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A DISCUSSION FOR THE REDUCTION IN THE LENGTH OF A PRESTRESSED CONCRETE RAILWAY TIE IN TIME

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Abstract

Increasing train speeds, contemporary requirements for reduced track maintenance costs and extended track service lives required the development and use of reinforced concrete and prestressed concrete ties. Railway engineers began to use concrete for their bi-block and monoblock railway ties heavily, following the development of an understanding for design and performance of concrete structures, production of high strength steel wires and preferable economy of prefabricated mass production for reinforced and prestressed concrete structural elements following the first half of 20th Century. Structural elements of a railway track such as reinforced or prestressed concrete ties have strict production tolerances that are not common for ordinary structural elements. Production of concrete railway ties takes place under strict dimensional control that ensures a nominal design gauge width for the railway track. Design specifications for prestressed monoblock ties frequently specify the gauge width and the shoulder width to be within 1 mm of the design width. However, prestressed concrete ties experience shortenings in length due to transfer of the prestressing force known as instant elastic shortening and shortenings due to concrete shrinkage and concrete creep in time that also relate to ambient relavite humidity.
The author conducted numerous studies on the matter, showed by calculation, and observed experimentally that if unaccounted for, such shortenings can surpass the allowed tolerances in time and result in the rejection of the produced tie for use in the railway track. This paper refers to previous studies by the author that brought international attention on the issue and presents a thorough and a practical evaluation of time related changes in tie lengths for a particular design for prestressed concrete monoblock ties under varying ambient humidity conditions.

Keywords: prestressing, concrete railway ties, shrinkage, creep, elastic shortening

1 Introduction

Railway ties align and secure rails at a fixed distance apart and transfer the forces that are imposed onto the rails to the underlying supportive materials. They are exposed to cyclic and dynamic train loads under the effects of ever-present environmental conditions. Ties of a high-speed railway line must be designed and produced to levels of dimensional precision higher than typical structural concrete elements such as beams, slabs and columns. Attainment of this precision provides for the economic, safe and reliable operation of contemporary railway services.
Train speed is heavily dependent on the railway track qualities and the loads are generated by the interactions of the wheels with the railhead. The gauge length tolerances for high-speed railways built according to the international standards can be specified to as low as

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+2 mm and -1 mm (1). However, due to gauge length variations, the interactions can take place between the flange and the inner side of the railhead as well, thereby increasing the number of possible points of contact between the wheel and the rail, provoking lateral and frictional forces, vibrations, disturbing ride comfort and ride stability, and inducing wheel and rail abrasions [2].

Contemporary freight and passenger railways today, frequently employ prestressed concrete monoblock railway ties. Design and production of these prefabricated ties involve the use of high-performance concrete and high strength steel wires and other steel attachments. Prestressing forces on these ties can reach and exceed 350 kN and the characteristic cylinder strength of the concrete used to produce the ties are typically above 50 MPa that may reach up to 70 MPa, depending on the prefabricated production method used to produce the ties. However, presence of the prestressing forces, time dependent qualities of concrete and the prestressing steel generates time dependent deformations on the railway ties that may exceed the specified dimensional tolerances of the railway ties. The initial elastic shortening of the ties following the release of the prestressing forces into the tie, followed by the shrinkage and creep of concrete causes the produced length of the tie to shorten in time. The relaxation of the prestressing steel along with the prestressing losses due to shrinkage and creep of concrete also reduce the effective prestressing force in the tie, which one must consider in the design of the ties. The relative humidity of the region within which the railway ties will serve, has a high influence on the shrinkage and creep values of concrete, which in return effects the initial prestressing force that must be transferred on to the tie to preserve a final and an effective value of prestressing force in the tie required for the mechanical needs of the tie after the losses. The effect of relative humidity on the dimensional changes of the ties also indicates the need to consider climate change during the expected service life of the railway tie.

This paper presents a summary of two previously presented papers that introduced the time dependent design dimensional variations of prestressed monoblock concrete railway ties to the international academic and engineering community of railway engineering. The sections that follow will show the measured contractions in the shoulder width of a railway tie in time and will also present the contraction estimates obtained through the empirical procedure presented in the relevant reference [3].

2 Considerations for shoulder width variations of a tie in time

Design and construction of the 212 km long Ankara - Polatlı– Konya high speed railway as a part of the project to connect the cities of Ankara – Konya was undertaken by a prominent national firm early in 2008 with national engineering and material resources. The district of Polatlı lies roughly 50 km to the west of Ankara, the connection for which to Ankara was constructed earlier. The two cities located within the central part of the Turkish Republic; known as the Central Anatolia Region, is going through a climate change. Figure 1 shows that the arid conditions of the region has shifted to values as low as 50 % within 36 years [4]. This is an on-going process and effects of climate change is visible in the region. The author, who took part early in the structural designs for the project, considered the projected effects of climate change on the dimensional tolerances of precision elements of the railway track and especially the prefabricated and prestressed railway ties.

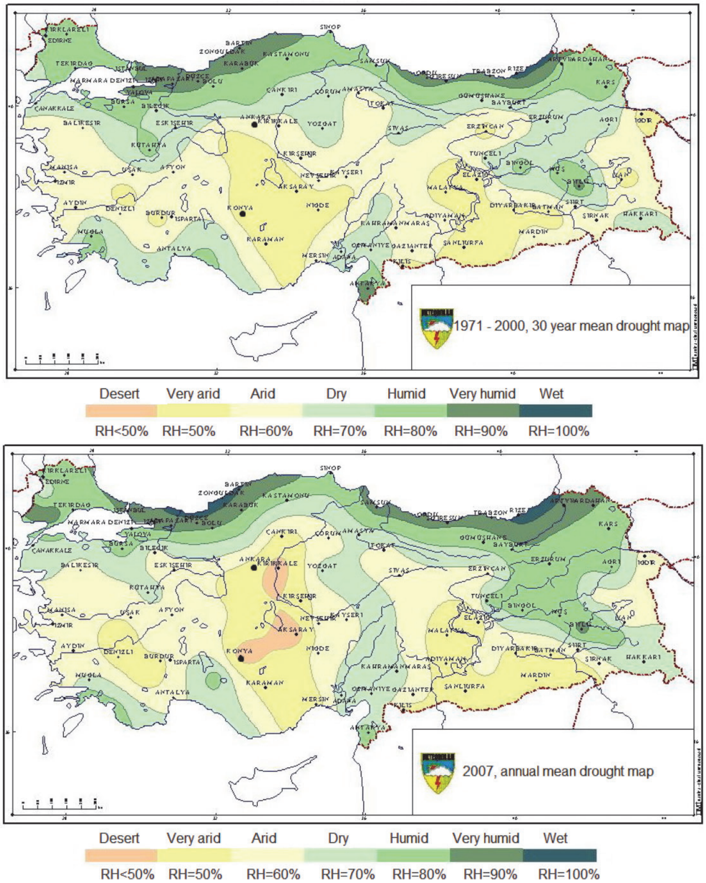


Figure 1 Variation of relative humidity in Turkey. [4]

The project involved the use of B70 type sleepers along the 212 km route between the district of Polatlı and Konya. The service speed along the route is 250 km/h and the design static axle forces for passenger trains and freight trains are 170 kN and 225 kN respectively. Design prestressing force on the ties is 350 kN, which was determined according to the design moment requirements and the projected prestressing losses within the arid climate of Central Anatolia. The ties had design tolerance requirements for their shoulder width of 1813 mm at +2 mm and -1 mm, meaning that the width of measured shoulders should not surpass 1815 mm and should not fall below 1812 mm. The lower value for the negative tolerance was because a reduced shoulder width increased the prospects of flange and railhead abrasion.

Ties produced with C65/80 class concrete had a variable cross section along its 260 cm long length that varied from roughly 530 cm^2 to 330 cm^2 under the rail seat to the centre of the tie. Prestressed design of such an element naturally involved mechanical as well as dimensional considerations for its design. Based on an estimated elastic modulus for the concrete in relation to not only the concrete strength but also the type and mechanical aspects of the aggregate used in the mix design, a preliminary evaluation for the projected longitudinal contractions were conducted based on the detailed empirical procedures presented in the relevant code [3]. Following the transfer of the initial prestressing force into the ties, the contractions were estimated for one year under varying relative humidity conditions as presented in Figure 2.

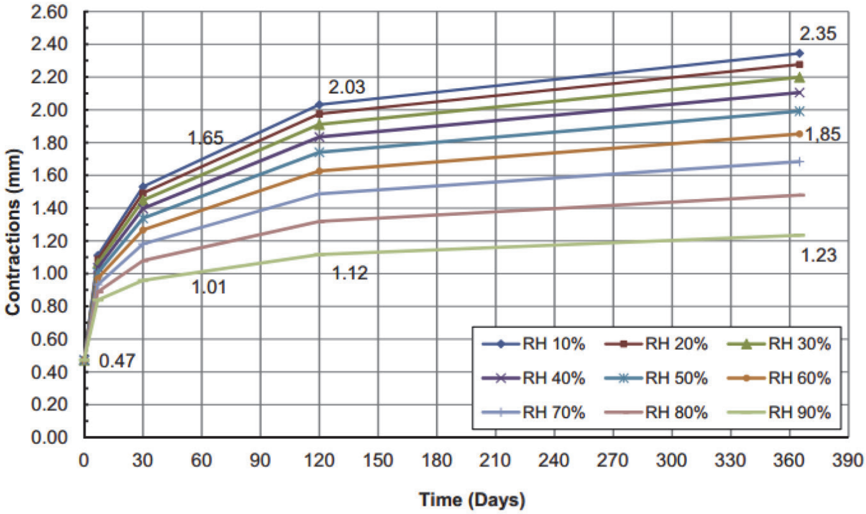


Figure 2 Estimated sleeper shoulder width contractions in one year [5, 6]

These estimates indicated that for all the relative humidity conditions considered that ranged from very wet ambient humidity conditions of RH 90 % to almost completely dry conditions of RH 10 %, within 2 months of their production, all the ties could contract more than 1 mm due to elastic shortening, shrinkage and creep and hence surpass the allowed dimensional tolerances for the sleepers. The estimates indicated that approximately 70 % and 90 % of the total shortening values expected to occur at the end of the 40-year service design lives of the ties occurred within 2 months and 1 year of the transfer of prestressing forces into the ties. These estimates naturally raise a concern with regards to the design dimensions of the moulds.

3 Shoulder width measurements of a tie in time

Following the estimates for the time dependent contractions expected along the ties, an experimental study was initiated to observe the variations in shoulder widths of count-32 ties during a two-month period in 2009. Figure 3 shows the measurement of tie shoulder width with a gauge that has a measuring precision of 0.01 mm. Ties were stored under ambient relative humidity conditions that varied between 60 % to 80 % within open air.

Figure 3 Measuring the shoulder width with a gauge within 0.01 mm. [6]

The nominal shoulder width for the test moulds was set at 1815 mm, which was produced to a tolerance of 0.5 mm. The mean of the shoulder widths as measured from the moulds was 1815.25 mm. Following the transfer of 350 kN ± 5 kN prestressing force into the ties, an initial shortening of approximately 0.5 mm was observed. The very low tensile stress relaxation class prestressing wires selected for this particular application, naturally lost about 3 to 5 % of initial prestressing due to this elastic shortening. Measurement in 1-month and 2-months indicated further shortenings of 0.3 mm and 0.2 mm with respect to the mean values respectively. In two-months, the measurements indicated a total shortening of 1 mm with respect to the shoulder width of the ties as measured within the moulds. Figure 4 shows the shoulder width variations in time for the 32-sleepers. Compared to the estimates presented in Figure 3, the estimates for the 60 % to 80 % relative humidity ranges were about 0.4 mm greater than what was measured at the mean level.

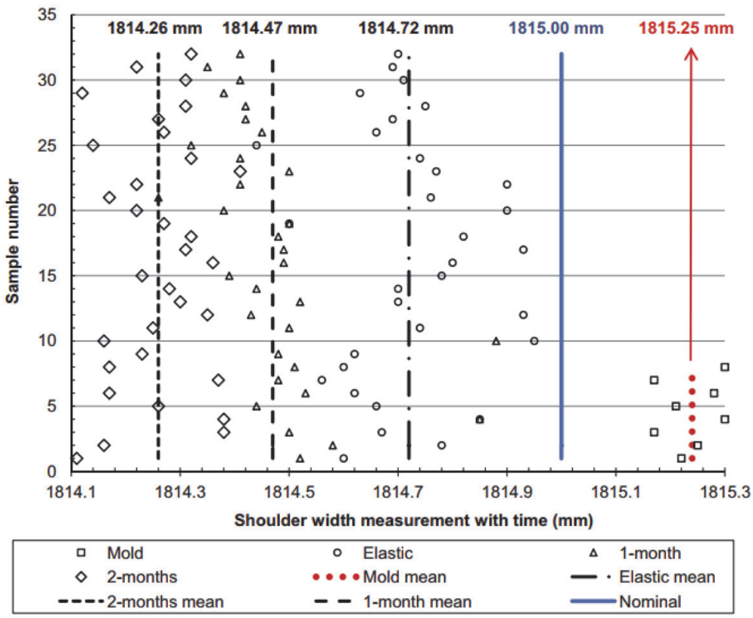
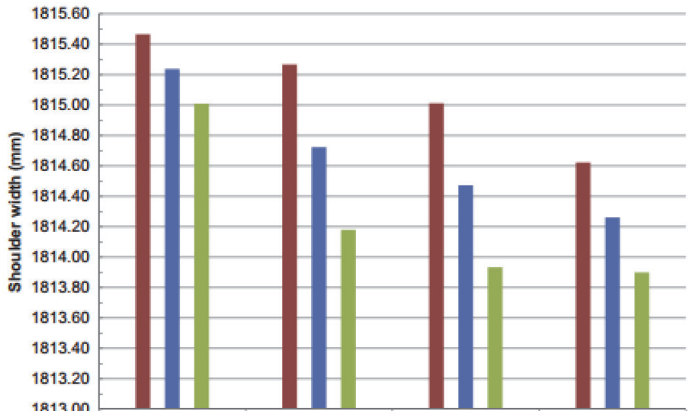


Figure 4 Shoulder width measurements for two months. [6]

However, a nominal design dimension needs to be determined based on a statistical evaluation. Composed fully of geological materials, variations in material properties reflect on to measure properties and the measured shoulder widths of the prestressed railway concrete tie vary as seen in Figure 5. The engineering importance of this variation relates to engineering needs and design tolerances. To this end, Figure 5 presents the likely shoulder width values within a 95 % confidence interval based on the estimated mean shoulder with value and its standard deviation. Such being the case, the expected shoulder width contractions vary between 0.85 mm and 1.2 mm with an average of 1 mm. An engineering design should be able to present the nominal mechanical and geometric qualities of its element to an agreed upon confidence level deemed necessary with respect to the design requirements for functionality and safety.

Finally, the importance of the concrete mix design and the geological quality and grade of aggregate used in the design must not be overlooked [7, 8]. The elastic modulus of concrete, which is a not a simple parameter to measure directly, relates to the aggregate within the strength grades of concrete used to produce the ties today. Despite the preference for volcanic aggregates such as basalt and granite in the production of the ties, geological availabilities and production economy can force designers to use select grades of sedimentary rocks such as limestone. Nevertheless, one must carefully consider the elastic modulus of a concrete along with its compressive strength. The elastic modulus values of two concrete mix designs using different aggregates but yield the same compressive strength can differ.



	Mold	Instant	1-month	2-months
Mean+4,47std	1815.47	1815.27	1815.01	1814.62
Mean	1815.24	1814.72	1814.47	1814.26
Mean-4,47std	1815.01	1814.18	1813.93	1813.90

Figure 5 Statistical variation of shoulder width measurements in two months. [6]

4 Conclusions

Railway engineering is a unique human endeavour that helped to initiate the development of certain sciences such as mechanics of solids and thermodynamics along with soil-structure interaction analysis, geotechnical engineering and metallurgy. Early railway engineers had to pursue into unknown scientific fields and produce solutions to human needs not yet clearly defined and supported by science. Therefore, the historic words, which suggests that "the history of railway engineering is written in blood" certainly has a truth to it such that many failures in the early days of railway engineering occurred due to oversights or lack of knowledge occurred during the development of railways. However, this is not the case today since we have stronger accumulation of knowledge to understand and better tools to analyse and assess railway behavior.
Railway engineering produced the ability to move larger number of people and larger amount of goods to longer distances in reliably defined shorter time intervals with respect to other means of land transportation and therefore magnified the power of human effort to unprecedented scales. This power was at the heart of the first industrial revolution. Today, contemporary railway engineering continues to preserve and extend the power of human effort with higher speeds and higher tonnages and higher service frequencies. Along this increasing demand in railway services, railway engineers need to respond with better materials and better techniques to provide for the needs of this guided means of land transportation.
Structural concrete found its place in almost every civil engineering effort since the end of the Second World War. Today, high performance concrete and other composite materials find their place for use in railway engineering. This paper evaluated a contemporary railway tie and considered the need to evaluate the effect of climate on its engineering properties. Nominal dimensions are an important aspect of engineering structures the precision of which

relates to the needs for functionality. Railway engineering structures such a railway ties, are important structural elements that require a higher order of precision compared to typical structural elements we see in reinforced concrete buildings and bridges. Prefabrication technology today, produces an array of structural elements designed for automated means of production and installation such as railway ties and tunnels segments. The dimensional precision of such elements is frequently specified within one millimetre to provide a proper fit among the structural components among which the concrete element is a part of. One does not encounter such a refined tolerance need for ordinary concrete structural elements, but contemporary civil engineering profession needs to respond to its new design requirements. Concrete structures and especially prestressed concrete structures undergo dimensional changes due to elastic shortening, creep, and shrinkage, which relate to cross section of the structural element, structural stiffness, forces imposed onto the element and the relative humidity of the climate within which the designed structure will serve. Effects of climate and most importantly the effects of climate change must not be ignored in design of contemporary civil engineering structures.

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