Finite Element Modeling of a Guardrail Post Mounted in Soil

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Abstract

This paper describes the development of a finite element model of a guardrail post mounted in soil. The post-soil interaction is modeled using the subgrade reaction method where the posts are supported by an array of nonlinear, uncoupled springs. The analysis is carried out using the nonlinear, explicit finite element program LS-DYNA3D and the results are compared to data from physical tests using a ballistic pendulum impacting soil-mounted guardrail posts. The resulting post-soil model is efficient and practical and is being used in models of guardrails and guardrail terminals that involve many soil-mounted posts.

Introduction

Developing roadside hardware with more consistent performance is an important aspect in improving roadside safety. Soil conditions in particular can have a dramatic affect on the performance of a wide variety of guardrail and guardrail terminal systems. The purpose of this paper is to present a computationally efficient and accurate method for modeling the interaction between a guardrail post and the soil.

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The performance of most guardrail systems is dependent upon the lateral stiffness of the guardrail posts. The post-soil interaction can be analyzed as a laterally loaded pile. Two basic approaches commonly used to solve laterally loaded pile problems are: (1) the soil-continuum approach where the soil is modeled by numerous tetrahedral solid finite elements and (2) the subgrade reaction approach where the post is supported by an array of uncoupled nonlinear springs.

Although explicitly modeling the posts, the soil and the interface between the two with numerous soil elements is conceivably the most physically realistic method of modeling the soil-post interaction, it is neither efficient nor practical for routine analysis due to the immense computational cost of performing such an analysis. Finite element analysis of vehicular impact into guardrail systems often requires 10 meters or more of a guardrail system to be modeled. The subgrade reaction approach is potentially as accurate and a far more practical method of analyzing the post-soil interaction.

Subgrade Reaction Method

The horizontal subgrade modulus, k_h, is used to determine the properties of the nonlinear springs that simulate the soil-resistance. The value of the subgrade modulus is influenced by many factors such as the relative density, moisture content, cohesiveness of the soil and depth below grade, as well as, the nature of the applied load, the post deflection, and the properties and geometry of the post. The method used in this study was proposed by Habibagahi and Langer and is based upon the bearing capacity concept (Habibagahi et al.,1984, Plaxico et al., 1998). For granular, non-cohesive soils typically used as roadway base material k_h is defined by:

$$k_h = N_q \frac{\sigma_e}{y}$$

Where σ_e is the effective overburden stress which is affected by the density and moisture content of the soil, y is the lateral deflection of the post and N_q is a lateral bearing capacity factor whose value is dependent upon post deflection, depth, post width and the angle of internal friction of the soil. More details on the constitutive modeling of the springs using the subgrade reaction method can be found in Plaxico et al. (1998).

Finite Element Model

A finite element model of a 150x200 mm timber guardrail post was developed and used in the post-soil interaction study. The post is 1,848 mm long with 1,118 mm of the post embedded in the soil. The material properties of the post are modeled as isotropic elastic-plastic with no failure criteria since the objective is to investigate the soil properties alone.

The post is supported by an array of spring elements placed along the faces of the post on two perpendicular sides beginning at the first row of element nodes below grade and extending to the bottom of the post, as shown in figure 1. The model consists of 154 discrete nonlinear spring elements (all springs are not shown in the figure for simplicity.) The stiffness of the springs is provided by load curves that are defined by the previous equation in which the spring stiffness increases with depth.

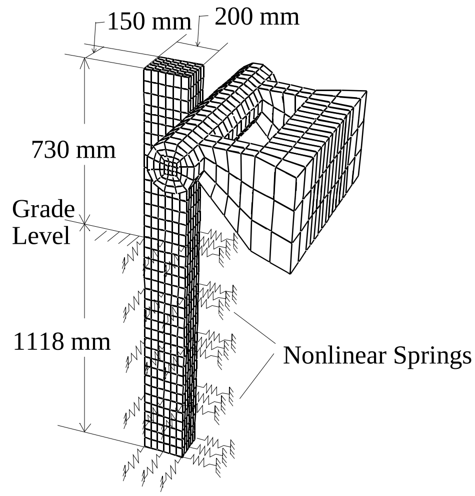

Figure 1. Finite element model

The springs in the model do not support the post in the vertical direction, therefore, the post was constrained in the vertical direction at one node on the back-side of the post (Sogge et al., 1980). Even though some vertical displacement is expected at grade level as that portion of the post pushes down into the soil, the amount of deflection is small and its effect on the simulation was considered to be insignificant.

Application and Results

The results of the analysis were compared to test data obtained from the literature (Holloway et al., 1996). The tests were performed using timber and steel guardrail posts embedded in cohesive and noncohesive soils.

The timber posts were rough sawed 150x200 mm Southern Yellow Pine. The noncohesive soil used in the tests was a dry poorly graded sand classified as an A-3 soil under the AASHTO soil classification system. The dry unit weight of the soil was not reported, therefore an estimated value of 1.806E-05 N/mm^3 was used in the calculations based upon the soil type and gradation. The angle of internal friction was approximately 35 degrees.

A steel frame bogie cart ballasted to a test weight of 1,388 kg impacted the guardrail posts at (32.9 km/hr). The striking surface of the bogie was a 200 mm diameter concrete filled standard steel pipe mounted 533 mm above grade (Holloway et al., 1996). A comparison between the analysis and the test is shown in figure 2. The initial impact forces are much higher in the simulation than in the test due to the high contact stress produced when the rigid bogie contacts the deformable post, but over the duration of the impact event the simulated response compares well with the test data.

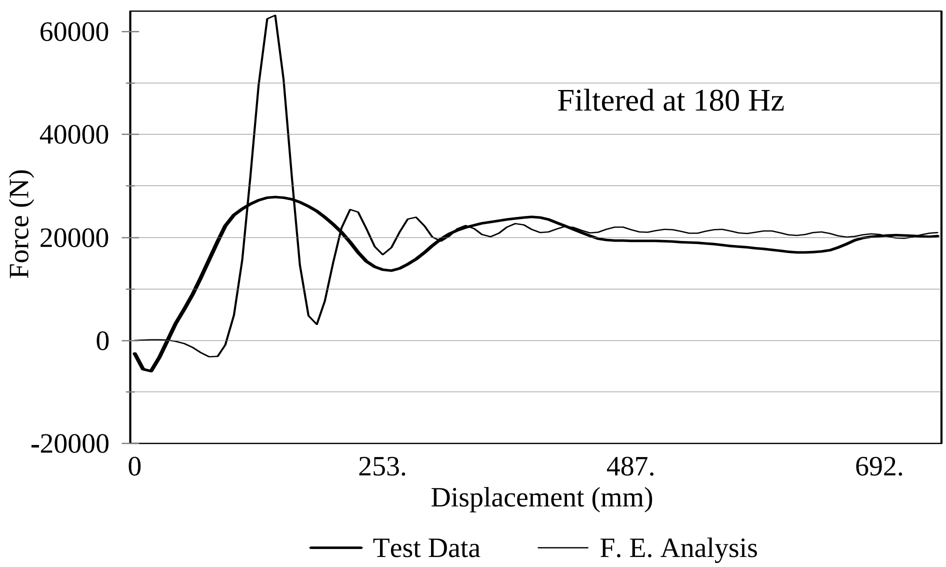

Figure 2. Force vs deflection of pendulum test and finite element analysis

Conclusions

The subgrade reaction method provides a computationally efficient and reasonably accurate method of modeling the behavior of dynamically loaded guardrail posts. The model is flexible enough to allow parametric investigation using a variety of soil characteristics such as moisture content, density and bearing capacity.

References

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