Effect of Post and Soil Strength on the Performance of a Guardrail Terminal

Greg S. Patzner[1], Chuck A. Plaxico[2], Malcolm H. Ray[3]

Abstract

The effect of wood post strength and soil strength on the dynamic performance of guardrail systems has long been a concern of the roadside safety community. Evidence from full-scale crash tests has suggested these parameters may significantly effect guardrail system performance. Essentially identical tests have resulted in widely varying outcomes that might be the result of varying post strengths and soil conditions.

A finite element model of a common guardrail terminal, the Modified Eccentric Loader Breakaway Cable Terminal (MELT), was developed to examine the effect of post and soil strength on the overall performance of the terminal system. A matrix of twelve simulations of a particular full-scale crash test scenario were conducted to establish the combinations of post and soil strengths that produce favorable results. The finite element simulations were conducted using the explicit nonlinear dynamic finite element software, LS-DYNA3D (Hallquist et al., 1994). The parametric simulations show that many combinations of soil and post strength increase the possibility of wheel snagging, pocketing, or rail penetration, while other combinations produce more favorable results. This parametric study helps identify design specifications that will maximize the safety and reliability of the guardrail terminal system.

Introduction

---

[1] Graduate Research Assistant, Center for Computer-Aided Design, University of Iowa, Iowa City, IA 52242. gpatzner@ccad.uiowa.edu

[2] Associate Research Scientist, Center for Computer-Aided Design, University of Iowa, Iowa City, IA 52242. cplaxico@ccad.uiowa.edu

[3] Assistant Professor of Civil Engineering, Center for Computer-Aided Design, University of Iowa, Iowa City, IA 52242. mhray@ccad.uiowa.edu

Guardrail terminals have been a focus of attention in roadside safety research for several decades. Guardrail terminals are one of the most challenging types of roadside hardware to design. Recently, three nearly identical full-scale crash tests produced widely varying results (Strybos and Mayer, 1997; Patzner, 1997). One possible explanation for the differences was variation in the post strengths and soil conditions.

The impact conditions for these full-scale tests were a 2000-kg pickup truck striking the terminal at a 20 degree angle with a velocity of 100 km/h, corresponding to NCHRP Report 350, test designation 3-35 (Ross et al., 1993). The impact point was at the third post from the beginning of the installation. The purpose of this test was to ensure that the terminal was sufficiently anchored to allow the vehicle to redirect. In the first test, Grade No. 2 posts were installed in a moderately strong soil with typical moisture content of 6.5%. This test resulted in rupture of the guardrail at the splice located at the downstream end of the terminal, and allowed the vehicle to penetrate the barrier. In the second test, Grade No. 1 Dense wood posts were used. The results of this crash test, however, proved to be unacceptable as well due to snagging of the front impact side wheel assembly on a guardrail post. The snagging of the wheel on the post caused extensive damage and instability of the vehicle, causing it to overturn. The cause of the wheel snag could not be precisely determined, but relatively wet soil conditions with a moisture content of 10.3% on the day of the test were suspected to have played a role in the failure. A third test was conducted using Grade No. 1 Dense wood posts mounted in a moderately strong, dry soil. This successful test met all crash testing specifications given in NCHRP Report 350.

A finite element model of the MELT used in the full-scale tests was developed in which the soil and wood post strengths could be varied parametrically. The soil model used the subgrade modulus approach, in which the posts were supported by an array of uncoupled nonlinear springs. Equations governing the stiffness of the springs contained parameters representing the moisture content, density, and angle of internal friction of the soil (Plaxico et al., 1998). The wood post model used an isotropic-elastic-plastic material model that includes a stress-based element failure criterion. Although wood is a complex anisotropic material, the isotropic-elastic-plastic model was validated through comparisons to physical testing (Plaxico et al., 1998).

Parametric Study of the Post and Soil Strength

Twelve finite element simulations were conducted involving three different post strengths and four different soil strengths. The soil strengths were determined by selecting different levels of moisture content, while holding all other parameters constant. The three post strengths corresponded to Grade No. 2 and Grade No. 1 Dense posts, as well as a post strength weaker than typical Grade No. 2. Three primary criteria were considered in evaluating the matrix of simulations: pocketing, wheel snagging, and guardrail rupture.

The potential for pocketing of the vehicle was determined from the maximum guardrail deflection. As shown in Figure 1, for a given post strength, the maximum guardrail deflection was relatively high for soils with a lower effective unit weight. As the effective unit weight of the soil initially increased, the maximum deflection decreased. This indicates that the soil strength is the parameter governing the dynamic response of guardrail systems installed in soils with a lower unit weight. At some critical soil strength, however, the post failure becomes the dominant factor in simulations involving Grade No. 2 and weak Grade No. 2 posts. When the soil becomes strong enough, it induces quicker failure of the posts because stresses are concentrated near the ground line. The result is larger guardrail deflections and increased chances of pocketing. In simulations involving Grade No. 1 Dense posts, however, the post failure effect does not become dominant. It appears that at this high post strength, the soil strength remains the dominant factor controlling the amount of guardrail deflection. Maximum guardrail deflection steadily decreased as the effective unit weight of the soil increased. The soil was not able to become strong enough to induce any additional post failure. Any increase in post strength above Grade No. 1 Dense will not greatly affect the performance of the guardrail system. Regardless of post strength, the amount of soil resistance on the anchor post seemed to govern the trend for soils with a high effective unit weight. As the soil resistance on the anchor post was increased, no more posts were broken, allowing less movement of the end post and, therefore, less guardrail deflection. Also determined from simulations for any given soil strength, as the post strength increases, guardrail deflection decreases. It was determined from the study that weak posts combined with either weak or strong soil produce the greatest potential for pocketing.

The potential for wheel snagging was measured from the peak accelerations of the front impact side wheel assembly. The most significant discoveries made regarding wheel snagging involved the high strength Grade No. 1 Dense posts and the weak Grade No. 2 posts. The peak accelerations observed for the mid-strength Grade No. 2 posts were constant across soil strengths and exhibited relatively lower potential for wheel snagging. Grade No. 1 Dense posts produced higher peak accelerations, especially in stronger soils. The weak Grade No. 2 posts, however, produced elevated accelerations in low strength soils, but not high strength soils. It could be concluded from the study and from evidence in full-scale tests that weak soil combined with either strong posts or very weak posts produce the most potential for wheel snagging.

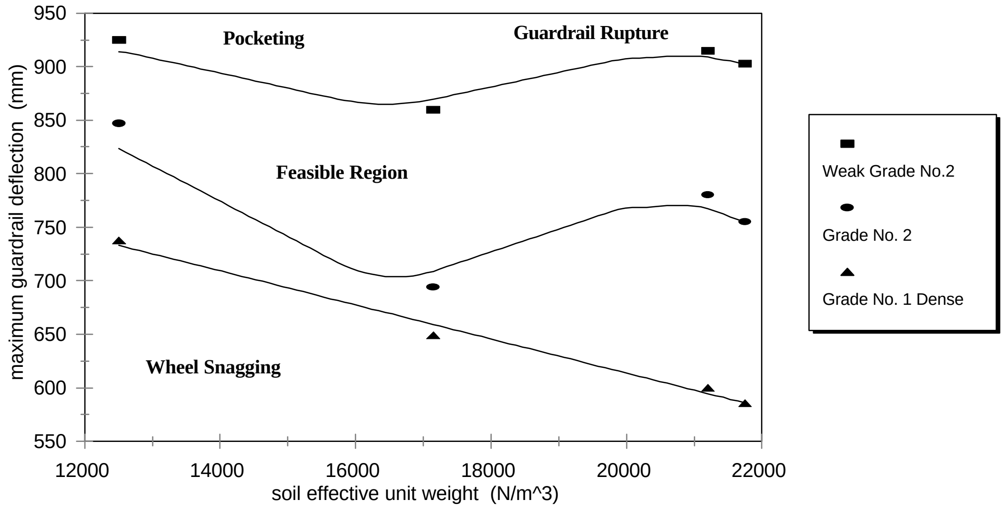

Figure 1. Feasible region of post and soil strengths

The potential for guardrail rupture was evaluated from the cross section forces observed near the splice that ruptured in the full-scale test. In general, the study showed that as the post strength increased, the possibility of guardrail rupture decreased. Also, as the soil strength increased, so did the chances of guardrail rupture. Simulations involving Grade No. 1 Dense posts, however, deviated slightly from the general trends. When Grade No. 1 Dense posts were mounted in a weak soil, the cross section forces were higher than those observed with weaker posts, but were still well below the magnitude of forces observed in strong soils. The combination of strong soil and weak posts, therefore, was the least favorable condition in regards to guardrail rupture.

Conclusions

During this investigation of the effect of post and soil strength on the performance of the MELT, several hypotheses were conceived in correspondence to each of the measurements for potential failure of the system. Each hypothesis eliminated a portion of the possible post strength and soil strength parameters from those that are likely to produce successful redirection of the vehicle in an NCHRP Report 350 test designation 3-35 impact scenario. Figure 1 shows the three potential failure regions on a plot of the maximum guardrail deflection against the soil effective unit weight and forms a feasible region of post and soil strengths. Although the boundaries created in the study are not firmly set and may be modified upon further investigation, they provide a basic understanding of the effect that the soil strength and post strength have on performance of the MELT in a redirection impact.

References

Hallquist, J.O., and D.W. Stillman, and T.L. Lin. LS-DYNA3D Users Manual - Version 930, Nonlinear Dynamic Analysis of Structures in Three Dimensions. Livermore Software Technology Corporation, April 1994.

Patzner, G.S. Effect of Wood Post Strength and Soil Strength on the Performance of the Modified Eccentric Loader Breakaway Cable Terminal (MELT) Under Impact Conditions Prescribed by NCHRP Report 350, Test 3-35. Masters thesis, Univ. of Iowa, Dec. 1997.

Plaxico, C.A., and G.S. Patzner and M.H.Ray. Response of Guardrail Posts Under Parametric Variation of Wood and Soil Strength. Transportation Research Board, 1998.

Ross Jr., H.E., and D.L. Sicking, R.A. Zimmer, and J.D. Michie. Recommended Procedures for the Safety Performance Evaluation of Highway Features. National Cooperative Highway Research Program Report 350, Transportation Research Board, Washington, D.C., March 1993.

Strybos, J., and J. Mayer. Full-Scale Crash Evaluation of a Modified Eccentric Loader Terminal, NCHRP Report 350 Test Designation 3-35, SwRI Test No. MLT-3. Federal Highway Administration, Washington D.C., February 1997.

Keywords:

1. Finite element
2. Guardrail
3. Soil
4. Wood Post
5. Roadside Safety
6. LS-DYNA3D
7. MELT
8. Terminal
9. Simulation
10. NCHRP