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"METHODS FOR RAILWAY TRACK GRANULAR LAYER THICKNESS DESIGN,"

by Dingqing Li, Ernest Selig* and Steven Chrismer

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Summary
Under the Association of American Railroads' (AAR) Heavy Axle Load (HAL) Implementation program, the AAR has developed design methods and charts to determine the granular layer thickness required to prevent railway subgrade failures under repeated traffic loads.** This methodology, along with AAR's newly developed Cone Penetrometer, is intended to reduce the maintenance costs associated with the operation of HAL traffic. The methods are believed to provide the best approach currently available and the results are consistent with the limited available field data. However, further verification of the design methods by field data and experiments is under way.

The main design parameters and procedures used will be discussed in the pages which follow. Parameters considered include:

- Dynamic wheel loads,
- Tonnage by million gross tons (MGT),
- Moduli of granular materials and subgrade soil, and
- Soil type and soil compressive strength.

Granular layer thickness is defined as the combined thickness of ballast and subballast between the subgrade surface and the tie bottom. The subgrade failures to be prevented are progressive shear failure (subgrade squeezing) and excessive plastic deformation (ballast pocket). These two types of subgrade failures are the most common soft subgrade problems under repeated HAL. Other types of subgrade problems such as subgrade attrition with mud pumping are not covered by the design methods. To obtain satisfactory track performance, adequate track drainage must also be provided with proper granular layer thickness.

*Department of Civil Engineering, University of Massachusetts, Amherst, MA
*** The design charts developed for selecting the granular layer thickness for various granular material and subgrade conditions will be given in a separate AAR report.*

Suggested Distribution:
- ❑ Bridges and Roadway
- ❑ Maintenance Planning
- ❑ Track Maintenance
- ❑ R&D\Test Department

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INTRODUCTION

Under Heavy Axle Loads (HAL), the subgrade will experience higher repeated stresses without proper granular layer thickness. The most common soft subgrade failures caused by HAL are progressive shear failure and excessive plastic deformation. Design methods were developed for selecting granular layer thickness required to prevent and remedy these two types of subgrade failures. Preliminary results using these methods are consistent with the limited field data available from the Association of American Railroads' Low Track Modulus and Hot Mixed Asphalt projects.

DESIGN TRAFFIC

The design methods emphasize the influence of repeated traffic loads on subgrade performance. Thus, the design traffic parameters are: static wheel loads, train speed, and traffic, as represented by MGT (million gross tons).

These parameters are converted into two variables: the design dynamic wheel load, P_d, and the total number of repeated load applications, N, for the design period. The design period, defined as the time for the track to carry the desired amount of traffic without having the subgrade strength influence the track performance beyond a degree specified, is based on maintenance costs and traffic speed restriction considerations. As an example, a design period may be about five years to coincide with a typical production tamping cycle.

A dynamic wheel load, P_{di}, corresponding to a particular static wheel load, P_{si}, is calculated by the AREA recommended equation as follows:

$$P_{di} = (1 + \frac{0.33V}{D})P_{si} \qquad (1)$$

where V = train speed (mph), D = wheel diameter (inches).

The number of repeated load applications during the design period is determined by:

$$N_i = \frac{T_i}{4P_{si}} \qquad (2)$$

where T_i = total tonnage for the design period in the same unit as P_{si}.

To represent the influence of all levels of wheel load on the subgrade performance, the following equation is used to convert N_i cycles of wheel load, P_{di}, to N_i^0 cycles of the design wheel load, P_d:

$$N_i^0 = N_i[\frac{P_{di}}{P_d}]^{m/b} \qquad (3)$$

where m, b = parameters are dependent upon soil type (see Exhibit 1).

Exhibit 1. Values of Soil Parameters a, b and m

Soil Type	a	b	m
CH (fat clay)	1.2	0.18	2.4
CL (lean clay)	1.1	0.16	2.0
MH (elastic silt)	0.84	0.13	2.0
ML (silt)	0.64	0.10	1.7

Note: Parameter "a" appears in Equation 8.

The total number of load applications, N, for the design load, P_d, is calculated by:

$$N = N_1^0 + ... + N_i^0 + ... \qquad (4)$$

PROPERTIES OF MATERIALS

Exhibit 2 shows the simplified granular layer overlying the subgrade. The granular layer thickness, H, includes both ballast and subballast layers. Analysis by Li (1) showed that the material property of the granular layer which most influences stress level in the subgrade is the resilient modulus of this layer. A stiffer granular layer will result in a lower stress level in the subgrade caused by repeated traffic loading. Thus, the material property considered for the granular layer is resilient modulus, E_b. The material properties considered for the subgrade layer include resilient modulus, E_s, soil compressive strength, σ_s, and soil type. In general, other conditions being the same, a stiffer subgrade will result in a higher stress level in the subgrade. However, this higher level of stress will be compensated for by the corresponding higher strength of the subgrade soil. For a stiffer subgrade, the increase in soil strength is generally greater than the increase in subgrade stress level.

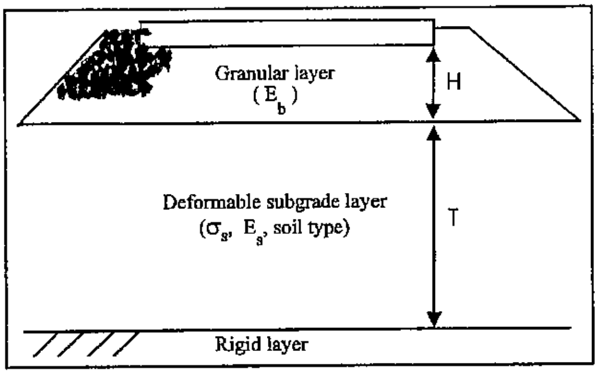

Exhibit 2. Depth Measurement Definitions

In Exhibit 3, some typical values of resilient modulus for the granular layer are given corresponding to the quality of the granular layer. Exhibit 3 also gives the ranges of resilient modulus and soil compressive strength for different subgrade soil conditions.

Exhibit 3. Material Properties of Granular Material and Subgrade Soil

Material Condition		Modulus (psi)	Compressive Strength (psi)
Granular Material	good	80,000	-
	medium	40,000	-
	bad	20,000	-
Subgrade	stiff	10,000 - 20,000	30 - 50
	medium	4,000 - 10,000	15 - 30
	soft	1,000 - 4,000	5 - 15

DESIGN CRITERIA

Two criteria are used for design of the granular layer thickness. One criterion is intended to prevent subgrade progressive shear failure (Exhibit 4) and the other criterion is intended to prevent excessive subgrade plastic deformation or ballast pocket (Exhibit 5). Both criteria should be evaluated to determine the one that gives the largest granular layer thickness in each particular case.

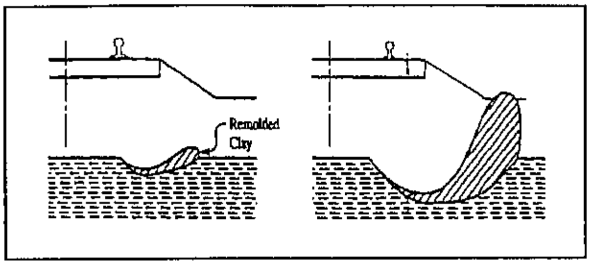

Exhibit 4. Progressive Shear Failure

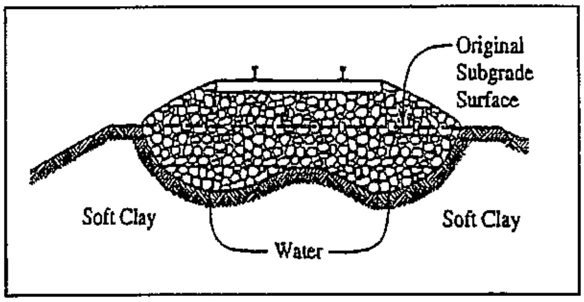

Exhibit 5. Excessive Plastic Deformation

Design Criterion 1: The established design criterion for preventing progressive shear failure is to limit the total cumulative plastic strain at the subgrade surface for the design period, i.e.:

$$\varepsilon_p \le \varepsilon_{pa} \qquad (5)$$

Design Criterion 2: In order to prevent excessive subgrade plastic deformation, the established design criterion is to limit the total cumulative plastic deformation of the deformable subgrade layer for the design period, i.e.:

$$\rho \le \rho_a \qquad (6)$$

DESIGN METHOD 1

The method based on Design Criterion 1 is called Design Method 1. This design procedure consists of the following three steps:

(1) Prepare the information for design:

- Traffic condition: P_d and N
- Allowable: ε_{pa}. For example, 3 percent of ε_{pa} can be selected for the design period.
- Subgrade soil type, σ_s, and E_s
- Granular material: E_b

(2) Determine allowable σ_{da} at the subgrade surface, using a chart such as Exhibit 6.

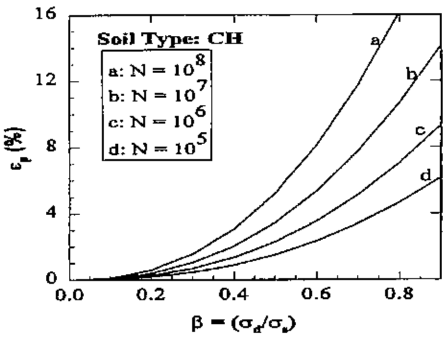

Exhibit 6. Allowable Deviator Stress

(3) Select the required granular thickness H:

- Calculate the strain influence factor, I_ε, by

$$I_\varepsilon = \frac{\sigma_{da} A}{P_d} \qquad (7)$$

The area factor A is 1000 square inches.

- Determine H/L using the design chart such as Exhibit 7. The length factor L is equal to 6 inches.

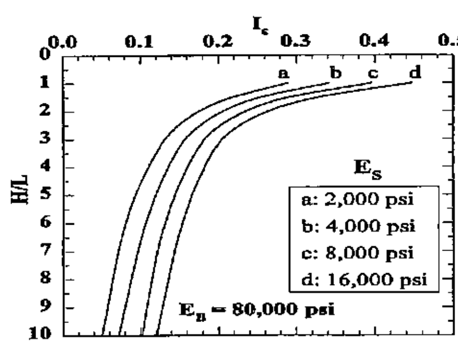

Exhibit 7. Granular Layer Thickness Chart

If σ_{da} at the subgrade surface is directly selected without using ε_{pa} for the design period, skip the chart shown in Exhibit 6 and proceed to Step 3.

DESIGN METHOD 2

The method based on Design Criterion 2 is called Design Method 2. Again, the design procedure consists of the following three steps:

(1) Prepare the information for design, similar to Design Method 1. An example of ρ_a for the design period is 1 inch.

(2) Calculate the deformation influence factor, I_ρ, by the following equation:

$$I_\rho = \frac{\frac{\rho_a}{L}}{a\left(\frac{P_d}{\sigma_s A}\right)^m N^b} \times 100 \qquad (8)$$

(3) Select the required granular thickness H, using a design chart such as Exhibit 8.

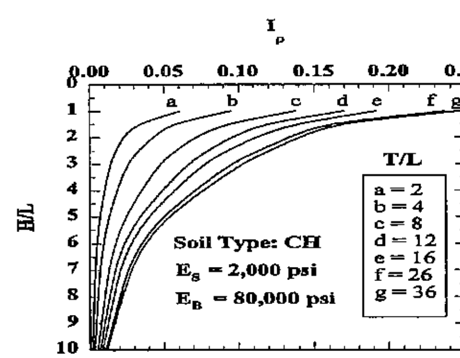

Exhibit 8. Granular Layer Thickness Chart

REFERENCE

1. Li, D. (1994), "Railway track granular layer thickness design based on subgrade performance under repeated loading," Ph.D. Dissertation, Department of Civil Engineering, University of Massachusetts, Amherst.

(Note: Contact Dingqing Li at (719) 584-0740 with questions or comments about this document.)

A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, WILL BE AVAILABLE AT A LATER DATE THROUGH THE AAR, PUBLICATION ORDER PROCESSING, 50 F STREET, NW, 5TH FLOOR, COG, WASHINGTON, D.C.,20001