NUMERICAL ANALYSIS ON STATIC LOAD CAPACITY OF PRESTRESSED CONCRETE SLEEPERS UNDER HYPOTHETICAL BEARING PRESSURE DISTRIBUTION

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To my beloved mother and family

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ABSTRACT

Prestressed concrete sleepers are currently designed based on permissible stresses concepts resulting from quasi-static wheel loads. It was designed to exceed the mean working load to avoid loss of bond in the prestressing due to cracking of the concrete sleepers. These loads allow for static response of the sleeper due to the mechanism of vertical load transfer between the rail and sleeper as well as the sleeper and ballast interaction. In practice, the designer apply uniform pressure distribution beneath each rail seat which is dependent on the track gauge and sleeper length as stipulated in many design standards. Applying uniform pressure distribution beneath each rail seat may not be necessarily applicable to all in-situ sleepers as the contact pressure distribution between sleepers and ballast is mainly influenced by the cumulative effect of the traffic loading at various speeds over a period of time as well as the quality of ballast maintenance. A significant amount of research has been conducted by researchers worldwide over the century in postulating a set of hypothetical contact pressure distribution on the sleeper-ballast interaction. This leads to predicament as to whether the designed sleepers under the assumption of uniform contact pressure distribution had the adequate static load capacity to withstand the designed vertical loading but under different contact pressure distribution pattern. To solve this predicament, numerical analysis using commercially available finite element package, LUSAS, is carried out and comparison is made with the experimental test results in validating the finite element model. The numerical analysis will be useful in predicting the maximum vertical loading prior to the cracking of the sleeper under various hypothetical contact pressure distribution patterns. From numerical analysis, prestressed concrete sleeper that is placed on ballast has reserve strength in static load capacity with a factor between 2.2 and 2.4 of the positive rail seat test load at crack initiation.

ABSTRAK

Reka bentuk *sleeper* konkrit prategasan adalah berdasarkan kepada konsep tekanan yang dibenarkan, hasil daripada aksi beban kuasi-statik roda. Ia direka bentuk untuk melebihi purata beban kerja bagi mengelakkan kehilangan daya tarikan di dalam prategasan yang disebabkan oleh keretakan. Beban ini membenarkan respon statik oleh *sleeper* yang disebabkan oleh mekanisma perpindahan beban menegak di antara rel dan *sleeper* serta interaksi antara *sleeper* dan *ballast*. Pereka bentuk mengenakan tekanan rata yang seragam di bawah setiap kerusi rel yang bergantung kepada tolok landasan dan panjang *sleeper* seperti mana ditetapkan di dalam banyak piawaian. Mengenakan tekanan yang seragam di bawah kerusi rel mungkin tidak benar untuk semua *sleeper* di landasan kerana tekanan permukaan di antara *sleeper* dan *ballast* dipengaruhi oleh kesan kumulatif daripada beban trafik pada pelbagai kelajuan pada suatu tempoh serta kualiti penyelenggaraan *ballast*. Jumlah penyelidikan yang ketara telah dilakukan oleh para penyelidik di seluruh dunia dalam menyediakan satu set hipotesis tekanan rata bagi interaksi *sleeper-ballast*. Ini membawa kepada persoalan samada reka bentuk *sleeper* dibawah andaian tekanan yang seragam mempunyai kapasiti yang mencukupi untuk menahan rekaan beban menegak tetapi di bawah pelbagai bentuk hipotesis tekanan rata. Untuk menyelesaikan persoalan ini, analisis berangka menggunakan pakej perisian komersil untuk model unsur terhingga, LUSAS, dijalankan dan perbandingan dibuat dengan keputusan daripada ujian uji kaji dalam mengesahkan penggunaan model unsur terhingga. Analisis berangka ini sangat berguna untuk meramalkan beban menegak yang maksima sebaik sebelum keretakan *sleeper* dibawah pelbagai bentuk hipotesis tekanan rata. Berdasarkan kepada keputusan analisis berangka, *sleeper* konkrit prategasan yang diletakkan di atas *ballast* mempunyai kekuatan rizab pada kapasiti beban statiknya iaitu diantara factor 2.2 dan 2.4 daripada beban ujian positif kerusi kereta api semasa keretakan mula berlaku.

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K_b	-	Ballast stiffness
h_b	-	Depth of ballast
l_e	-	Effective supporting length of half sleeper
l_b	-	Width of sleeper underside
α	-	Ballast stress distribution angle
E_b	-	Elastic modulus of the ballast
f_c'	-	Specified compressive strength of concrete
E_c	-	Elastic modulus of the concrete
f_{ct}'	-	Tensile strength of the concrete
L1	-	Unloaded with external load
L2	-	Load at initiation of crack
L3	-	Load at ultimate state
D	-	Diamter of prestressing tendon
A_s	-	Area of prestressing tendon

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CHAPTER 1

INTRODUCTION

1.1. MODERNIZATION OF THE BALLASTED RAILWAY TRACK NETWORK IN MALAYSIA

The Government of Malaysia through Keretapi Tanah Melayu Berhad (KTMB) is embarking on an exciting challenge in modernizing its ballasted railway track through the implementation of double tracking and electrification of its railway system on the west coast of the peninsular.

This includes the already completed Rawang-Ipoh Project, the ongoing Ipoh-Padang Besar Project and the Seremban-Gemas Project as well as the upcoming Gemas-Johor Bahru Project. Total project cost of the modernization of this ballasted railway track is approximately RM 30 billion.

The modernized ballasted track is designed to replace the colonial track of 90 km/h top speed with the 140 km/h maximum operational speed which could go up to its limit of 160 km/h on certain stretches. This will directly reduce the transit time for both passengers and goods traffic which in return will stimulate developments and economic growth along its corridor.

Once the network between Johor Bahru and Padang Besar is completed, it will further spur and enhance the growth of international container traffic through train services between the ports of Malaysia. It will definitely pave the way for the success of the Indonesia-Singapore-Malaysia-Thailand Growth Region.

1.2. FUNCTIONS OF TRACK COMPONENTS AND THE LOAD PATH

The design of a railway system is typically divided into two main components namely the design of trains or rollingstock and the design of the supporting structure (Remennikov, Kaewunruen, 2008). It is expected that the track structures will guide and facilitate the safe, economic and smooth passages of any passenger and freight trains.

By considering the static and dynamic loads acting on the track structure, railway track structures is primarily analysed and designed to avoid excessive loading which may induce damage to the track substructure and superstructure. This include track components such as rails, rail pads, mechanical fasteners and concrete sleepers (superstructure) as well as geotechnical systems such as ballast, sub-ballast and subgrade or formation (substructure). Fig. 1.1 shows the cross sectional layout of a typical ballasted track (Selig & Waters, 1994).

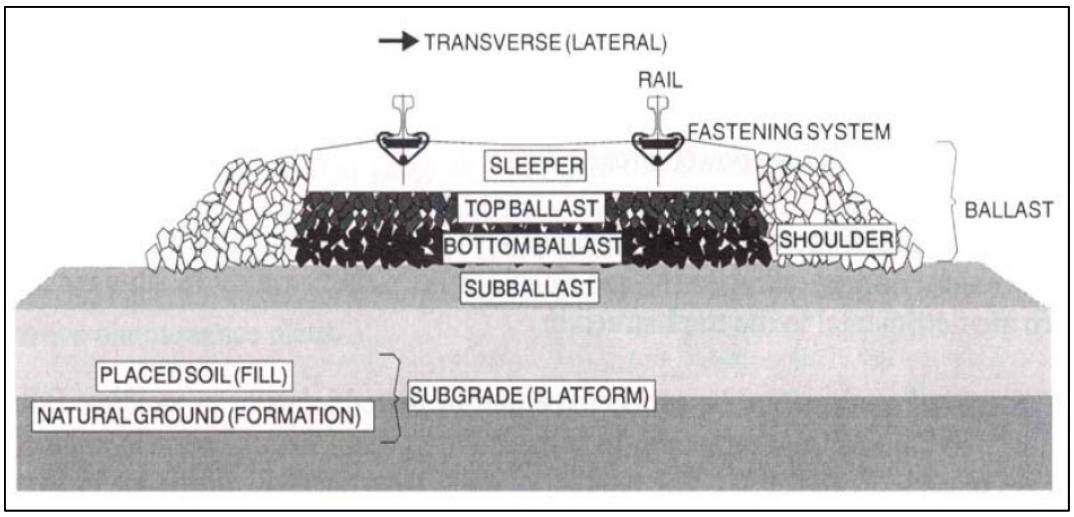

Figure 1.1: Cross sectional layout of a typical ballasted track (Selig & Waters, 1994)

As a longitudinal steel members positioned on the equally spaced sleepers, rails are the critical component in guiding the rolling stocks. Its main function is to accommodate and transfer the loads from the rolling stock to the supporting sleeper. With adequate strength and stiffness in the rails, a steady shape and smooth track is maintained and various forces exerted by travelling rolling stocks are resisted. In modern electrified track, rails had additional function of serving as an electrical conductor for railway signaling system.

Both mechanical fasteners and rail pads are the primary components of the fastening systems. Apart from keeping the rails in position on the sleepers, the mechanical fasteners withstand the three dimensional forces of vertical, lateral and longitudinal as well as the overturning movements of the track. Mechanical fastener also transfer forces caused by wheels, thermal change and natural hazard from rails to the adjacent set of sleepers.

As the other primary components of the fastening systems, rail pads which are placed on the rail seat are essential in filtering and transferring the dynamic forces from the rails and mechanical fastener to the sleepers. The dynamic force is predominantly from the travelling rolling stocks and the high damping coefficient of the rail pads considerably reduces the excessive high-frequency force components to the sleepers. The resiliency provided by the rail pads to rail-sleeper interaction has resulted in the alleviation of rail seat cracking and contact attrition.

Sleepers are part of the track component that rest transversely on the ballast with respect to the longitudinal rail direction. It was first made using timber before evolving to steel, reinforced concrete and to the most common type seen today, prestressed concrete. This evolution is closely related to improve durability and longer service life span. In terms of its functionality, sleepers are critical in (i) providing support and restraint to the rail in vertical, longitudinal and lateral direction, (ii) transfering load from the rail foot to the underlying ballast bed, and (iii) retaining proper gauge and inclination of the rail by keeping anchorage for the rail fastening system.

Underneath the sleepers in providing tensionless elastic support is ballast, a free-draining coarse aggregate layer typically composed of crushed stones, gravel, and crushed gravel. Depending on the local availability, basalt and granite are usually the selected material for ballast due to its strength characteristic for load transfer. In between the ballast and the underlying subgrade is sub-ballast, commonly composed of broadly graded slag, broadly sand-gravel or crushed aggregate. The last support to sustain and distribute the resultant downward dynamic loading along its infinite depth is subgrade or also known as formation. Subgrade includes existing soil and rock as well as other structures such as pile embankment and the recent high performance materials of geotextiles and

geofabrics. To prolong track serviceability, the infinite depth of subgrade must have adequate bearing capacity, provide good drainage and yield tolerable smooth settlement.

1.3. PROBLEM STATEMENT

As reviewed by Doyle (1980), one of the main functions of prestressed concrete sleepers is to transfer the vertical loads to the ballast and formation. This vertical loads subject the sleeper to bending moment which is dependent on the pressure distribution exerted by the ballast underneath the sleeper.

In practice, a uniform pressure distribution is assumed in design to calculate the static load capacity of the sleeper in withstanding the bending stresses. This also lead to a four point bending moment test at the rail seat in the laboratory (AS 1085.14-2003) based on the assumption that the sleepers would behave similar to those of the in-situ ones. (Remennikov, Murray, Kaewunruen, 2008)

However, this assumption is not completely true as the bearing pressure distribution on the sleeper-ballast interaction is mainly depending on the degree of voids in the ballast underneath the sleeper. The major influence factors in determining the degree of voids are the traffic loading and train speed. Both factors are time dependent as cumulative effect of the traffic loading at various speeds will gradually change the structure of the ballast and the subgrade. A remarkable effort by Talbot (1913-1940), other researchers and standards have postulated a set of hypothetical bearing pressure distribution on the sleeper-ballast interaction and their corresponding bending moment diagrams.

Therefore, quantifying the rail seat load and the bearing pressure distribution is the most critical steps in designing the sleeper to withstand vertical loading. Numerical analysis using a commercial finite element package, LUSAS, was carried out to check on the assumption made on the laboratory test as well as to check whether the assumption of uniform pressure will provide an overestimate of

the sleeper's static load capacity in relative to other hypothetical bearing pressure distribution.

The preliminary applied rail seat load in the design and numerical analysis will be based on 20 tonne axle load which is the maximum imposed load as regulated by the Malaysian Railway Authority although it is acknowledged excessive wheel load over 400 kN due to wheel or rail abnormalities may occur once or twice in the sleeper's design life span of 50-100 years (Kaewunruen, Remennikov, 2009). This is considered a rare event and it is not economic to design sleeper for such a high static load capacity.

Subsequently, the rail seat load will be increased if the bending stress limit is not exceeded. If the bending stress is exceeded prior to rail seat load based on 20 tonne axle load, a lower load will be applied to predict what load the sleepers will fail under flexure.

1.4 . OBJECTIVES OF THE STUDY

The objective of this study are :

a) To develop two-dimensional model of presetressed concrete sleepers using finite element analysis modelling;

b) To compare the finite element analysis model with the load-deflection response of the centre negative moment experimental test as previously conducted by Kaewunruen and Remennikov (2006a);

c) To verify if the assumed uniform bearing pressure distribution on the sleeper-ballast interaction is not underestimating the design if other hypothetical bearing pressure distribution pattern occurs;

d) To predict the maximum vertical static loading capacity at crack initiation stage and ultimate state on various hypothetical bearing pressure distribution patterns.

1.5. SCOPES OF THE STUDY

The scope of this study are :

a) To review the analysis and design of monoblock prestressed concrete sleepers by referring to Section 4 of AS 1085.14-2003 as practiced by the track designer of KTM Double Track Projects;

b) To perform numerical analysis using finite element software, LUSAS, with various hypothetical bearing pressure distribution on the sleeper-ballast interaction as the controlled variable.

c) To apply specification of sleeper dimension, rail seat loading, material properties and other technical parameters based on the centre negative bending moment test carried out by Kaewunruen and Remennikov (2006a). The ballast stiffness will be based on technical specification used in KTM Double Track Project.

d) To only consider quasi-static wheel loads in the full scale experiments and numerical analysis, impact loads are omitted.

e) To only consider independent, closely spaced, discrete and linearly elastic springs for the beams on elastic foundation. Continuum approach is omitted as effects on local pressure distribution are assumed negligible in the transverse direction of the track.