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Deformation measurements and a stability analysis of the slope at a coal mine waste dump

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ABSTRACT

This study surveyed and investigated the deformation of the coal waste dump slope and the natural ground slope under the waste dump at Dogye village in Samcheock city, Gangwon Province, Korea. Multiple sets of south-north tension cracks were observed at the crest of the coal waste dump slope. These cracks were greater than 100 m in length, and the resulting drop head averaged 1.0–1.5 m. To investigate the behaviors of the waste dump slope and the natural slope under the waste dump, wire sensors and a rain gauge were installed at the crest of the waste dump slope, and inclinometers were installed in the natural slope of the ground under the waste dump. According to the monitoring results, the deformation at the crest of the waste dump slope steadily increased and then converged over time due to the effect of the infiltration of rain into the ground after rainfall. In addition, the horizontal deformation of the natural slope under the waste dump was affected by the accumulated precipitation. The basis of this effect is that the rate of increase of the maximum horizontal deformation tends to show increasing or convergent behavior according to the precipitation. The slope stability analysis showed that the safety factor of the natural slope before the discharge of the waste was 2.14. Meanwhile, the safety factor of the waste dump slope, including the natural slope in the dry season was 1.66 and the safety factor in the rainy season was 0.98. The natural slope before the discharge of the waste and the coal waste slope, including the natural slope remained stable during the dry season but became unstable during the rainy season, especially when the ground water level in the waste dump slope becomes rising as a result of infiltration by rainwater. The waste dump slope and the natural slope under the waste dump experienced deformation due to the increasing weight placed on the waste dump by the infiltration resulting from rainfall.

1. Introduction

Environmental hazards caused by abandoned mine waste storage facilities include ground subsidence resulting from neglected mine shafts, leakage of acidic mine sewage, pollution from the deposits of tailings and muck, and failure of the slope of the waste dump (Dobry and Alvarez, 1967; Wagener et al., 1997; Blight, 2000; Stuart et al., 2003). In Korea, most mines are located in rugged, mountainous areas. In general, a mine is first developed by the excavation of horizontal shafts from an outcrop near the crest. Mine wastes produce a small-scale waste dump by forming an embankment along the valley during the early stages of excavation. The mine is then developed through the excavation of inclined or vertical shafts. As the amount of mine wastes increases, the waste dump develops from a small-scale waste dump without a supporting system to a large-scale waste dump with reinforcement. The unattended waste dump slopes resulting from the closures of mines not only damage the landscape but also could be hazardous to life and property if heavy rains occur. For this reason, rigorous preventive measures are necessary (Brink, 1998; Lo and Klohn, 1996; Kang et al., 2004).

In particular, abandoned waste dumps that do not receive proper repair and maintenance can often experience partial losses of slope and surface erosion (Blight and Amponsah-da Costa, 2004). The occurrence of such structural problems raises concerns about the stability of abandoned waste dump slopes. Actual cases of partial slope loss and slope deformation, including the deformation of the natural slope under a waste dump due to the weight of the deposited waste, have been reported (Berti et al., 1988; Alonso and Gens, 2006; Scott et al., 2007; Cho et al., 2011). Therefore, research that could contribute to both environmental and geotechnical stability is needed for abandoned mine areas.

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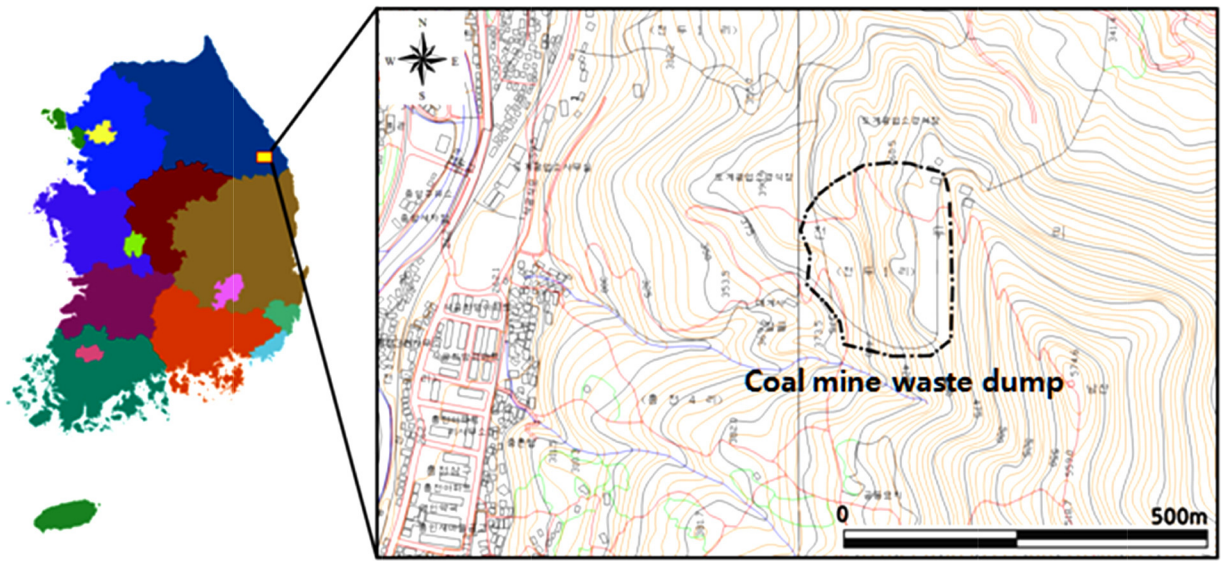

Fig. 1. Location and topographic map of the study area.

The causes of slope failure in a waste dump are categorized as intrinsic factors (or potential causes) and external factors (or direct triggers). A slope failure occurs if an intrinsic factor is coupled with an external factor. For example, a slope with intrinsically vulnerable geological properties and structure is at risk of failure as a result of external events such as rainfall and ground cutting.

To evaluate the stability of a waste dump slope, the physical and mechanical properties of the waste dump should be identified in addition to diverse geological and hydraulic factors. In general, the shape of a waste dump slope is governed by the ground conditions under the slope and the shear strength of the mine wastes (Gens and Alonso, 2006). The scale of a waste dump slope is decided by the amount of waste, the maximum filling height, and the slope angle. The filling method and the shape of the natural ground under the waste dump also influence the shape of the waste dump slope (Van Zyl, 1993; Upadhyay et al., 1990).

In this study, the deformation of the coal waste dump slope and the natural slope of the ground located under a coal waste dump in Korea were investigated, and the causes of deformation were analyzed. In addition, the stability of the study area was evaluated through a stability analysis of the waste dump slope. To measure the behaviors of the waste dump slope and the natural slope under the dump, wire sensors were installed at the crest of the waste dump, and inclinometers were installed in the natural slope under the dump. The correlation between precipitation and the deformation of the waste dump and surrounding ground was analyzed based on precipitation data collected at the study site. The engineering properties of the waste dump and the surrounding ground were investigated to obtain input data for the stability analysis. A stability analysis of the waste dump slope, including the natural slope under the dump, was then conducted. Based on the results obtained from the measurements and the analysis, the causes of the deformation of the waste dump slope were identified, and the pattern of deformation was characterized.

2. Study site

2.1. Topographical and geological characteristics

Fig. 1 shows the location of the study site and a topographic map. The study site is situated in Heungjeon-ri, Dogye-eup, Samcheok City, Gwangwon Province, Korea, at N 37°1′ and E 129°2′. As illustrated in the topographic map, the main ridge of the natural slope follows a north-northwest and south-southeast direction, and the small ridges near the coal waste dump have an east-west orientation.

Fig. 2. Panoramic view of the study area.

Fig. 2 shows an aerial view of the study site and shows the coal waste dump built on the ridge of the natural slope. As shown in Fig. 1, many houses and various parts of the social infrastructure of the area, including roads and railroads, are located under the coal waste dump at Dogye village. Therefore, a slope failure at the waste dump would most likely cause significant losses of life and property.

According to a geological map of the study area, the stratum of the study site belongs to the Hambaeksan Formation and primarily contains black and citrine sandstone and shale. The Hambaeksan Formation runs through the middle of the study site toward the border with the Heungjeon Formation to the west, along the Osipcheon Fault. The primary rock type is very coarse-grained sandstone consisting primarily of large white quartz grains. A layer of white or citrine coarse-grained sandstone and a thin layer of dark-grey shale