ANALYSIS OF STRESS DISTRIBUTION IN METER GAUGE RAILROAD TRACKS SUBJECTED TO MODERATE AXLE LOADS AND RAIL SPEEDS

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ABSTRACT

This paper presents the characteristics of traffic stress distribution in the track substructure with an emphasis on those of meter-gauge railroads subjected to moderate axle loads (12-20 metric tons) and rail speeds (50-120 km/h). Such conditions are prevalent to the contexts of rail transportation in Thailand. A computer program based on three-dimensional beam-on-elastic foundation (BOF) theory is employed to calculate stresses in the substructure due to traffic loads. An assemblage of rails, pads, and ties is supported by the substructure consisting of multiple layers of elastic materials. Each is characterized by a nonlinear model of stress-dependent resilient modulus. The numerical method is validated by the substructure stresses measured from a fully instrumented rail track section under real services. A series of numerical parametric studies are performed using the validated BOF model however with different boundary conditions. Key track parameters used in the calculations are the axle load, rail speed, and stiffness and thicknesses of the ballast, subballast, and subgrade layers. The values these parameters are selected to best represent the traffic and track conditions of railroads founded on the soft cohesive soils of the central region of Thailand. The calculated track stresses are analyzed and employed to determine cumulative deformations of the subgrade soil using a simple plastic strain model. Comparison between the predicted deformations due to repetitive axle loads and those monitored from the experiment track section is made. Then the applicability of this approach to predict subgrade settlements in meter-gauge tracks under moderate axle loads and rail speeds is preliminarily assessed.

Keywords: Railway track substructure, Meter gauge, Stress distribution, Beam on elastic foundation

1. Introduction

This paper presents the stress distribution in the track substructure subjected to moderate axle loads and rail speeds. The applications of this are to preliminary studies for preventing railroads subgrade failures due to repeated traffic loads. The computer program used in this study is a three dimensional model based on an elastic and multilayer approach. Several multilayer track models have been developed and validated for analysis of stress on the track structure. The model GEOTRACK (Ching, C. S., and Adegoke, 1980) is an example of the calculation of the track structure. A common feature of these multilayer models is the incorporation of all major components of the track and subgrade, i.e., rails, ties, fasteners, ballast, subballast, and subgrade layers (Li and Selig 1998). This model can be used to estimate the stress distribution in the subgrade layer. Additionally, the preliminary analyze of the stresses can be predicted the proper granular layer thickness for preventing two common of subgrade failures. The model has been validated by comparison with those monitored from the real experiment in the track section.

2. Objectives of the study

2.1 To analyze the characteristics of stress distribution in meter gauge railroad tracks subjected to moderate axle loads and rail speeds.

2.2 Investigate the applicability of Li and Selig's method for determination of granular layer thickness for the meter gauge railroad track.

3. Background

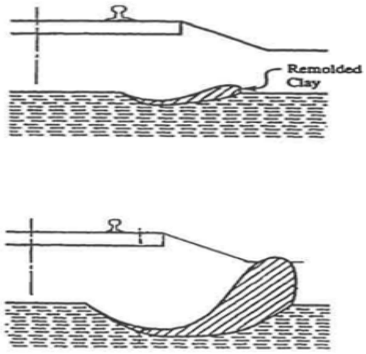
The building code defines the minimum design requirements to ensure the safety during working. In construction, the damage can occur in every moment, even the construction is compliant with the building code. Two common of based design are selected to describe in this study.

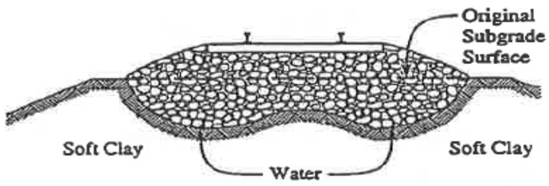
Firstly, limit state design is the limit for safety and serviceability requirements before the failure occurs. This method can be ensured that the structures will not reach the limit state and not become to the ineligible for its intended. Two main limit states are limited state of collapse and limit state of serviceability. The limit state of collapse deals with strength and stability of the structure under the maximum design load. The other one, limit state of serviceability, deals with deflection and cracking under service loads.

Secondly, performance based design is an approach to any complexity of construction. Constructing in this way is required a certain predictable or measurable performance. This approach provides the freedom to develop tools and method to evaluate the entire life cycle of the building process. The design in this study is the one of the designs which used performance based design to produce a good track structure performance.

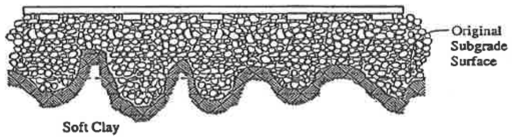
Two main failures of track subgrade caused by repeated loading are the progressive shear failure as can be seen in Figure 1 and the excessive plastic deformation as in Figure 2.

In the fine grained soil or the soft subgrade soil, subgrade progressive shear failure as illustrated in Figure 1 begins at the subgrade surface and gradually develops to a greater extent under repeated loading. The surface gradually squeezes outward and upward to the path of least resistance and result in heaved soil. Heaved soil occur at the shoulder of the track side thus, it hinders the water flow out of the track and allow the water entering from above granular layer. This problem is aggravating the subgrade failure and especially in the soft layer on the top.





(a)



(b)

Figure 1 Subgrade progressive shear failure

Figure 2 Excessive plastic deformation

(a) Cross section (b) Longitudinal Section

Excessive subgrade plastic deformation as illustrated in Figure 2 leading to ballast pockets can occur in fine grained subgrade soil and repeated loading. The ballast pocket results from the vertical component of progressive shear deformation. The deformation caused by the compaction or consolidation of the entire subgrade layer due to repeated loading. A ballast pocket accompanied with a little heave can result in a large deformation.

Increasing the granular layer thickness provides a good of subgrade performance because the distance from the ballast surface and subgrade surface are increasing. Therefore, the determination of an adequate granular layer thickness is the simple way to adjust both the of progressive shear failure and the excessive plastic deformation. An other type of subgrade failure, such as massive shear failure, mud pumping, subgrade attrition is not considered in this study because they are not producing a good performance by increasing the granular layer thickness.

4. Analysis of stress distribution in railroad track

The approach was selected in this study named GEOTRACK. This approach is a three-dimensional and the elastic multilayer model for analyzing the stress and deformation in the rails, ties, ballast, subballast, and the subgrade layer. The model computes as a function of axle loads, properties of rail and tie, properties of ballast, subballast, and the underlying subgrade layer.

The components of the track show in Figure 3 consist of rails which represented as a linear elastic beam supported by a reaction from the intersection of the tie and rail. The parameters to specify the rail (Ching, C. S., and Adegoke, 1980) are the cross-sectional area, modulus of elasticity, moment of inertia. The connection between the tie and rail is the linear spring with a specified spring constant. Ties are specified by parameters including the cross-sectional area, modulus of elasticity, moment of inertia. In each tie separate to 10 equals rectangular segments which supported by the ballast reaction.

These forces applied to the ballast surface as a concentrate forces and uniform over the circular area. The substructure component consists of ballast, subballast supported by the subgrade layer. They are all described by the Poisson's ratio and the modulus of elasticity. The layers are all infinite in both horizontal and vertical directions.

The forces from the rails applied to the ties based on beam on elastic foundation, whereas the reaction between the ties and ballast used the Burmister's approach. Burmister's is ananalytical that provides the flexibility matrix of the substructure component. The forces from the tie act to the ballast in the circular area instead of the rectangular area because it was more economical to compute. A concentrate load in each segment of the tie was converted into uniform pressure distributed over the circular area to obtain the flexibility matrix, S_{ij}^{pq}, of foundation (Adegoke, 1980). As the matrix represented as follows;

$$\delta_i^{p} = S_{ij}^{pq} X_j^{q} \tag{3}$$

where δ_i^p is the deflection at the intersection of rail i and tie p, X_j^q is the tie ballast force acting on the j th segment of tie q, which represent as a uniform load, S_{ij}^{pq} is the vertical deflection of the i th segment of the tie p obtained from Burister's equation subjected to the unit load distribution as a uniform load over a circular area of the j th segment of tie q.

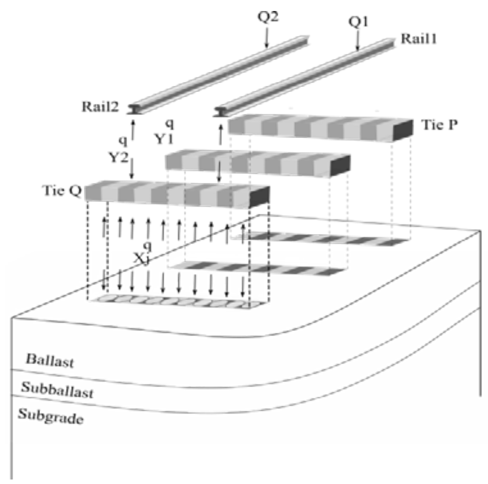


Figure 3 Track elements in GEOTRACK

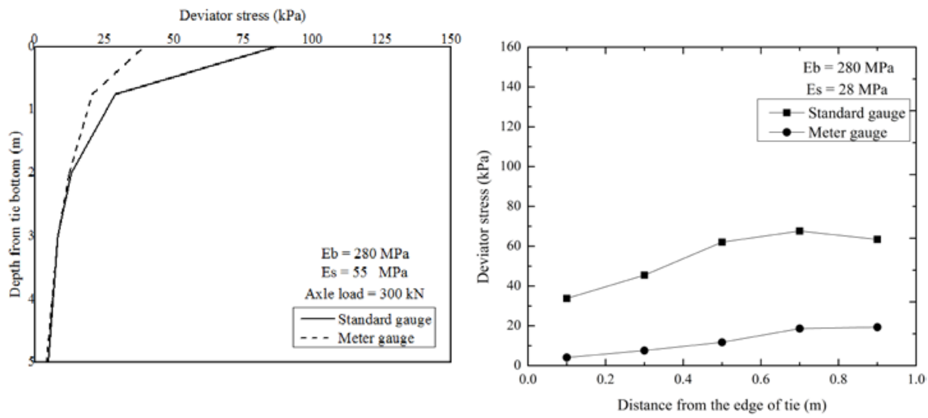
5. Standard gauge vs. meter gauge

Table 1 has shown the comparison of track variables between meter gauge and standard gauge. The comparison of the deviator stress between the standard gauge and meter gauge in a downward direction at the tie end is shown in Figure 4a. Consider at zero point which is the granular layer surface found that the deviator stress in standard gauge is more than the meter gauge then it tends to close to each other with depth. This result illustrates that type of track directly affect to the stress in the substructure. Figure 4b also shows the deviator stress, but in parallel to the tie direction by comparing standard gauge with meter gauge. Obviously, the deviator stress of the standard gauge is higher than the meter gauge.

Table 1 Track properties of meter gauge and standard gauge

Track variables	Value	
	Meter gauge	Standard gauge
Gauge (m)	1.000	1.435
Base width of tie (m)	0.26	0.273
Base length of tie (m)	2.0	2.6
Spacing (m)	0.6	0.61

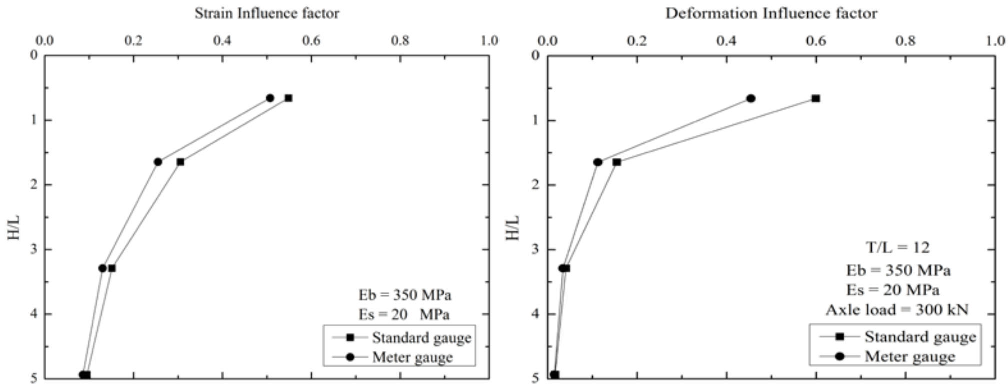
Figure 4 clearly seen that the deviator stress in standard gauge is more than meter guage in both of downward and parallel to the tie direction. In Figure 4(b), the stress was shown just only half length of tie (symmetry). Thus, the track width is the factor that affect to the deviator stress in both of the parallel to the tie and downward direction. The calculation in the appropriate stress leads to show out the best results for the subgrade performance.



(a) (b)

Figure 4 Comparison of the deviator stress in the standard gauge and the meter gauge influenced by: (a) downward with depth (b) parallel to the tie

Figure 5 shows the design charts for preventing the track subgrade failure. Figure 5(a) illustrates that the strain influence factor which preventing the progressive shear failure while Figure 5(b) illustrates the deformation influence factor which preventing excessive plastic deformation. For preventing progressive shear failure as can be seen in Figure 5(a), the granular layer in standard gauge provides more of thickness than a meter gauge. The variables H is the granular layer thickness and L is a factor that use for several unit of calculation (in this study use L = 0.152m).



(a) **(b)**

Figure 5 Comparison of the influence factor between the standard gauge and meter gauge: (a) Strain influence factor; (b) Deformation influence factor

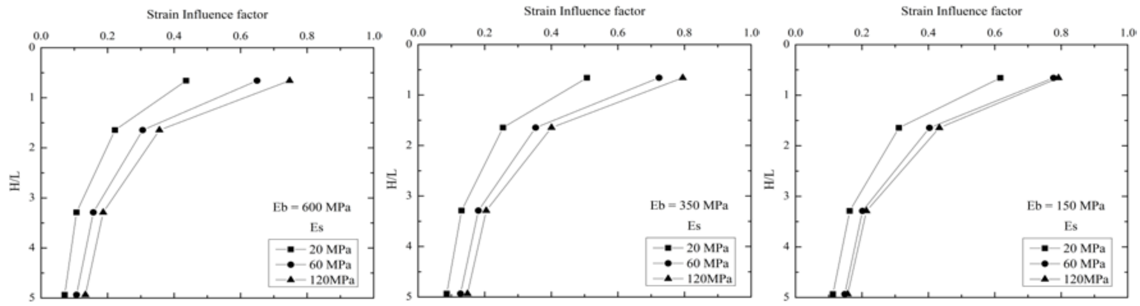
In the other hand, to preventing excessive plastic deformation, the granular layer in standard gauge also provides more of thickness than a meter gauge. To prevent both of the progressive shear failure and the excessive plastic deformation needs to determine in both of strain influence factor and deformation influence factor. The maximum of granular layer thickness will selected to best subgrade performance. Such a comparison in Figure 5, the strain influence factor chart provides more of granular layer thickness than the deformation influence factor chart in both of standard gauge and meter gauge. Therefore, chart (a) was selected to preventing in both of the progressive shear failure and the excessive plastic deformation.

6. Design application

For preventing progressive shear failure in subgrade layer, the adequate granular layer thickness was required. Figure 6 illustrates the strain influence factor with a recommending depth of the granular layer. In each chart, the difference of granular layer stiffness was performed. Figure 6(c) illustrated that, the lowest of granular layer stiffness provides more of the granular layer thickness compared to Figure 6(a) and (b). In addition, Figure 6(c) also shows that if the stiffness of the granular layer and subgrade layer are close to each other, the strain influence factor tends to constant. The increasing of granular layer stiffness leads to increasing its strength also thus, the stress distributes to the substructure was diminished, then a few of granular layer thickness are sufficient.

To determine the granular layer thickness for preventing progressive shear failure, the deviator stress at the subgrade surface and dynamic wheel load were provided. The strain influence factor represented by the following equation (AREA, 1996):

$$I_{\varepsilon} = \frac{\sigma_d A}{P_d} \qquad (1)$$



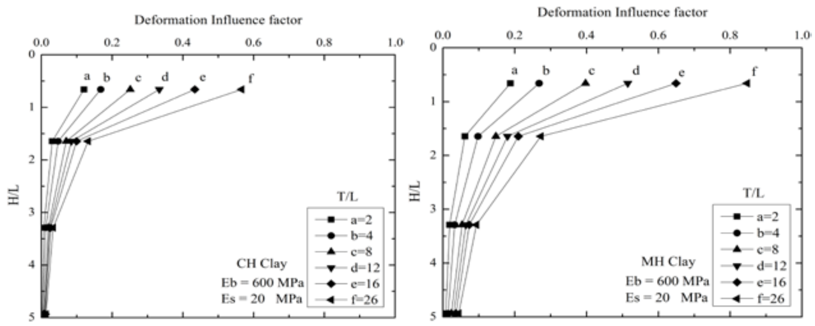
(a) **(b)** **(c)**

Figure 6 Example of granular layer thickness design charts for preventing progressive shear failure in meter gauge: (a) Eb=600 MPa; (b) Eb=350 MPa; (c) Eb=150 MPa

where the σ_d is the deviator stress at subgrade surface; P_d is the dynamic wheel load. However, A is the area factor to make the strain influence factor dimensionless and arbitrarily selected to be 0.645 m^2. The strain influence factor got from equation (1), then choose the subgrade stiffness in considered chart. H/L will form in only H by dividing by L. L is just a length factor for dimensionless chosen arbitrarily to be 0.152 m.

For preventing the excessive plastic deformation, the design charts have been developed. Figure 7 shows the example of the granular layer thickness with various type of soil. In each curve corresponds to one subgrade layer depth.

To calculate the deformation influence factor in Figure 7 is based on the allowable deformation and design dynamic wheel load. The following equation (Li and Selig, 1998) provides the allowable deformation influence factor.



(a) **(b)**

Figure 7 Example of granular layer thickness design charts for preventing excessive plastic deformation in meter gauge: (a) CH clay; (b) MH (elastic silt)

$$I_\rho = \frac{\frac{\rho_a}{L}}{a\left(\frac{P_d}{\sigma_s A}\right)^m N^b} \times 100 \qquad (2)$$

where ρ_a is allowable total subgrade plastic deformation for the design period; N is the total equivalent number of load repetitions during the design period; P_d is the design dynamic wheel load; σ_s is the soil compressive strength; a,b,m is the parameter depends on soil type; A,L is the Area factor and he length factor (A=0.645 m^2, L=0.152 m). The deformation influence factor got from equation (2) then choose the chart related to soil type that considered. H/L will form in only H by dividing by L. L is just a length factor for dimensionless chosen arbitrarily to be 0.152 m. A comparison of Figure 8 (a) and (b) found that MH or elastic silt provides more of the granular layer thickness compared to the CH clay.

7. SIMULATION VS. FIELD MEASUREMENT

Comparison of the stress between the field measurement and the predicted from the simulation was performed. The wheel load, ballast and subballast thickness have been measured from the real experiment track section. The stress from the track section and the predicted value illustrate as in Figure 8.

Three points of stress on the track structure were compared, that is ballast surface, subballast surface and the subgrade surface. All of three point was measured under the tie end. In simulation step, the static wheel load obtained to convert to dynamic wheel load by recommended equation as follows (AREA, 1996):

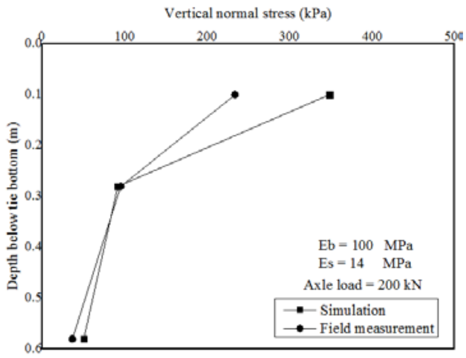


Figure 8 Comparison of the stress between the predicted and field measurement

$$P_d=(1+\frac{0.0052V}{D})P_{si} \quad (3)$$

where V is the train speed(km/hr), D is the wheel diameter(m).

The observation of the predicted study found that, the 0.58m thickness of the granular layer (0.28m for ballast layer and 0.3m for subballast layer) produces more of the stress at the ballast surface than the stress in real experiment. However, both of the stresses are distributed in gradually decreasing with depth.

The discrepancies of this comparison are properties of the track structure was assumed, such as modulus of elasticity of the ballast and subballast layer and the soil unit weight, etc. This paper proves that, the modulus of elasticity affects a lot to the stress distribution. Thus, the recommendation of this paper is the elastic modulus of both ballast and subballast layer were required.

8. Conclusion

The new design charts for preventing subgrade failure in the track structure has been developed by the GEOTRACK model. The adequate granular layer thickness is the key of this study, whereas the track structure also directly related to the distribution of stress in the subgrade thus, the meter gauge also considered in this study. The adequate granular layer thickness can prevent both of the progressive shear failure and the excessive plastic deformation which is the mostly failure occurred in the soft subgrade soil and repeated load.

Other conditions also considered include the wheel track diameter, resilient modulus, soil compressive strength and the intensive of stress. Analysis based on the appropriate conditions will lead to reduce the cost of track maintenance. For accuracy of this study is the real experiment in the track section is made. The applicability of this study is to preliminary predicted the stress, deformation in the subgrade layer and the adequate granular layer in meter gauge subjected to moderate axle loads and rail speeds.

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