



Excavation cycle times recorded during sinking of a deep shaft in crystalline rock – A case example at Ventilation Shaft of Mizunami URL, Japan



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ABSTRACT

Realistic and properly planned excavation cycle times developed prior to tunnel construction are an important issue for dependable project management, including cost estimation and time saving. Existing design studies, conducted to estimate the total cost for geological disposal, have been limited to estimates of approximate construction total time schedules. There were no case studies which compared the detailed excavation cycle time used in design studies with the actual results from an excavation taking into account each excavation cycle operation and task. In this paper, analyses of actual cycle time recorded during the sinking of the Ventilation Shaft of the Mizunami Underground Research Laboratory and comparison with the planned cycle time developed in the design stage are intended for an evaluation of the baseline work plan and schedule and for optimization of the calculations for application to shaft construction in any future repository in Japan. Actual times to perform three operations, drill and blast, muck removal and concrete lining emplacement were much larger than expected and represent the largest portion of the total excavation cycle time and had the largest impact on the efficiency of the excavation cycles and schedules. Operating at increasingly greater depths and excavating harder, more competent rock combined to significantly affect the shaft sinking speed. The underlying reasons for increases in actual times for the excavation cycle operations compared to their design estimates fall into three categories: constraints on construction; to ensure safety; and maintenance.

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1. Introduction

Realistic and properly planned excavation cycle times (hereafter, Ect) developed prior to tunnel construction are an important issue for dependable project management, including cost estimation and time saving. Especially, if the design phase Ect significantly underestimates the actual Ect, there could potentially be a huge, negative impact on the project, i.e., potentially, a big financial loss in a large tunnel project such as one for the geological disposal of HLW (High-level radioactive waste), with inherently huge underground excavations in a rock mass. Therefore, minimizing Ect differences between plan and actual are required in design studies of tunnel excavation.

Existing design studies (Harmon and Lazur, 1984; Kim and Choi, 2006; Kukkola and Saanio, 2005; NIREX, 2005; Read, 2011),

conducted to estimate the total cost for geological disposal, have been limited to estimates of approximate construction total time schedules. There were no case studies which compared the detailed Ect used in design studies with the actual results from an excavation taking into account each excavation cycle operation and task as discussed in this paper. Moreover, recent examples of the excavation of deep shafts similar in size to those for HLW repositories are decreasing in Japan since there have not been any new coal mines developed in Japan for over 20 years (Sakurai et al., 2009).

In this paper, analyses of actual Ect recorded during the sinking of the Ventilation Shaft of the Mizunami Underground Research Laboratory (MIU) and comparison with the planned Ect developed in the design stage are intended for an evaluation of the baseline work plan and schedule and for optimization of the Ect calculations for application to shaft construction in any future repository in Japan. The comparison includes not only a review of the Ect but also a review of the method and underlying assumptions used to

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calculate the cycle times in the design process and comparison with the actual construction results.

The Mizunami Underground Research Laboratory (MIU), an “off-site” URL, constructed and operated by Japan Atomic Energy Agency (JAEA) at Mizunami City in Gifu Prefecture, central Japan, involves a comprehensive research program of investigations in a deep underground crystalline rock environment for R & D into geological disposal of High Level radioactive Waste (HLW). The MIU is being developed and operated in three overlapping phases: Surface-based Investigation phase (Phase I), Construction phase (Phase II), and Operation phase (Phase III) with a total duration of around 20 years. The overall project goals of the MIU Project in Phases I through III are: (1) to establish techniques for investigation, analysis and assessment of the deep geological environment and (2) to develop a range of engineering technologies applicable to deep underground environments in Japan (Saegusa and Matsuoka, 2011).

The MIU consists of a circular Ventilation Shaft (4.5 m diameter) and a Main Shaft (6.5 m), both with 0.4 m thick concrete lining, and horizontal tunnels connecting the shafts every 100 m depth (Matsui et al., 2011). Excavation of the Ventilation and Main Shafts reached GL-500 m in FY2011. During Phase I, the design work for surface and underground facilities in the MIU was completed with the aim of providing a foundation for engineering technologies to safely construct and operate a deep underground facility built for the purpose of data acquisition and demonstrating disposal technologies (Saegusa and Matsuoka, 2011). The design work incorporated development of Ect estimates prior to MIU construction as a basis for estimating overall costs and schedule requirements for the proper operating management of the MIU.

Repositories for the geological disposal of HLW will include vertical access shafts and/or ramps and disposal rooms, which are an assemblage of disposal tunnels comprising the underground facilities (NUMO, 2013; Svensk Kärnbränslehantering AB, 2009). Vertical access shafts will be utilized to transport the HLW, buffer and backfill materials and for mucking operations during construction and for access to the repository. Use of vertical shafts will be essential from the viewpoint of ventilation and personnel access and vertical shafts make it possible to effectively excavate at increasing depths during the construction phase and to transport the HLW to the disposal panels during the operation phase. Discussion of the cycle time during shaft sinking is important for the future geological disposal project, therefore the authors undertook the challenge of discussing, recording and validating the Ects in the MIU with the goal of providing relevant input to shaft construction in a future HLW geological disposal project.

2. Construction of the MIU

2.1. Geological setting of the study site

The bedrock at the MIU site consists of the widely distributed Toki granite (Upper Cretaceous to Lower Paleogene) and overlying Miocene sedimentary rocks, the Toki, Akeyo and Hongo Formations of the Mizunami Group. Pleistocene gravel of the Seto Formation overlies the bedrock (Tsuruta et al., 2013a). Fig. 1 provides a vertical cross-section of the Ventilation and Main shafts and horizontal Sub Stages connecting both shafts in the MIU below the unconformity at GL-168 m between the Mizunami Group and the Toki granite. The general geology of the Main shaft is also shown, indicating the distribution of faults and fault zones. There are many differences in the geological conditions in the Main and Ventilation Shafts with respect to hydrothermal alteration. Intrusive rock (lamprophyre) exists along the fault plane only in the Main Shaft.

Extensive hydrothermal alteration of the intrusive rock and in the fault zones in the Main Shaft is evident by the abundance of clay minerals. Rock strength, i.e., the uniaxial compressive strength, is usually less than 3 MPa on average, in the hydrothermally altered zones in the Main Shaft. This is much less than in the rock from the Ventilation Shaft where it is in the order of 173 MPa (Hirano et al., 2009; Tsuruta et al., 2009). In addition there is no soft, hydrothermally-altered rock as in the Main Shaft (Fig. 1). This paper discusses Ect during sinking of the Ventilation Shaft where sound, high strength granite, without hydrothermally-altered, low strength rock, is distributed.

From the pattern of structural development and spatial distribution of fractures, the Toki granite in the MIU is divided into two domains, namely the Upper Highly Fractured Domain (UHFD) and the Lower Sparsely Fractured Domain (LSFD) (Tsuruta et al., 2013b). According to Tsuruta et al. (2013b), there is a high frequency of low angle fractures in the UHFD due to presence of sheeting joints. This is reflected in the results of well logging during Phase I in which investigations indicated there is high porosity in the UHFD. Fracture frequency is lower below GL-460 m, the boundary between the UHFD and the LSFD in the Ventilation Shaft (Fig. 2).

2.2. Excavation method and procedures

The excavation cycle and component operations are illustrated in Fig. 3 and are as follows:

(i) Drill and blast operations

A shaft jumbo with two hydraulic drifters is used for drilling blast holes. After they are drilled, rock mass blasting is done using non-electric detonators and water gel explosives. All equipment (e.g. dewatering pumps) are removed from the shaft, and protective mats are placed prior to blasting to prevent muck scattering. Moreover blasting is only carried out after the scaffold has been raised from 20 to 30-m above the shaft face to prevent damage from fly-rock and pressure shocks induced by blasting to the scaffold. After blasting, a fan at surface in the soundproof housing over the Ventilation Shaft and local fans in the Sub Stages were used to ventilate the air in the shaft. Workers are allowed to enter five minutes after blasting.

(ii) Muck removal operations

The shaft mucker attached to the bottom of the scaffold and the kibble removes muck after each drill and blast cycle for disposal at surface. A mini-backhoe is transported from the surface to the shaft face for scaling to dislodge any loose rock from the shaft wall and trim rock from the walls to the design shaft diameter. And then the kibble, filled with muck, is hoisted from the shaft face to surface. Muck is deposited in a temporary yard through the chute in the derrick over the shaft before loading into dump trucks for transport off-site.

(iii) Shaft wall mapping, drainage mat installation

Geologists map the shaft wall by sketching and photographing fractures on the shaft wall and recording information on lithologies and structures and thus obtain data necessary for rock mass classification (e.g. RMR (Bieniawski, 1989) etc.) and hydrogeological characterization. Drainage mats installed along the shaft wall help to remove any groundwater inflow into the shaft. Anchor bolts are installed quickly with two to secure the required piping.

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