Influence of prestress losses on the dynamic over static capacity ratios of railway concrete sleepers

Ngamkhanong, Chayut; Kaewunruen, Sakdirat

DOI:
10.5281/zenodo.1405563

SynerCrete'18 International Conference on Interdisciplinary Approaches
for Cement-based Materials and Structural Concrete
24-26 October 2018, Funchal, Madeira Island, Portugal

INFLUENCE OF PRESTRESS LOSSES ON THE DYNAMIC OVER STATIC CAPACITY RATIOS OF RAILWAY CONCRETE SLEEPERS

Chayut Ngamkhanong [(1),(2)] and Sakdirat Kaewunruen [(1),(2)]

(1) Department of Civil Engineering, School of Engineering, University of Birmingham, Birmingham B152TT, United Kingdom
(2) Birmingham Centre for Railway Research and Education, School of Engineering, University of Birmingham, Birmingham B152TT, United Kingdom

Abstract

Railway sleeper, which is placed underneath the rail, is one of the main components of railway track. Railway sleepers can be made of timber, concrete, composite materials etc. Prestressed concrete sleeper is one of the most popular types which can be seen in railway track all over the world. However, loss of prestress is a significant concern as it can affect strength of member and its serviceability including stresses in concrete, cracking etc. In prestressed concrete applications, the most important variable is the prestressing force. It was observed that the prestressing force can be reduced with time because of several factors such as creep and shrinkage of concrete, steel relaxation, friction loss, anchorage slip etc. RESPONSE2000 was used to evaluate the static and dynamic capacities based on the modified compression field theory. The study results exhibit that the losses of prestress have significant effects on the overall strength of prestressed concrete sleepers. It is recommended to take into account the effect of prestress losses in standard design of prestressed concrete sleepers.

1. Introduction

Railway sleepers are a main part of railway track structures. Railway sleepers embedded in ballasted railway tracks are laid to support the rails. The main functions of sleeper are to redistribute loads from the rails to the underlying ballast bed, to secure rail gauge and to enable safe passages of rolling stocks. It should be noted that railway sleepers are a structural and safety critical component in railway track systems [1-6]. The sleepers can be typically made of timber, concrete, steel, composites etc. Remarkably, railway prestressed concrete sleepers have been used in railway industry for over 50 years [7, 8]. Prestressed concrete sleepers would have an improved structural capacity and/or serviceability as compared to conventional reinforced concrete sleepers. However, they are prone to deterioration issues as cracks may occur and expand during operation. Moreover, losses of prestress are a serious concern since it affects the strength of prestressed concrete member. In fact, the prestressing force in prestressed concrete can be reduced due to the initial losses and long-term losses [9, 10]. Initial prestress losses occur when the prestress is transmitted to the concrete, there is contraction due to prestress. This contraction causes a loss of stretch in the wire. Loss can be expressed as percentage or in terms of stress or in terms of total deformation or in terms of strain. According to the literature [11], it is interesting to note that prestrain in steel has a significant effect on the strength of steel. The strength increases with the increasing of pre-strain in steel but the elongation decreases.

Generally, railway track structures often experience impact loading conditions due to wheel/rail interactions associated with abnormalities [12] in either a wheel or a rail. Wheel/rail irregularities induce high dynamic impact forces along the rails that may greatly exceed the static wheel load. Although, the dynamic behaviour of railway sleepers has been studied [13-17], the considerations of its behaviour when the sleepers under go prestress losses, have not been fully studied. This paper investigates and presents an advanced railway concrete sleeper modelling capable of parametric analysis into the effect of prestress loss on the dynamic behaviors of railway sleepers. This paper considers the wide range of prestress loss in order to cover all the possible behaviours as the railway sleeper may experience higher time dependent losses [18]. The dynamic factors are highlighted. The emphasis of this study has been placed on the impact capacity of the sleepers. The improved understanding in this paper will help update the practical maintenance issues in railway industry. The understanding of the dynamic capacity of railway concrete sleepers will also help improve technology for track condition monitoring [19].

2. Methodology

2.1 Modified compression field theory

The ultimate moment has been used to represent the capacity of prestressed concrete sleepers. In general, concrete sleepers would fail in bending or shear bending mode. The moment capacities are predicted by the adaptation of modified compression field theory using Response-2000 [20]. This software is a nonlinear sectional analysis for the analysis of concrete elements. The theory is capable of predicting the behaviour of reinforced concrete subjected to in-plane shear and normal stresses. The concrete stresses in principal directions along with prestressing steel are considered in only axial direction and uncracked portion will carry on to sustain a load in the analysis [21]. The assumptions of this theory are that the deformation plane section remains plane after loading and there is no transverse clamping stress across the depth of the section. It is also assumed that prestressing wires and concrete are bonded perfectly. The section can be failed in only pure bending or shear-bending modes. The dimension of prestressed concrete sleeper is shown in Figure 1. There are 4 layers with 22 tendons. The ultimate strength of 1860MPa and elastic modulus of 200000MPa are considered. The high strength concrete with the cylinder compressive strength of 55MPa is taken into account.

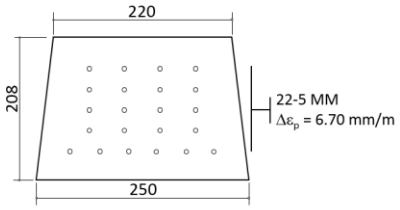


Figure 1: Prestressed concrete sleeper dimension.

2.2 Effect of strain and loading rates

In this study, it is assumed that prestressing wires and concrete are bonded perfectly. It should be noted that the strain rate plays a role in material strengths. The prediction of moment capacity has been carried out using the data obtained from the previous experiments [22, 23]. It should be noted that the average total duration of impact forces is about 4 ms. In this study, the strain rate of concrete used is 2 s^{-1} as recommended by previous studies. It is known that the dynamic ultimate strain of prestressing steel is about 0.02, and the total duration of impact force influencing the steel fibre is roughly from 6 ms. This is because the impact stress wave delays during the stress propagation and will be impeded through concrete [24]. Hence, the strain rates of prestressing wires are estimated to be 6 s^{-1}. The dynamic strength of materials can be obtained as the input for the sectional analysis using Eqs. (1) and (2) as follows.
Concrete:

$$\frac{f'_{c,dyn}}{f'_{c,st}} = 1.49 + 0.268\log_{10}\dot{\varepsilon} + 0.035[\log_{10}\dot{\varepsilon}]^2 \quad (1)$$

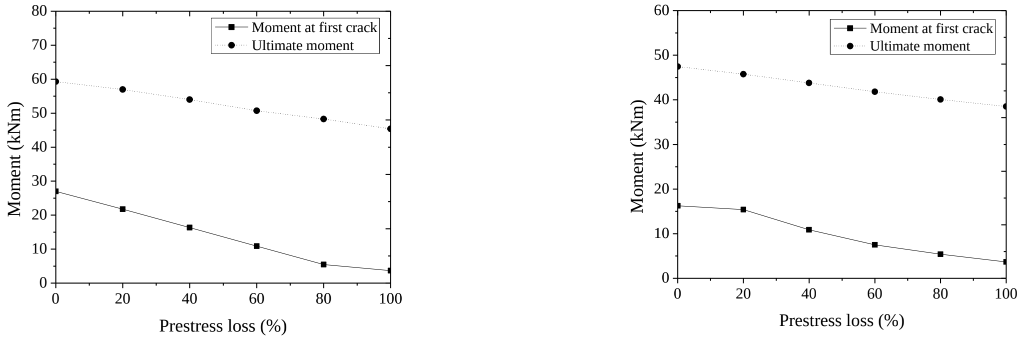
Prestressing wires:

$$\frac{f_{y,dyn}}{f_{y,st}} = 10^{0.38\log_{10}\dot{\varepsilon}^{-0.258}} + 0.993 \quad (2)$$

Where $f_{y,dyn}$ is the dynamic upper yield point stress, $f'_{c,st}$ is the static upper yield point stress of prestressing wires (about 0.84 times proof stress), and $\dot{\varepsilon}$ is the strain rate in tendon.

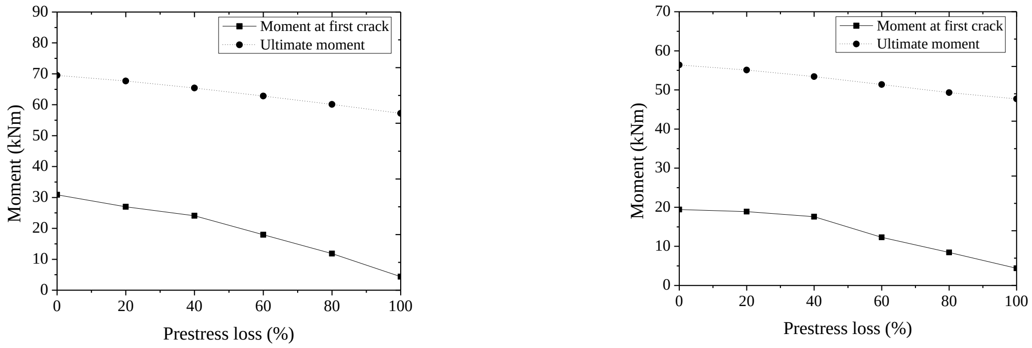
3. Results and Discussions

Figure 2 show the static moment capacities of prestress concrete sleepers with the consideration of prestress loss. It is clearly seen that prestress losses play a significant effect on prestressed concrete strength especially at first crack. The moment at first crack decreases with the increasing of prestress loss. They are observed as linear trends in both positive and negative directions. The trends of results are quiet similar to the strength of steel [11] with the consideration of pre-strain as it highly effects the moment at first crack rather than ultimate strength. It is also interesting to note that the difference between moment at first crack and ultimate strength of prestressed concrete sleepers slightly increase with the increase percentage of prestress losses as prestress loss has a little effect in ultimate moment capacity. Dynamic capacities of prestressed concrete sleepers are shown in Figure 3.



a) Positive moment
b) Negative moment

Figure 2: Static capacities of prestressed concrete sleepers at various prestress losses.



a) Positive moment
b) Negative moment

Figure 3: Dynamic capacities of prestressed concrete sleepers at various prestress losses.

Figure 4 shows dynamic over static ratios at various prestress losses. It can be seen that the dynamic factors of both positive and negative ultimate moment are in the range of 1.15-1.25. As for the dynamic factor of moment of first crack, it is observed that the dynamic factors of positive and negative moments are in the range of 1.15-2.17 and 1.19-2.26. However, it should be noted that when the huge losses of prestress are applied, the moment at first crack cannot be predicted accurately. This is because the moments observed are at very low range and software cannot provide the appropriate step of results.

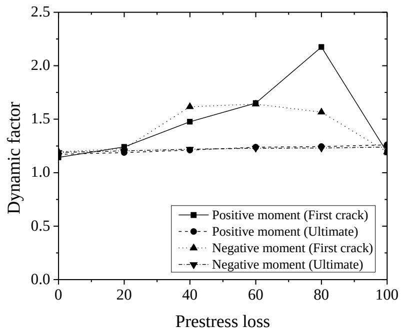


Figure 4: Dynamic factors

4. Conclusions

This study presents the dynamic factor of railway concrete sleepers considering the effects of prestress losses. Dynamic factors are presented in term of the ratio between dynamic and static capacities. The results obtained show that the dynamic factors of ultimate moment are in the range of 1.15-1.25. Moreover, the ranges of 1.15-2.26 are also observed as the dynamic factor of moment at first crack. Nevertheless, it should be noted that the moment at first crack cannot be predicted precisely when the huge losses of prestress are considered. It is interesting to note that the prestress losses have more significant effects on moment at first crack rather than ultimate moment since it shows the variation of dynamic factors associated with prestress losses. The results show that the losses of prestress have crucial effects on the overall strength of prestressed concrete sleepers.

Acknowledgements

The authors are sincerely grateful to European Commission for the financial sponsorship of the H2020-MSCA-RISE Project No. 691135 "RISEN: Rail Infrastructure Systems Engineering Network," which enables a global research network that tackles the grand challenge of railway infrastructure resilience and advanced sensing in extreme environments (www.risen2rail.eu) [25].

References

[1] Fryba, L., Dynamics of railway bridges, Thomas Telford Czech Republic (1996)
[2] Gamage, E., Kaewunruen, S. and Remennikov, A.M., Design of holes and web openings in railway prestressed concrete sleepers, Railway Engineering Conference, Edinburgh, UK (2015)
[3] Kaewunruen, S. and Remennikov, A.M., Structural safety of railway prestressed concrete sleepers, Aust. J. Struct. Eng 9(2) (2009), 129–140
[4] Kaewunruen, S. and Remennikov, A.M., On the residual energy toughness of prestressed concrete sleepers in railway track structures subjected to repeated impact loads, Electronic Journal of Structural Engineering 13(1) (2013), 41-61
[5] Remennikov, A.M., Murray, M.H. and S. Kaewunruen, S., Conversion of AS1085.14 for railway prestressed concrete sleeper to limit states design format, AusRAIL Plus 2 (Dec 2-6, Sydney, Australia) (2007)
[6] Remennikov, A.M., Murray, M.H. and S. Kaewunruen, S., Reliability based conversion of a structural design code for prestressed concrete sleepers, Proceedings of the Institution of Mechanical Engineers: Part F Journal of Rail and Rapid Transit 226(2) (2012), 155-173
[7] Kaewunruen, S. and Remennikov, A.M., Sensitivity analysis of free vibration characteristics of an in-situ railway concrete sleeper to variations of rail pad parameters, Journal of Sound and Vibration 298(1) (2006), 453-461
[8] Kaewunruen, S. and Remennikov, A.M., Investigation of free vibrations of voided concrete sleepers in railway track system, Proceedings of the Institution of Mechanical Engineers Part F: Journal of Rail and Rapid Transit 221(4) (2007), 495-507

[9] Li, D., C. Ngamkhanong, C. and Kaewunruen, S., Time-dependent topology of railway prestressed concrete sleepers, IOP Conference Series: Materials Science and Engineering 245 (3) (2017)

[10] Li, D., C. Ngamkhanong, C. and Kaewunruen, S., Influence of Surface Abrasion on Creep and Shrinkage of Railway Prestressed Concrete Sleepers, IOP Conference Series: Materials Science and Engineering 245 (3) (2017)

[11] Zulfi, F.R. and Korda, A.A., Effect of pre-strain on mechanical properties and deformation induced transformation of 304 stainless steel, J. Phys.: Conf. Ser, 739 (2016)

[12] Remennikov, A.M. and Kaewunruen, S., A review on loading conditions for railway track structures due to wheel and rail vertical interactions, Structural Control and Health Monitoring 15(2) (2008), 207-234

[13] Ngamkhanong, C., Li, D. and Kaewunruen, S., Impact capacity reduction in railway prestressed concrete sleepers with vertical holes, IOP Conference Series: Materials Science and Engineering 236(1) (2017)

[14] Ngamkhanong, C., Kaewunruen, S. and Remennikov, A.M., Static and dynamic behaviours of railway prestressed concrete sleepers with longitudinal through hole, IOP Conference Series: Materials Science and Engineering 251(1) (2017)

[15] Kaewunruen, S. and Remennikov, A.M., Dynamic flexural influence on a railway concrete sleeper in track system due to a single wheel impact, Engineering Failure Analysis 16(3) (2009), 705-712

[16] Kaewunruen, S. and Remennikov, A.M., Dynamic properties of railway track and its components: recent findings and future research direction, Insight-Non-Destructive Testing and Condition Monitoring 52(1) (2010), 20-22(3)

[17] Ngamkhanong, C., Li, D. and Kaewunruen, S., Impact capacity reduction in railway prestressed concrete sleepers with surface abrasions, IOP Conference Series: Materials Science and Engineering 245(3) (2017)

[18] Ngamkhanong, C., Kaewunruen, S. and Costa, B.J.A., State-of-the-Art Review of Railway Track Resilience Monitoring, Infrastructures, 3(1) (2018), 3

[19] Ngamkhanong, C., Li, D., Remennikov, A. and Kaewunruen, S., Dynamic capacity reduction of railway prestressed concrete sleepers due to surface abrasions considering the effects of strain rate and prestressing losses, International Journal of Structural Stability and Dynamics (2018), DOI: 10.1142/S0219455419400017

[20] Bentz, E.C., Sectional analysis of reinforced concrete members, University of Toronto, Department of Civil Engineering (2000)

[21] Remennikov, A.M. and Kaewunruen, S., Experimental load rating of aged railway concrete sleepers, Engineering Structures 76(1) (2014), 147-162

[22] Kaewunruen, S. and Remennikov, A.M., Impact capacity of railway prestressed concrete sleepers, Engineering Failure Analysis 16(5) (2009), 1520-1532

[23] Li, D., C. Ngamkhanong, C. and Kaewunruen, S., Influence of vertical holes on creep and shrinkage of railway prestressed concrete sleepers, IOP Conference Series: Materials Science and Engineering 236(1) (2017)

[24] Wakui, H. and Okuda, H., A study on limit-state design for prestressed concrete sleepers, Concr Lib JSCE 33 (1999), 1–25

[25] Kaewunruen, S., Sussman, J.M. and Matsumoto, A., Grand Challenges in Transportation and Transit Systems, Frontiers in Built Environment, 2(4) (2016)