifer around the shaft and it is considered to be one of the solutions for shaft lining failures. However, due to the process of grout injection into the soil layer, the effect is dependent on the actual geological conditions and it cannot be guaranteed. Besides, as the high grout injection pressure is needed when this method is applied in aquifer, the injection pressure may have an obviously negative impact on the shaft lining. From the above results, it can be concluded that a new treatment method has to be developed in order to control shaft lining failure under the depths and geological conditions in eastern Chinese coal mines.

In Chapter 3, the new treatment method developed in this research is described in order to prevent shaft lining failure and solve the problems of conventional treatments. This method is meant to construct an underground continuous impervious curtain (UCIC) around the shaft lining in an aquifer using a chain conveyer cutter (CCC) with the freezing method. The CCC was originally developed for improvement of ground which mixes the cement and soil or rock during cutting the ground. The construction of UCIC consists the four steps of drilling freezing holes, freezing an aquifer, constructing UCIC using CCC and thawing an aquifer. As the operation of this method can be done from the inside of the shaft, the UCIC can be constructed at any depths. The CCC can also create a required quality and homogeneity UCIC at certain areas around the shaft lining. Moreover, as the cement grout is directly mixed with the excavated gravel or soil in this method, the impact on shaft lining is reduced compared with that of the strata grouting one. From the above advantages of this new treatment method, it seems to be a practical way to construct the UCIC.

In Chapter 4, a series of the numerical analysis are conducted using an axisymmetric finite element model in order to evaluate the effects of the new treatment method on preventing shaft lining failure and developing guidelines for the appropriate design of UCIC. From their results, it can be said that in the case that the depth of aquifer is about 150m, the ground behavior induced by dehydration and drawdown of an aquifer can be controlled by the construction of UCIC with about a 2 m thickness, and then the stress concentration appearing in the shaft lining can be reduced. As a result, the shaft lining failure can be prevented effectively by this new treatment method. Moreover, it can also be made clear that this new treatment method can be applied widely for several geological conditions if the width and strength of the UCIC are designed appropriately according to the depth of the aquifer and the geological conditions.

In Chapter 5, the effect of the extraction of a coal seam on the stability of the shaft lining in which the new treatment method is applied is discussed by means of numerical analysis. The closer the mining panel is to the shaft, especially to the aquifer, the larger the stress concentration occurs in shaft lining and the risk of occurrence of shaft lining failure is increased dramatically. Hence, compared with the basic standard of the design of shaft pillars that the width should be more than that of the depth, wider shaft pillars have to be left around the shaft lining, especially in the aquifer. However, if the new treatment method is applied, the stress concentration in the shaft lining induced by the extraction of the coal seam is relieved, and the stability of shaft lining in the aquifer can be maintained by leaving a coal pillar the same width as that of the basic standard. Hence, the application of this new treatment method not only can maintain the stability of shaft lining, but also can increase the extraction ratio.

Chapter 6 concludes the results of the current study and recommendations for the future research.