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Design Study of Steel Fibre Reinforced Concrete Shaft Lining for Swelling Ground in Toronto, Canada

Min Seong Kim and **Sean Seungwon Lee** *

Department of Earth Resources and Environmental Engineering, Hanyang University, Seoul 04763, Korea; thenext207@hanyang.ac.kr

* Correspondence: seanlee@hanyang.ac.kr; Tel.: +82-02-2220-2243

Abstract: Reinforced concrete (RC) is a widely used construction material around the world. RC has many advantages in terms of structural stability. However, the reinforcement of RC requires extensive labour costs. Steel fibre reinforced concrete (SFRC) has been widely studied to replace steel bars in concrete structures over the decades. However, most underground structures, such as tunnel lining, are usually designed using conventional RC for long-term stability due to unexpected geotechnical characteristics, such as directional and depth-dependent varied lateral pressure, earthquakes, groundwater, and time-dependent swelling behaviour. In this paper, an alternative design of shaft structure using SFRC, based on the original RC designed data in the Toronto region, was studied to evaluate the feasibility of SFRC replacing conventional RC. A key geological feature of the site is that the bedrock is comprised of Georgian Bay shale, which exhibits long-term time-dependent deformation (TDD). The capacities of RC and SFRC for the shaft lining were calculated based on the Canadian concrete design codes CSA A23.3 and RILEM TC 162-TDF, to assess the benefit of adding steel fibre, and several analytical solutions were used to calculate the applied load on the lining. A specialised TDD constitutive model in Fast Lagrangian Analysis of Continua (FLAC) 2D was developed to estimate whether the optimum installation time of the shaft lining, based on the geological reports, is appropriate under swelling behaviour, and evaluate the resultant long-term stability. The calculated hoop thrust and bending moment for several loading cases were within the capacity of the SFRC shaft lining. The numerical analysis demonstrated that the proposed lining installation time could be reduced, despite consideration of the long-term TDD behaviour.

Keywords: shaft lining; steel fibre reinforced concrete; time-dependent deformation; finite element method

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1. Introduction

Underground spaces have been developed to accommodate various types of infrastructure in congested urban areas. Underground structures are significantly different from superstructures because they are constantly subjected to various vertical/horizontal loading from surrounding ground, depending on geotechnical factors such as density, porosity, permeability, elastic modulus, Poisson's ratio, rock strength, joint sets, depth, and groundwater [1–3]. In addition, accidental events, such as earthquakes, can cause structural problems to underground structures [4–6].

Vertical shafts are essential in order to access the tunnel level necessary for construction, ventilation, and maintenance purposes from the ground level. In general, shaft structures have been constructed in a circular shape to sustain the lateral pressure using the arching effect [7–9]. Generally, these shaft linings are predominantly loaded in compression with low flexural loading due to their circular shape. Therefore, in these cases, plain concrete linings are structurally adequate; however, most underground structures are designed with steel reinforcements to withstand the high bending moment from the varied lateral loads in different directions. Reinforced concrete (RC) has many advantages in terms of strength, durability, fire, and weather resistance, that make it ideal for usage