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High performance concrete requirements for prefabricated high speed railway sleepers

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HIGHLIGHTS

- Prestressed concrete sleeper production uses long-line and carousel methods.
- Carousel method offers a faster rate of sleeper production.
- Prevention of aggregate segregation is strictly necessary.
- Minimum required early concrete strength class at prestress transfer is C40.
- Curing conditions must prevent delayed ettringite formation.

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ABSTRACT

Modern high-speed railway tracks require the use of prefabricated high performance concrete sleepers. Compared to wood sleepers, high performance concrete sleepers with their higher density and weight, provide the required stability to railway tracks for high-speed travel. Higher durability of concrete compared to wood also provides an important basis for the preference of concrete as the construction material for railway track sleepers. This paper, through a case study of sleeper production for a high-speed railway project, presents the strength and performance requirements and addresses unique production aspects of prestressed concrete sleepers designed with high strength concrete produced by the carousel method. This paper also highlights the importance of concrete tensile strength in sleeper design and prevention of aggregate segregation during sleeper production and the important provisions for the attainment of early concrete strength within carefully monitored curing conditions to prevent delayed ettringite formation.

1. Introduction

Ballasted railway tracks currently provide an economical solution to many railway transportation needs today. Fig. 1 shows a common cross-section of a single ballasted track on a fill. In the event when the ballasted track is within a cut, the sub-ballast layer directly bears on the natural ground.

Ballasted railway superstructures consist of rails, attachment pieces that connect the rails to sleepers, elastomeric bearing pads underneath the rails, sleepers embedded in the ballast layer, ballast layer supporting and laterally confining the sleepers and the sub-ballast layer under the ballast layer. The subgrade formed by the fill and the natural ground constitute the substructure. The ballast and the sub-ballast layers are composed of granular materials that reduce the bearing pressures exerted by the sleeper to levels allowed on the subgrade. The sub-ballast has fundamental duties of providing drainage and filtering for the ballast layer above and frost protection for the subgrade below [1].

Fig. 2 shows a sleeper vertically acted by train wheels and the bearing stress distribution under the sleeper. The static axle load of a high-speed train would be in the range of 170–190 kN depending on the tractive capabilities of the axle [2]. The dynamic axle loads would be dependent on the train speed, axle suspension system, wheel diameter and the track conditions. There are many theoretical and empirical approaches to estimate the dynamic load values of static axle loads. These estimates yield dynamic load values for a train speed of 250 km/hour up to 2.5 times the static axle load values depending on the track and axle conditions [3,4]. The top part of the figure shows the sleeper free of bending deformations, followed by the deformed shape of the sleeper and the resulting bearing stresses underneath the sleeper. The supporting stresses due to ballast reaction underneath the sleeper develop

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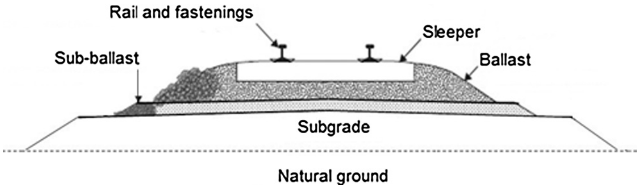

Fig. 1. Cross-section of a single ballasted track on a fill.

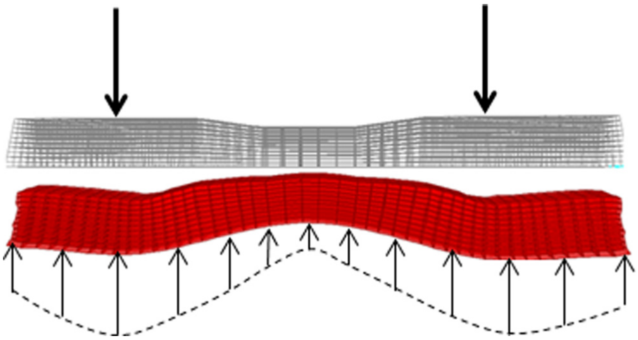

Fig. 2. Development of variable bearing pressure under a sleeper acted on by vertical axle loads.

primarily in relation to the relative deformability's of the supporting granular materials and the sleeper.

The curvature of a bent sleeper produces tensile stresses at the bottom surface of the sleeper at the rail seats where the wheel loads are acting and at the top surface of the middle section of the sleeper. Compressive stresses form at the top surface of the sleeper at the rails seats and the bottom surface at the middle section of the sleeper. The sleeper design must provide resistance to the estimated stresses. Concrete lacks the sufficient tensile strength to resist the estimated stresses thereby necessitating the suppression of tensile stress and crack development in the sleeper by prestressing.

Combined with prestressing, concrete becomes an economic material of choice for sleeper production. The sleeper material requirements change depending on the method of prestress introduction into the sleeper, the sleeper manufacturing methodology and manufacturing space requirements. This paper introduces the design requirements for C60 grade high performance concrete material for prestressed high-speed railway sleepers, designed and produced by a patented end plate bearing prestressing system. This paper also highlights the particular early strength and curing requirements for the selected production method.

2. Historical development of concrete sleepers

The highest railway service speed attained before the introduction of Shinkansen in Japan in 1964 was approximately 160 km/hour. Shinkansen shifted the train speed to levels to 200 km/hour that required a reevaluation of the mechanical characteristics of railway track. The 40 km/hour increase in speed may not appear much unless one acknowledges the 56% higher kinetic energy of a train moving at 200 km/hour with respect to the same train moving at 160 km/hour. High-speed service required continuous rail welding that required increased lateral track stiffness [5]. The connector requirement of the rails with the sleepers required flexibility and sustained connectivity with the sleepers. In order to generate revenue and meet the demand, high-speed service required more time for the track in service and lesser track closure time for track maintenance and repair. Scarcity and maintainability of wood as a sleeper material became a problem in time and many countries needed an alternative design material for economic sleeper production. The new requirements called for an economic sleeper element that allowed reliable connectivity for the rail, longer service life and higher lateral track stiffness.

Following their introduction in 1950′s, many countries developed their unique designs of prefabricated high performance concrete sleepers. For instance in Germany concrete sleepers has unique notations such as B58, B70 and B90 where the letter B denotes the word "beton" and the last two digits signifies their year of introduction [6]. The variable cross sectional design of the sleeper along its longitudinal axis resulted from many studies concerning the soil-structure analysis of the sleeper bearing on the ballast layer [7–9]. These studies indicated variable bending moments along the sleeper, which allowed the development of non-prismatic sleepers with variable cross-sections along its length depending on the required bending rigidity to resist the expected bending moment at a particular location along the sleeper. Fig. 3 shows a 260 cm long B70 type sleeper.

The required number of sleepers along a typical railway route is variable. For instance, the railway route of interest in this paper is a 212-km long double-track high-speed railway located in the Central Anatolia region of Turkey for a design service speed of 250 km/h. This route included prefabricated high performance concrete sleepers spaced at 60 cm and required an approximate count of 710,000 sleepers. Design with variable cross section as opposed to a prismatic sleeper improves the economy of sleeper production. For instance, the B70 type sleeper used in the project shown in Fig. 3 with a length of 2600 mm has a volume of 0.115 m^3 and a mass of 290 kg.

Width and height of the non-prismatic B70 sleeper is variable along its length. The maximum bottom width of this sleeper is 300 mm and its minimum bottom width is 220 mm. The maximum sleeper height is 210 mm and the minimum sleeper height is 175 mm. The prismatic volume of this sleeper with the given maximum dimensions is 0.136 m^3. The non-prismatic design provides a 15% saving in concrete volume per sleeper, which means approximately 0.2 m^3 of concrete savings for every count-9 sleepers. For estimated count 710,000 sleepers that furnish the 212-km long double-track route, concrete material saving by volume sums up to 15,000 m^3.

3. Prestressing requirements and production methods for sleepers

The second design aspect of a sleeper is its design with respect to expected stresses in service and in extreme loading conditions. Occurrence of tensile stresses in structural concrete elements

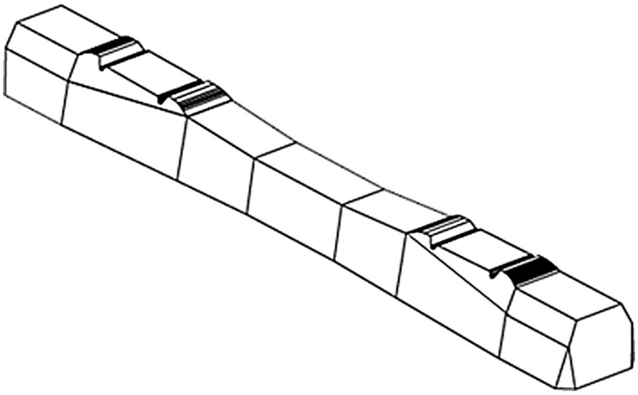

Fig. 3. Perspective view of a B70 type sleeper.