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Fracture mechanics analysis of pre-stressed concrete sleepers via investigating crack initiation length

F. Rezaie *, S.M. Farnam

Department of Civil Engineering, Bu-Ali Sina University, Hamedan, Iran

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ABSTRACT

This paper presents an investigation on pre-stressed concrete sleepers based on the principles of fracture mechanics in concrete material. To evaluate fracture mechanics parameters pre-stressed concrete sleepers with different initiation crack length varying between 0 mm and 45 mm increasing by 5 mm steps are used. A three-point bending loading condition is considered. Finite element software is employed to model the sleepers and to calculate the parameters of fracture mechanics such as K_{Ic} and crack growth. Finally, in this study for validation, load–displacement diagram of 5 experimental samples is compared with numerical model of finite elements for validation of model. The paper shows that an expansion in crack instability follows from increasing crack-to-depth ratio, initial toughness, the crack stability and crack unstable toughness, the crack instability expansion begins. The paper also shows a good agreement between the numerical and experimental results via comparing the results of the 5 samples with the numerical model.

1. Introduction

1.1. Pre-stressed concrete sleeper

Railway sleepers are among the most important elements of any railway track system. In a railway structure, sleepers play a major role by conveying train axle loads to the underlying ballast supporting system. Simple concrete sleepers were built for the first time used for the path between Nuremberg and Bamberg in Germany in 1906 [1]. However, concrete sleepers do not fully satisfy the needs of the industry. Low quality of concretes which resulted in low strength together with general lack of tensile strength have resulted in the introduction of high strength and pre-stressed concretes since 1943 [2]. These types of concretes have gained significant popularity in the world and by extension in Iran. In the railway network of Iran, mono block pre-stressed concrete sleepers B70 are more common mainly because of their high strength and other benefits. Mechanical studies on concrete sleepers have been done in 1960s. Gustavsson has done researches on the static and dynamic analysis of concrete sleeper and put sleeper under the loads of rail and ballast in the finite element method [3]. Antony and Wolanski have studied the ductile behavior of pre-stressed and reinforcement concrete beams using ANSYS software [4]. They model four point bending beams and show the growth of crack from initial crack until failure. Remennikov and Kaewuruen have studied the static behavior of pre-stressed concrete sleepers considering non-linear characteristics of the materials using an experimental method [5]. Remennikov and Kaewuruen a have also done numerical and experimental studies of the pre-stressed concrete sleepers under static and impact loads, using finite element method [6]. Rezaie et al.

* Corresponding author.
E-mail address: frezaie@basu.ac.ir (F. Rezaie).

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investigated longitudinal crack control of pre-stressed concrete sleepers. The effects of extra pressure in rawlplug positions were simulated by applying cylindrical pressure inside the rawlplug holes using experimental and numerical analysis [7].

1.2. Fracture mechanics of concrete

Since the birth of the science of fracture mechanics in the early twentieth century, in one hand due to excessive use of concrete materials and on the other hand quasi-brittle behavior in the concrete, a large number of numerical and theoretical studies are done on the properties of the fracture of a concrete elements, given the different conditions of the elements or by taking various sizes [8–10]. Concrete has a high compressive strength, conversely it doesn't have tension strength. It has been talked about increasing the tension strength of concrete for a long time, in order to use the positive characteristic of the concrete, i.e. its compressive strength, to find a prefect element for different loadings. The idea of reinforcement and pre-stressing produces a compound in the concrete that has been proven by different studies to be effectively improving the loading capacity and fracture mechanics characteristics of the material. The existence of rebar increases the tensile strength of the concrete while pre-stressing prevents crack initiation and growth. The experimental investigation was conducted on a series of simply supported concrete beams with an aim to determine the fracture energy of the composite beam and apply the concept of fracture mechanics to predict flexural strength Azad et al. [11]. Royse et al. used a method to study the fracture in lightly reinforced concrete beams and indicated that there was a direct relationship between load capacity and rebar ratio in the section [12]. In 2007, the problem of the assessment of minimum reinforcement in the bridged crack model of concrete members has been examined both theoretically and experimentally by Forveret et al. [13]. Shauwyet et al. in 2011 used acoustic emission technique to estimate the parameters of fracture mechanics of normal concrete [14]. Studies have been done in the field of analysis of reinforced concrete fracture mechanics in recent years but there were few in the case of analysis of fracture mechanics on pre-stressed concrete [7]. Therefore, in this study numerical analysis of fracture mechanics of a real-size element is addressed. Main fracture parameters of a notched pre-stressed concrete sleeper such as force-displacement diagram, crack growth and K_{Ic} are determined. In this paper for validation, Load–displacement diagram of 5 experimental samples is compared with numerical model of finite elements for validation of model.

2. Numerical model of pre-stressed concrete sleeper

For numerical and analytical modeling, the software Abaqus/Cae 6.12–1 is used. The model's geometry tried to be as real as possible with minimal inaccuracy. The dimensions are introduced into the model considering the real specimens manufactured in the factories using the regulated tolerances. Fig. 1 depicts the actual geometry of a pre-stressed concrete sleeper.

2.1. Properties of materials

2.1.1. Compressive strength

Concrete is the main component of pre-stressed concrete sleeper that must have a 7-day strength of 44 MPa and minimum 28-day should be equivalent to 59 MPa on 150 mm × 150 mm cubic samples.

2.1.2. Stress–strain diagram of high strength concrete in compression

Concrete's stress–strain diagram is shown in Fig. 2 after concrete specimen reaches to the maximum compressive strength f_c', concrete can be more displacement under lower loads, without being damaged. This status provides a ductile behavior for concrete in the area of maximum loads and close to ultimate damage.

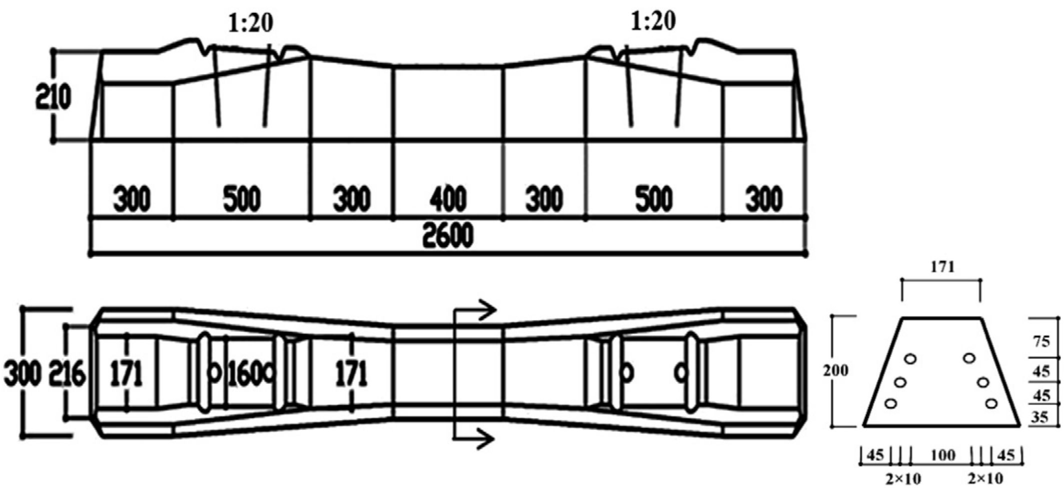

Fig. 1. Geometrical sizes of pre-stressed concrete sleeper B70 (mm) [5].