Quarterly Progress Report

To the

National Cooperative Highway Research Program
(NCHRP)

On Project 22-12(3)

RECOMMENDED GUIDELINES FOR THE SELECTION OF TEST LEVELS 2 THROUGH 5 BRIDGE RAILINGS

For period
October 1 to December 31, 2011

From
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Introduction

The objective of this project is to develop recommended guidelines for the selection of Test Levels 2 through 5 bridge rails considering in-service performance. This report will describe the progress achieved in this project in the previous quarter with respect to the seven tasks identified in the work plan. The following sections will describe the task-by-task progress identifying work items accomplished and any problems encountered in the research. A section describing the contractual status of the project (i.e., funding, schedule, etc.) appears at the end of the report and the progress summary tables and plots appear in Attachment A.

Panel comments and research team's responses on previous quarterly reports are included as Attachment B (with the exception of some editorial comments on Attachment D there were no comments on last quarter's report). This quarterly report and attachments as well as all future quarterly reports can be found on the World Wide Web at http://www.roadsafellc.com/NCHRP22-12-3/QPR/. In order to comply with the NCHRP Limited-Use document policy, all the documents on the project webpage have been password protected such that they are accessible only to the project research team and panel. All the documents are password protected PDFs and the password for all documents in this project is "Hatton."

Task 1: Literature Review

<u>*Statement of Work*</u> *Conduct a literature review to collect and summarize existing information regarding in-service performance of bridge rails and barrier selection guidance.*

This task is now complete.

Task 2. Survey of States

Conduct a survey of states to determine their practices and policies regarding the selection of bridge rails. This survey should also determine the need for guidance on bridge rail test level selection.

This task is now complete.

Task 3. Interim Report

Submit an interim report that summarizes Tasks 1 and 2 and includes an updated work plan for the remaining tasks. The work plan shall include priorities and budgets for developing guidance for selecting the appropriate bridge rail. It is recognized that multiple studies may be required to address all aspects and that the total cost may exceed the available project funds.

This task is now complete.

Task 4. Panel Meeting

Approximately 1 month after submittal of the interim report, meet with the NCHRP panel to review the report and proposed work plan. Work on Task 5 shall not begin without prior approval of NCHRP.

This task is now complete.

Task 5. Execute Approved Work Plans

Execute the approved work plan.

NCHRP Project Staff notified the research team that the Phase II work plan was approved by the panel on May 5th. The project was divided into three Phases. Phase I, which includes Tasks 1 through 4, is complete and consists of the preliminary work in the project. Phase II involves Tasks 5 through 7. In order to fit the scope of work into the available time and funding, the panel directed the research team to limit its investigations in Phase II to the closed-profile concrete family of bridge railings. These railings would be the New Jersey and F shapes, the vertical wall and constant slope wall. The only close-profile concrete railing that would be useful for representing TL-2 is the low-profile concrete railing. There is some installed inventory in Iowa, Florida and Texas. Phase III would involve similar activities as Phase II but addressing a much broader range of bridge railings. At this time, Phase III is unfunded but the research team and panel anticipate that the results of Phase II will be an effective pilot study that demonstrate to SCOR the importance of further work on this topic.

Task 5A: Concrete Safety Shape Bridge Rail Capacity Data
The research team is still gathering and reviewing barrier capacity data from TTI and MwRSF. This task is still underway, so final results and conclusions are not yet available; however, a preliminary analysis of the results was presented in the previous quarterly report in Attachment G5.

In another on-going project (i.e., NCHRP project 22-27), Ray, Carrigan and Plaxico are developing a barrier penetration model for use in the update to RSAP (i.e., RSAPv3). Attachment E provides a discussion prepared for NCHRP 22-27 describing how penetration is being handled in the updated RSAP that will be used in this project. The approach used in their study is based on a combined mechanistic-probabilistic approach using crash statistics. The type of barrier performance is obviously dependent on the impact conditions of the encroaching vehicle and a variety of approaches have been used in past roadside safety cost-benefit programs. BCAP, a program developed to do benefit-cost in the selection of bridge railings in the 1980's, used a mechanistic approach to predict penetration and rollover in truck crashes; the ABC program, an updated version of BCAP, introduced improved equations for penetration and rollover; the earlier versions of RSAP used the impact severity (IS) to help predict penetrations. In all of these cases, a simple equation for predicting rollover or penetration was used and compared to some critical value. There are two main difficulties with this mechanistic approach: (1) Vehicle dynamics are complicated and not easily reduced to one simple equation and (2) The capacity of barrier is typically not known since tests to failure are seldom performed. For these reasons mechanistic methods have not worked particularly well in benefit-cost cost programs like RSAP.

The 22-27 research team explored the strengths and weaknesses of both the mechanistic and probabilistic approaches and determined that the best compromise considering accuracy, implementation and model development was to use a combined mechanistic-probabilistic approach. Since crash reconstruction data does not accurately distinguish between barrier penetrations caused by (1) structural failure, (2) rolling over the barrier and (3) vaulting, those events were combined into a single variable denoted by the acronym, PRV (Penetration/Rollover the barrier/Vault).

While mechanistic methods have the advantage that they are grounded in the physics of the problem, getting a simple closed-form solution usually involves making many broad assumptions about the impact which may or may not be correct, as was discussed in Attachment G5 in the previous Quarterly Report. Simple one-equation models like those used in BCAP and RSAP 2.0.3 simply are not adequate to capture the full range of vehicle dynamics, and it is not practical to incorporate detailed nonlinear dynamic impact analysis to investigate vehicle trajectory and collision due to the extensive computations that are typically required in such an effort; particularly in the context of RSAP where tens of thousands of simulated encroachments are needed.

A major flaw with most mechanistic penetration models is that once capacity has been reached it is assumed the barrier is totally compromised when in fact the capacity load is really just the beginning of the failure process. The barrier may often contain and redirect the vehicle even though there are structural failures. In other words, reaching capacity does not necessarily mean the vehicle will penetrate the barrier.

These weaknesses in the mechanistic approach lead the research team to strongly consider the probabilistic approach. The advantage of a statistical approach is that a complete understanding of the physics of the problem is not required since the data represents the real events. The disadvantage is that such methods require that there be crash data available in sufficient quantities to develop meaningful statistical models.

As mentioned earlier, the approach adopted for use in RSAP v3 is a combined mechanistic-probabilistic approach where the probability of penetration is determined based on three basic criteria:

- **Criterion A:** If the *structural capacity* of the barrier is less than the *impact severity* (IS) [Olsen,], then penetration occurs.
- **Criterion B:** If the *capacity* of the barrier is greater than the *kinetic energy* (KE) of the vehicle then all the kinetic energy of the vehicle would have been expended before the capacity of the barrier was breeched. In this case the probability of penetration is set to zero.

- **Criterion C:** If, however, the barrier capacity is greater than the impact severity and is less than the kinetic energy of the impacting vehicle, then the probability of penetration is based solely on crash statistics.

An alternative method being considered for use in RSAPv3 is to assume that for very low impact speeds and angles (i.e., low *IS* values) the probability of penetration would be very low and would increase gradually as the impact conditions approached the capacity of the barrier. Further, the probability of penetration when impact conditions are at barrier capacity should not be 100%, but should continue to increase toward 100% as the impact conditions continue to increase beyond barrier capacity. A possible representation of such a model is based on a hyperbolic tangent function defined by:

$$P(Penetration|collision) = 0.5 * \tanh\left[\left(\frac{IS}{Capacity} - A\right) * B\right] + 0.5$$

Where *A* defines the point of symmetry of the curve and *B* controls the rate of change in probability (i.e., the steepness of the curve) as the curve approaches and passes through the point of symmetry of the curve. As the value of *B* decreases, so does the slope of the curve at the point of symmetry. Figure 10 in Attachment E shows a possible probability function using the above equation with *A* = 1 and *B* = 4. In this example, the theoretical capacity of the barrier is the point of symmetry. As with all probabilistic models, however, it is necessary to have crash data available in sufficient quantities to develop meaningful statistical models.

Task 5B Concrete Safety Shape Bridge Railing Validation Data
Work is continuing on analyzing crash data from a variety of States. A summary of the data which has been collected and the results obtained to-date have been included in Attachment D. The research team has used concrete median barriers to determine the severity of bridge rail crashes, as described in the attachment. The consequences of penetrating the bridge rail will be further evaluated this quarter. The team has completed the analysis of data from New Jersey, Washington, Massachusetts and Pennsylvannia. We have obtained and in the process of analyzing data from Texas and Kansas and these analyses should be complete in the coming quarter.

Task 5C: Concrete Safety Shape Bridge Railing Costs
This subtask is now complete was documented in Attachment E5 and Attachment F5 of the last quarterly progress report.

Task 5D: Develop Guidelines for New Construction Concrete Safety Shaped Bridge Railings

This subtask has not been initiated.

Task 6. Recommendations

Submit the recommended guidelines. After review by the NCHRP, arrange for the AASHTO Highway Subcommittee on Bridges and Structures, T-7 Technical Committee for Guardrail and Bridge Rail to review the draft guidelines. If appropriate, revise the draft guidelines.

This task has not been initiated.

Task 7. Final Report

Submit a final report that summarizes the entire research effort and includes the guidelines in a stand-alone appendix.

This task has not been initiated.

Contractual

A summary of the progress and fiscal status of the project is shown in Attachment A.

Sincerely,

Malcolm H. Ray, P.E., Ph.D.

Attachment A: Fiscal and Schedule Summary
Attachment B: Panel Comments
Attachment C: Recent Example of a Bridge Penetration
Attachment D: Closed-Profile Concrete Bridge Railing Validation Data
Attachment E: Penetration Considerations