台灣中北部廢棄煤礦地盤下陷潛勢分析

Potential Analysis on Ground Subsidence Hazards of Abandoned Coal Mines, Northern Taiwan

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摘 要

台灣地區對煤礦開採而造成之環境災害甚少研究，且許多礦區資料如：礦區設施平面圖、坑口位置、礦渣堆分布範圍以及採掘跡等重要空間資料得來不易。而國內目前一重要案例係為台北縣中和市東運瓷土礦（前身為彰和煤礦）於 89~92 年間陸續發生多次的地盤下陷(坑道及採掘跡)。期間，工研院能資所曾以地電阻與透地雷達之相關地球物理探測進行分析，雖對地下岩體性質與岩層破壞之幾何型態（岩體滑動面與地盤下陷）有初步研判結果，然在地盤下陷推估方面與機制探討上仍較缺乏。因此本研究採三個面向：資料收集與建立、資料分析與現地調查，以及災害評估等三階段進行野外調查之地表煤礦坑口位置與相關地下片/坑道測量高程點，以及相關坑道分布、採掘跡範圍（亦即地下開採空間）等空間資料，然後以多下陷槽推估模式結合地理資訊系統強大之空間分析（spatial analysis）功能，輔以地理統計方法（geo-statistic）來建立、評估礦區之地下採掘跡所造成地盤下陷潛在災害的範圍。

本研究自 93 年至 99 年累積七年廢棄煤礦區之現地普查成果，以及中北部廢棄礦區現地災害案例調查與野外露頭之煤層上覆岩盤剖面進行試作煤礦上覆岩層強度之 CMRR 分析。其結果為現地災害案例多位於距地表淺層之地下採掘跡或坑口附近，且岩體強度均落在 CMRR<45 之弱岩類別，因此也提供災害潛勢高－低之相對比較因子。典型之災害類別如建物牆壁龜裂、路面沉陷、電線桿傾斜及樑柱受損，乃至於地表發生落盤（sink hole）等災害現象亦於本研究中多所驗證。在地盤下陷量與範圍推估方面係以多下陷槽理論推估礦區地下採掘跡範圍內之最大下陷量（S_{max}）計算，結果顯示由開採煤層之上覆岩盤引發滑動機制所造成之下陷槽沉陷量（採掘跡之 FX_{01} 推估值範圍 0.03~3m）比上覆岩盤引發垂直破壞者較大（採掘跡之 FX_{02} 推估值範圍 0~0.4m），且沉陷槽之型態明顯受到前者之機制所控制。且災害案例之驗證也均落於推估之較大沉陷量範圍（如中和東運瓷土礦案例之 0.19m、烘內坑煤礦本坑案例之 2.97m）。

此外，中和市東運瓷土礦案例在 93 年 9 月（二處）以及 96 年 11 月（一處）計發生三次較大規模之地盤下陷災害。其主因可能為舊有之彰和煤礦坑道於廢坑後，仍有進行大量黏土及矽砂的的開採，導致後來地下掏空容積擴大、上覆岩體支撐脆弱才發生「落盤」之現象。雖然本研究無法進行需大量費用之鑽井監測數據工作，而僅能以最大推估下陷量以及現地災害徵兆與現象來驗證。然多下陷槽模式之地盤下陷推估與輔助 CMRR 之潛勢高低，在台灣地區因人為之地下採礦而造成地盤下陷災害應用上，是可以值得後續深入探討與應用的。

關鍵字：地盤下陷、廢棄坑道、採掘跡、空間分析、多下陷槽模式、煤礦上覆岩體強度分類

Abstract

The ground subsidence could be caused by underground mining activities. In Taiwan, the coal mines are abandoned completely and not reclaimed during the past decade. The crucial point is how to characterized the unknown spatial geometry from underground data. Fortunately, such data had been reorganized and digitalized by Bureau of Mine, M.O.E.A., R.O.C.. The main purpose of this study is to identify the phenomena of subsidence, characterize the geospatial data by using GIS technology, predict the maximum subsidence by profile model, and evaluate the risk assessment of such hazard that might be affected on residences and their surroundings.

As mentioned above, three phases are identified following by data collection, site investigation and characterization, and risk evaluation. In the second phase, Kriging geostatistic is used to characterized the geometric elements of coal seams（strike planes and dip directions）by putting the elevations of underground data into Arc-GIS software. Then the excavated surfaces, the configuration of mined adits and inclined shafts, even the thickness of overburdens could be generated by GIS-3D spatial analysis. There are many methodologies to predict the subsidence. The empirical method developed by National Coal Board（1965,1975）is still commonly used in the worldwide coal mine experiences. But it depends on large amount of records measured from mined area. The most popular one is profile function. It is the simple way to calculate the maximum subsidence by using limited data such as depth of overburdens, extracted height, angle of draw（in experience）, and dip of coal seam. Torano, et al.（2000） proposed a new methodology called multiple subsidence troughs that combined the concepts of profile function and finite element analysis to explain the mechanism of subsidence acted on inclined coal beds. The result of predicted calculation is very closed to the observed data. In this study, by the integration of GIS map algebra and mathematic profile function, the maximum subsidence in each point could be calculated and the new subsidence contours would be created.

There are many hazardous cases in studied area. The most serious one is the Ton-yung clay mine which located in Chung-Ho City of Taipei County is. It was characterized by secondary mining activity for silicate-sand deposit after coal mine finished in 1975. The secondary mining had the scale of ground deformation enlarged during these years. Hazard phenomena such as sink holes, fractures on buildings and roads, acid mine drainage, slope collapse, are easily to find in this mine area. The records of level measurement also showed that ground deformation is still proceeding in a rate of 3 cm per year. The spatial variation of subsidence trend are similar to each other, though the subsidence amount was not compared very well between mathematic prediction and level measurement in this case. Also, the predicted data revealed that subsidence behavior is dominated by roof strata slip mechanism rather than breaking one. It is meaningful in making the difference between horizontal strata and inclined strata when subsidence occurred.

The strength of roof rock is also considered as geological factor in the study. Coal Mine Roof Rating（CMRR）is developed by former Bureau of Mine, U.S.（Molinda and Mark, 1994）with extensive experiences in coal mine ground control. The rating system is ranging from 0 to 100 and divided into 3 types naming weak, moderate and strong roof, respectively. According to the geo-mechanical test of 28 rock samples drilled from coal-bearing strata, the CMRR unit rating are ranged from 15~45（weak roof）. In recent years, the investigation of geo-engineering property of rock mass in slope area had been finished by Central Geological Survey, M.O.E.A.. According to the hazard investigation *in situ*, it shows that most of cases are located in “weak roof” area. In other words, such data might be provided for the risk assessment of subsidence.

Finally, the study is tried to integrate modern technology with classical subsidence models to solve the uncertain problem. The powerful GIS calculating system could provide a better way to characterize the spatial geometry underground and the prediction of subsidence. But there are still lots of works to do if we want to make “prediction” getting closer to “real” subsidence. For the potential hazard of subsidence it is difficult to find and the rock mass system is heterogeneous. What we know is still limited. Nowadays, land-use and planning is an important issue in Taiwan. Most of abandoned coal mines are located in urban area. The economic interests and conflicts might hide the subsidence problem. It is important to pay more attention to ground subsidence caused by abandoned coal mines.

KEYWORDS: Ground Subsidence, Abandoned Tunnels/adits, Stope, Spatial Analysis, Multiple Subsidence Troughs, Coal Mine Roof Rating（CMRR）