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LONG-TERM BEHAVIOURS OF RAILWAY PRESTRESSED CONCRETE SLEEPERS DUE TO SHORTENING PARAMETERS

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ABSTRACT

Long-term behaviours of railway prestressed concrete sleepers are critical parameters in determining durability and performance functions required for predictive maintenance management. The time-dependent behaviours vary largely due to their creep, shrinkage and elastic shortening responses. Many investigators in the past have proposed various material models to predict shortening effects but those were mostly applied to general reinforced concrete members. In contrast, prestressed concrete design has adopted those models for predicting the structural behaviour of prestressed concrete structures such as long span bridges, stadiums, silos and confined nuclear power plants, etc. Such the constitutive models have led to a concern of practitioners whether those existing predictive models could be realistically applied to prestressed concrete. Due to high initial elastic shortening in prestressed concrete, the creep and shrinkage effects should be critically re-evaluated in flexural members. This paper presents a comparative investigation using a variety of methods to evaluate shortening effects in railway prestressed concrete sleepers. Three common design codes have been considered, including European Standard EUROCODE2, American Standard ACI and Australian Standard AS3600-2009. The study results show that EUROCODE2 and AS3600 are very coherent and consistent. It also shows that ACI code will need to be revised to take into account various environmental factors. The insight of this study will help rail track engineers to improve predictive maintenance model of railway infrastructure and to minimise time spent on inspection activities, which are critical part of asset operations.

Keywords: railway, prestressed concrete, sleepers, long-term behaviour, shortening effects.

1. INTRODUCTION

Rail transport first appeared in 1820s which was critical to the Industrial Evolution and the development of economies. Nowadays, railway transportation system has become very important for both of passengers and freight transportation. It provides a highly enjoyable ride for passengers or freight. With railway technology developing dramatically, high-speed trains have been designed for long distance transportation. The speed of fastest train, Shanghai Maglev (China), is up to 430km/h. In addition, larger capacity for heavy-haul trains is required in freight transportation.

Therefore, the rail track structure must meet current design requirements for geometry, strength and load capacity to ensure safe and stable trip. Conventional or ballasted track can be divided into superstructure and substructure. The superstructure consists of rails, rail pads, sleepers, fastening system. The substructure includes ballast, sub-ballast and formation. Railway sleepers (or called 'railroad ties' in North America) are the main element of rail track structure. The main functions of railway sleepers are:

1. To support rail and maintain the track gauge.
2. To distribute loads to substructure.

Materials employed in sleepers can be timber, steel, concrete and any other engineered materials. Prestressed concrete sleepers are most commonly used type of sleeper around world (Taherinezhad, J. et al. 2013). Prestressed concrete sleepers have been developing for decades with long life cycle, low maintenance cost and good structural performance in comparison with reinforced concrete sleepers. Prestressed concrete sleepers are expected to withstand high dynamic loads and harsh environments. However, concrete structure, owing to its material property, is deforming with time which is risky from creep and shrinkage. Time-dependent behaviours can result in deformation, crack and loss of prestress to cause potential risks for trains using the sleepers. Therefore, prediction of time-dependent behaviours becomes essential when considering serviceability limit state (Byle, K. 1998, Razak, H. 1986, Taherinezhad, J. et al. 2013). This paper presents design considerations for estimating the long-term behaviour of prestressed concrete sleepers. In addition, three design (Eurocode 2, ACI and AS3600-2009) methods will be used to compare.

2. PRIDICTING TIME-DEPENDENT BEHAVIOURS

2.1. Creep Prediction

The concrete under load that strain increases with time is due to creep. Therefore, creep can be defined as the increase in strain under the sustained stress and it can be several times as large as the initial strain (Bhatt, P. 2011). If the load is removed, the strain decreases immediately due to elastic recovery and a gradual incomplete recovery due to creep. This behaviour is shown in Figure 1. When creep is taken into account, its design effects are always evaluated under quasi-permanent combination of actions irrespective of the design situation considered, i.e. persistent, transient or accidental.

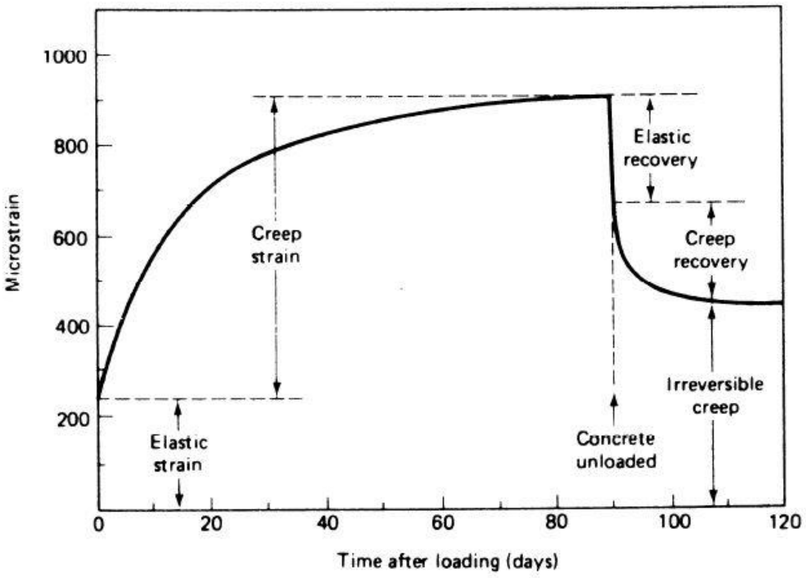

Figure 1: Time dependent creep

2.1.1. Eurocode 2

The total creep strain ε_{cc} (∞, t_0) of concrete due to the constant compressive stress of σ_c applied at the concrete age of t_0 is given by:

$$\varepsilon_{cc}(\infty, t_0) = \varphi(\infty, t_0) \times \frac{\sigma_c}{E_c} \tag{1}$$

Where (∞,0) is the final creep coefficient, which the value of σ_c does not exceed $0.45f_{ck}$ (t_0). E_c is the tangent modulus.

$$\varphi(\infty, t_0) = \varphi_{RH} \times \frac{16.8}{\sqrt{f_{cm}}} \times \frac{1}{(0.1 + t_0^{0.20})} \tag{2}$$

$$\varphi_{RH} = 1 + \frac{1 - 0.01 \times RH}{0.1 + h_0^{0.333}}, \quad f_{cm} \leq 35MPa \tag{3}$$

$$\varphi_{RH} = (1 + \frac{1 - 0.01 \times RH}{0.1 + h_0^{0.333}}\alpha_1)\alpha_2, \quad f_{cm} > 35MPa \tag{4}$$

$$\alpha_1 = (\frac{35}{f_{cm}})^{0.7}, \quad \alpha_1 = (\frac{35}{f_{cm}})^{0.2} \quad f_{cm} = f_{ck} + 8MPa$$

$$t_0 = t_{0,T}(\frac{9}{2 + t_{0,T}^{1.2}} + 1)^{\alpha} \geq 0.5, \tag{5}$$

$$\alpha = \{-1(S), 0(N), 1(R)\}$$

Where: RH = relative humidity in %, h_0 = 2Ac/u mm, Ac = cross sectional area, u = perimeter of the member in contact with the atmosphere, S, R and N refer to different classes of cement.

2.1.2. ACI

According to ACI 209-92, the predicted parameter is creep coefficient $\varphi(t,t_0)$ and the equation is given by:

$$\varphi(t,t_0)=\frac{(t-t_0)^{\psi}}{d+(t-t_0)^{\psi}}\varphi_u \tag{6}$$

where $\varphi(t,t_0)$ is creep coefficient at any time t when a load applied at age t_0.

d (days) and ψ are considered constants for a given member shape and size that define the time-ratio part. ACI-209R-92 recommends an average value of 10 and 0.60 for d and ψ respectively.

φ_u is the ultimate creep coefficient.

For the ultimate coefficient φ_u, the average value is given:

$$\varphi_u = 2.35$$

According to ACI-209R-92, the creep coefficient φ_u needs to be modified by correction factors. Therefore, φ_u should be multiplied by six factors.

$$\varphi_u = 2.35\gamma_c \tag{7}$$

$$\gamma_c = \gamma_{c,t0}\gamma_{c,RH}\gamma_{c,vs}\gamma_{c,s}\gamma_{c,\psi}\gamma_{c,\alpha} \tag{8}$$

Where $\gamma_{c,t0}$ = loading age coefficient

$\gamma_{c,RH}$ = ambient relative humidity coefficient

$\gamma_{c,vs}$ = the volume to surface ratio of the concrete section coefficient

$\gamma_{c,s}$ = slump coefficient

$\gamma_{c,\Psi}$ = fine aggregate coefficient

$\gamma_{c,\alpha}$ = air content coefficient

2.1.3. Australian Standard 3600-2009

The creep coefficient at any time φ_{cc} can be determined by:

$$\varphi_{cc} = k_2k_3k_4k_5\varphi_{cc.b} \tag{9}$$

Where k_2 is the development of creep with time; k_3 is the factor which depends on the age at first loading τ (in days); k_4 is the factor which accounts for the environment; and k_5 is the factor which accounts for the reduced influence of both relative and humidity and specimen size.

2.2. Shrinkage prediction

Bhatt, P (2011) stated that both of creep and shrinkage are influenced by the same parameters. Shrinkage is not an entirely reversible process like creep and it can be also influenced by relative humidity, surface exposed to atmosphere, compressive strength of concrete and types of cement.

2.2.1. Eurocode 2

The total shrinkage strain εcs can be given by:

$$\varepsilon_{cs}=\varepsilon_{ds}+\varepsilon_{as} \tag{10}$$

Where ε_{ds} is drying shrinkage strain; and ε_{as} is autogenous shrinkage strain.

2.2.2. ACI

The shrinkage stain $\varepsilon_{sh}(\mathrm{t},t_c)$ at age of concrete t (days), predicted from the start of drying at $\boldsymbol{t_c}$ can be calculated by:

$$\varepsilon_{sh}(t)=\frac{(t-t_c)^{\alpha}}{f+(t-t_c)^{\alpha}}\varepsilon_{shu} \tag{11}$$

$$\varepsilon_{shu}=780\times 10^{-6}\ mm/mm\ (in/in)$$

Where f (in days) and α are considered constants for a given member shape and size that define the time-ratio factor

ε_{shu} is ultimate shrinkage strain

$(t-t_c)$ is the time between end of curing and any time after curing

2.2.3. Australian Standard 3600-2009

The total shrinkage strain ε_{cs} is shown below:

$$\varepsilon_{cs}=\varepsilon_{cse}+\varepsilon_{csd} \tag{12}$$

Where ε_{cse} is autogenous shrinkage strain; ε_{csd} is drying shrinkage strain.

3. SLEEPER DETAILS

The effects of shortening and approximate deflections for estimating creep, shrinkage strain will be evaluated. The fundamental engineering properties of prestressed concrete sleeper used for calculation are based on previous research by Remennikov et al. The results are generated for comparisons between Eurocode 2 (EC2) and Australian standard 3600-2009 (AS). Figure 2 shows the cross section at rail seat of the prestressed concrete sleepers. The parameters of prestressed concrete sleeper are shown below (Kaewunruen. S et al., 2011):

(1) Sleeper length: 2700mm

(2) Track gauge: 1600mm

(3) Prestressing nominal force: 550kN

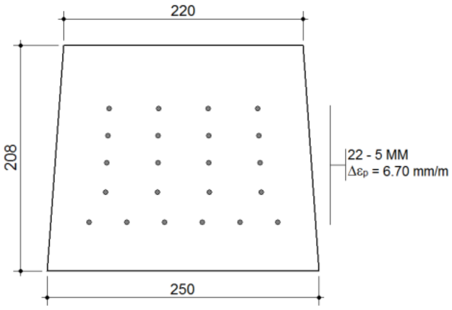

Figure 2: Cross section of railway sleepers

The case is estimated for 18250 days (50 years) in same conditions (uniform dimension of sleepers, 70% relative humidity, steam curing)

4. RESULTS AND DISCUSSIONS

4.1. Creep Shortening

To investigate creep shortening, the 7 cases have been analysed using different characteristic strength (20MPa, 25MPa, 32MPa, 40MPa, 55MPa, 65MPa, 80MPa), which are plotted in Figure 3. The data of creep shortening are calculated by EC2 and AS codes respectively. All the cases are estimated from 1 day up to 18250 days (50 years) in the same conditions (uniform dimension of sleepers, 70% relative humidity, steam curing etc.).

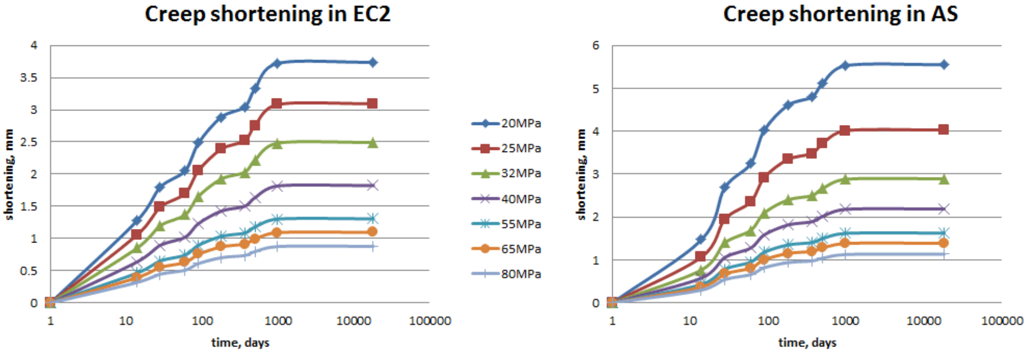

Figure 3: creep shortening

4.2. Shrinkage Shortening

Figure 4 shows 7 cases of different strength of prestressed concrete sleepers on the shrinkage effect. The data of shrinkage shortening are calculated by EC2 and AS3600-2009 codes respectively.

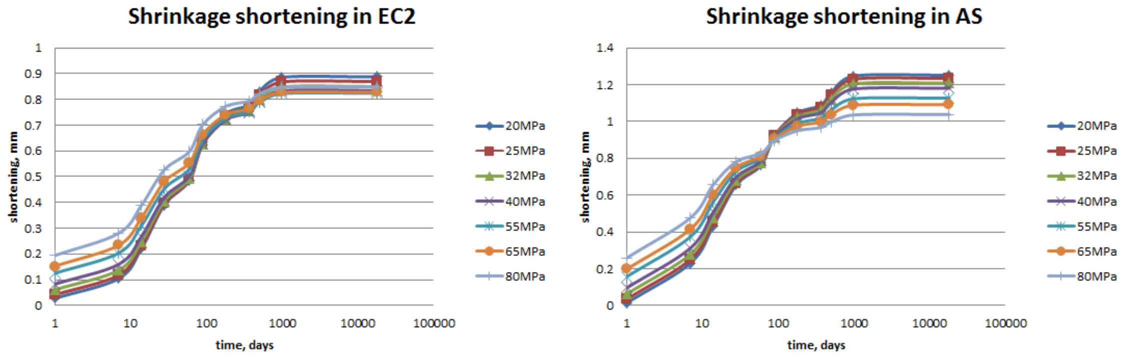

Figure 4: shrinkage shortening

Based on the sensitive analysis, we found that long-term performance in prestressed concrete sleeper depends on various factors. According to obtained data, the shortening depends on strain, which means large strain leads to more shortening in prestressed concrete sleeper. Previous research had stated that the higher strength of concrete has less loss of prestress and concrete strength less than 25MPa was not suitable for use in prestressed concrete sleepers (Li, D et al., 2016). Figure 3 and Figure 4 indicate total long-term shortening (due to creep and shrinkage), which higher strength of concrete has less shortening. However, in initial period, higher strength has more shortening than lower strength concrete due to autogenous shrinkage. The ACI results haven’t shown on this paper because both of creep or shrinkage calculation doesn’t directly relate to concrete strength.

5. CONCLUSIONS

In practice, the use of the railway infrastructure system rapidly increased, which means time-dependent behaviour could have more significant influence for deformation of components. When shortening and deflection occur in prestressed concrete sleepers, the track gauge could change with shortening and deflections. It is hazard that train derails because of track gauge change. Furthermore, there are many other factors to affect prestressed concrete sleepers shortening and deflections like relative humidity, curing conditions, age at first loading, temperature, abrasion etc. In this paper, Eurocode 2 and AS3600-2009 are used in predicting creep and shrinkage shortening and deflection. Comparison between design codes provides the insight into long-term performance of prestressed concrete sleepers. This paper presents shortening and deflections due to creep and shrinkage. It will improve the rail maintenance and inspection criteria in order to establish appropriate sensible remote track condition monitor network in practice.

6. ACKNOWLEDGMENTS

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