Construction and Building Materials 109 (2016) 25–33

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental study on transfer length of an eco-friendly prestressed concrete sleeper

Taehoon Koh [a], Younghoon Bae [b], Moochul Shin [c,*], Seonkeun Hwang [a]

[a] New Transportation Systems Research Center, Korea Railroad Research Institute, Gyeonggi 437-757, South Korea
[b] High-speed Railroad Systems Research Center, Korea Railroad Research Institute, Gyeonggi 437-757, South Korea
[c] Department of Civil and Environmental Engineering, Western New England University, Springfield, MA 01119, USA

HIGHLIGHTS

- An eco-friendly PC sleeper was developed by using GGBF slag and EAF oxidizing slag.
- CO_2 emissions and the usage of natural were reduced.
- The transfer lengths in the eco-friendly concrete sleeper were measured.
- The transfer lengths of the eco-friendly concrete sleeper were significantly improved.
- The long-term effects of the eco-friendly concrete were relatively insignificant.

ARTICLE INFO

Article history:
Received 14 July 2015
Received in revised form 19 January 2016
Accepted 21 January 2016
Available online 2 February 2016

Keywords:
Transfer length
Eco-friendly prestressed concrete sleeper
Ground granulated blast furnace (GGBF) slag
Electric arc furnace (EAF) oxidizing slag
Railway track structure

ABSTRACT

This study focuses on investigating transfer length in a newly developed eco-friendly concrete prestressed concrete sleeper. A next generation prestressed concrete sleeper was developed at the Korea Rail Research Institute (KRRI) in order to improve structural performances of the current prestressed concrete sleepers while addressing some environmental issues such as CO_2 emissions and a lack of natural resources. The authors used ground granulated blast furnace (GGBF) slag and electric arc furnace (EAF) oxidizing slag to reduce the amount of Portland cement (III) and natural sand. To ensure the safety and structural integrity of the newly developed sleeper prior to a mass production and installation in the field, the structural performances of this newly developed eco-friendly concrete sleeper ought to be studied. One of important structural performances of prestressed concrete members which should be measured is transfer length. Unlike other civil engineering fields, no design guidelines for transfer length in prestressed concrete sleepers have been established in the railway industry. For example, the American Concrete Institute Building Code and the American Association of State Highway and Transportation Officials Bridge Design Specifications specify the required transfer length in prestressed concrete beams or girders depending on the size of prestressing wires or strands. Therefore, this study examines transfer length in the newly developed eco-friendly concrete sleeper and compares that with the transfer length in traditional prestressed concrete sleepers. Four sleepers are manufactured for each concrete, and the transfer length in each sleeper is monitored at the day of prestress release, and 7, 28 and 90 days. As monitoring the behavior of the sleepers over 90 days, the long-term effect on the transfer length is also investigated. The study demonstrates that the transfer length in the eco-friendly concrete sleepers is not only shorter than that of the traditional prestressed concrete sleepers, but also found to be more desirable since the prestress is fully developed prior to the railseat area.

1. Introduction

Prestressed concrete has been widely adopted in many civil engineering structures such as bridges, dams, high pressure reactor vessels and so on over last decades [1–4], since prestress can delay early crack development due to the disadvantage of concrete in tension. Railway industries around the world including Europe, Asia, Oceania and North America also have adopted prestressed concrete sleepers instead of traditional wooden sleepers as the demand of loadings and interests in high speed trains have increased [5–9]. The advantages of prestressed concrete sleepers

* Corresponding author at: 1215 Wilbraham Rd., Springfield, MA 01119, USA.
E-mail address: moochul.shin@wne.edu (M. Shin).

http://dx.doi.org/10.1016/j.conbuildmat.2016.01.035
0950-0618/

are low maintenance cost, longer service life, higher structural capacity etc. A typical service life of prestressed concrete sleepers is expected to be 50 years or longer [9].

Building and highway industries have been using prestressed concrete beams and girders. One of the important structural properties of prestressed concrete beams or girders is transfer length. Transfer length is defined as the length from one edge of a prestressed beam to the point where the effective prestress is fully transmitted through the body of concrete. According to the American Association of State Highway and Transportation Officials (AASHTO) specifications, the transfer length in a prestressed concrete girder shall not be greater than 60 d_b, where d_b is the diameter of a prestressing wire or strand [10]. Also, the American Concrete Institute (ACI) shear design guideline suggests that the transfer length shalle be equal to 50 d_b [11]. However, no design guidelines on transfer length in prestressed concrete sleepers in the railway industries around the world have been established to the best of the authors' knowledge. The importance of establishing and/or having a recommended design guideline for the transfer length in prestressed concrete sleepers is associated with their structural performances. The railseat area of a prestressed concrete sleeper where the static and dynamic track loadings are predominantly transmitted is located near the each end of a concrete sleeper. When the transfer length in a prestressed concrete sleeper falls into the railseat area of the prestressed concrete sleeper, the shear strength of the prestressed concrete sleeper would be less sufficient than a prestressed concrete sleeper in which the prestress is fully developed prior to the railseat area. Furthermore, positive bending cracks at the railseat area would be prematurely developed when the transfer length extends beyond the railseat area.

Recently, researchers at Kansas State University studied the importance of transfer length in existing prestressed concrete sleepers in the United State of America [12,13]. They examined the transfer length in various types of prestressed concrete sleepers with respect to sizes, and indentation patterns of different prestressing wires and strands. Furthermore, they investigated the long-term effect on the transfer length in the prestressed concrete sleepers. They reported that the transfer length increased up to 76% over time compared with the transfer length measured at the day of prestress release. Many researches showed a similar conclusion that transfer length in prestressed concrete structures/members increases over time due to creep and shrinkage of concrete [14,15].

The Korea Railroad Research Institute (KRRI) recently developed a new generation prestressed concrete sleeper, which can be environmentally friendly, yet still satisfies all the requirements for a prestressed concrete sleeper as one of the main structural components [16]. The main motivations of the new development of the eco-friendly prestressed concrete sleeper were to reduce the amount of Pozzolan type III cement usage, and recycle industrial by-products with the aim of using less natural resources. The authors managed to minimize CO_2 emissions while requiring less amount of natural resources. For developing the eco-friendly prestressed concrete sleepers, they were able to reduce 30% of Portland type III cement by introducing ground granulated blast furnace (GGBF) slag, and replace entire natural fine aggregate (river sand) with electric arc furnace (EAF) oxidizing slag. In the concrete industry specifically in South Korea, one of the environmental issues is a lack of natural sand. Because natural sand is insufficient, the concrete industry in South Korea has been using sea sand as a fine aggregate after washing them, and crushed gravels together with good quality sand (e.g. river sand). The usage of sea sand is a viable solution as long as the sand can be free from salt [17]. However, washing process is associated with environmental and economic issues. Furthermore, using sea sand as a fine aggregate is of concern due to the possibility of residual sodium chloride [18]. Therefore, it is a dire need to find an alternative fine aggregate instead of natural sand. The authors demonstrated that using EAF oxidizing slag, which is the main byproduct of steel manufacturing process, was a suitable alternative to natural sand.

In this study, the transfer length in the newly developed eco-friendly prestressed concrete sleepers is thoroughly investigated and compared with the transfer length in the traditional prestressed concrete sleepers. In addition, the long term effect on the transfer length is studied. The transfer length at the day of prestressing release, 7, 28 and 90 days are monitored. Prior to installing the newly developed eco-friendly concrete sleepers in the field, they ought to be tested to ensure their serviceability and structural performances.

2. Eco-friendly prestressed concrete sleeper

One of important mechanical properties when developing of the eco-friendly concrete sleeper was the compressive strength requirements specified in the Korea Railway Standard [19]. It specifies that the initial compressive strength of concrete at the day of prestress release shall not be less than 35 MPa, which is 70% of the minimum required compressive strength of concrete at 28 days. 50 MPa is the minimum required compressive strength according to the Korea Railway Standard. Two industrial slags were used to develop the eco-friendly concrete pursuant to the national standard requirements of concrete for prestressed concrete sleepers (PSCSs). Furthermore, the standard specifies that water to cement ratio (W/C) shall not be greater than 0.35. Due to its low water cement ratio, a polycarbonic acid-based water reducer was added into concrete mixtures for better workability and slump requirement.

As an alternative/supplementary binding material to Portland type III cement, ground granulated blast furnace (GGBF) slag was introduced. 30% of Portland type III cement was replaced by GGBF slag. CaO and SiO_2 are the first two highest compositions in Portland type III cement, and they are also the first two highest compositions in GGBF slag. The previous research found that the alkali-aggregate reactivity issue and the durability of concrete were even improved when GGBF slag was used together with the cement as a binder [20].

Another industrial by-product used for the developed eco-friendly concrete was electric arc furnace (EAF) oxidizing slag. According to the KS F 4571 Standard by the Korean Agency for Technology and Standards, EAF oxidizing slag is known as a proper alternative material to natural sand [21]. Therefore, instead of using natural sand, the recycled EAF oxidizing slag was used to produce the eco-friendly PSCSs. Finally, a compressive strength test was performed with 100 mm $\times$ 200 mm eco-friendly concrete cylinders. The compressive strengths showed satisfactory results. The strength of the tested eco-friendly concrete cylinders was found to be 73 MPa, which was higher than that of traditional concrete cylinders (51 MPa) at 28 days. Furthermore, the initial strength of the eco-friendly concrete cylinders was superior to the initial strength of the traditional concrete cylinders. It was critical that the initial strength of the newly developed eco-friendly concrete be mature enough and higher than the traditional concrete, since the prestressing wires are normally released within 24 h after pouring the concrete. The maturer concrete becomes, the better structural performances would be. The more details regarding the mechanical properties and performances of the eco-friendly concrete can be found in the previous study [16].

3. 95% average maximum strain method for measuring transfer length

In order for effective prestress of prestressing wires or strands to be fully transferred to a concrete body, a certain length is