Quarterly Progress Report #1

To the

Maine Department of Transportation
(MEDOT)

Project NETC 18-1

Development of MASH Computer Simulated Steel Bridge Rail and Transition Details

Research Agency: Roadsafe LLC, Canton, ME
Principal Investigator(s): Chuck A. Plaxico, Ph.D.

State Project No.: 023430.18
Federal Project No.: 2343018

Project Start Date: 09-October 2018 Contract Funds Approved: $199,936.20
Project Completion Date: 31-December 2019 Spent to Date: $32,720.95
Funds Expended 16.36% Work Done 16.36% Time Expired 20%

List the Technical Liaisons and other individuals who should receive copies of this report:

Jeff Folsom, Alex Bardow, David Kilpatrick, James LaCroix, Bob Landry, Chris Mooney, Dale Peabody, Michael Savella, Georgette Chahine, and Kirsten Seeber.

Introduction

The objectives of this project are to: 1) review existing NETC bridge rail and AGT designs and assess performance aspects to determine preliminary MASH compliance/equivalency, 2) review current standard details and specifications for NETC style bridge rails and transitions used by MaineDOT, NHDOT, RIDOT and VTrans to identify differences in material specifications and dimensional details and 3) evaluate the crash performance of the NETC bridge rail and approach guardrail transition (AGT) designs using finite element analysis (FEA) computer simulation. The impact conditions and assessment procedures for the FEA will conform to the specifications in *MASH* for TL-3 or TL-4 (as appropriate) and will included evaluations of structural capacity of the railing, risk of occupant injury, and vehicle stability during impact and redirection. The systems included in the evaluation are listed below along with the target test level for each system:

- Bridge Rail Systems:
  - NETC curb-mounted 2-Bar Rail (TL3)
  - NETC curb-mounted 3-Bar Rail (TL4) (4-bar curb mounted NETC rail would be considered equivalent to this type)
  - NETC sidewalk-mounted 4-Bar Rail (TL4)
- Bridge Rail Transitions:
  - NETC Style 2-Bar Rail to Thrie Beam (TL3) (NHDOT steel rail transition)
  - NETC Style 3-Bar Rail to Thrie Beam (TL4) (NHDOT steel rail transition)
  - Concrete Transition Barrier to Thrie Beam (TL4) (MaineDOT standard detail)

This report will describe the progress achieved in this project in the previous quarter with respect to the eight (8) 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. A summary of the fiscal and schedule status of the project is included in Attachment A. The research team's responses to panel comments on previous reports (e.g., QPR and interim reports) is provided in Attachment B.

Task Summaries

Task 1. Literature Review and Preliminary Assessment of Current Designs

A review of published literature and ongoing research will be conducted to investigate performance aspects of select bridge rail systems used among the Northeast States, as well as, other designs that have demonstrated MASH compliance/equivalency.

This task was completed this quarter. A draft interim report detailing the findings of Task 1 was submitted to MEDOT on 12/18/2018. This report was revised and resubmitted 1/4/2019. The following is a brief summary of the conclusions.

A critical review of current standard details and specifications for NETC style bridge rails and transitions used by MaineDOT, NHDOT, RIDOT and VTrans was performed to 1) determine *MASH* equivalency for each State's design per Section 13 of the AASHTO *LRFD Bridge Design Specifications [AASHTO12]* and 2) identify differences in material and dimensional details for each state's design. Preliminary recommendations for standardized designs were then provided based on the review to better ensure consistency for NETC style designs, considering constructability and performance. The crash performance of the recommended designs will be further evaluated based on *MASH* crash testing conditions and criteria using finite element analysis in subsequent tasks of this study.

In most cases, the recommendations included the least conservative value for each design detail, which has either shown acceptable R350 crash testing performance or met the LRFD strength criteria for *MASH* loading. In this way the more conservative design details are assumed to have sufficient strength. The one exception was the sidewalk-mounted 4-bar design, which did not meet the current recommended strength requirements based on the LRFD calculations. In that case, it was decided that the current design would be evaluated using finite element analysis to determine crash performance (e.g., MASH TL-3 or TL-4).

Redesign of the bridge rail systems is outside the scope of the study; however, if the FEA analyses shows poor performance for any system design, then recommended modifications will be provided for improving crash performance.

For more details on this task, refer to the interim report or chapter 3 of the Draft Project Report included as Attachment E with this QPR.

Task 2. Finite Element Model Development and Validation

The design details approved by MaineDOT in Task 1 will be evaluated using finite element analysis (FEA). Prior to use of the models for assessing the crashworthiness under MASH conditions, detailed FEA models of select bridge rails and transition systems will be developed, and the finite element analysis code LS-DYNA will be used to simulate crash tests to assess the validity of the models.

Task 2a: Development and Validation of NETC 4-Bar Bridge Rail Model

This task was initiated this quarter. (i.e., Quarter 1) and was completed at the beginning of Quarter 2. The details of this task are included in chapters 5 and 6 of the Draft Project Report in Attachment E. A brief summary of this task and conclusions is provided below.

A detailed finite element model of the NETC 4-Bar bridge rail was developed based on construction drawings provided in the full-scale test report for this system and the standard drawings for NHDOT. The FEA model included 120 feet of the bridge rail. The basic components of the bridge rail model include:

- Fifteen (15) W6x25 posts,
- One (1) 12”x10”x1” post-base plate at each post,
- Four (4) anchor bolts at each base plate connecting the base plate to the sidewalk/deck,
- Fifteen (15) HSS 4 x 4 x ¼-inch tube rails that are 23.94 feet long (each) and hardware,
- Five (5) HSS 8 x 4 x 3/16-inch tube rails that are 23.94 feet long (each) and hardware,

- Twenty (20) splice tubes 20 inches long (each) made from 3/8-inch thick steel plate and bolt hardware,
- Concrete sidewalk and short length of bridge deck based on NHDOT drawings,
- Sidewalk steel reinforcement based on NHDOT drawings.

The model includes fifteen posts spaced at 8 feet (typical) on centers; and five sections of tube railing at 23.94" each, including splice connections with a ¾-inch splice gap between adjoining rails. The geometry of these components was modeled according to the drawings in the test report. Additional details of the FEA model for each of the bridge rail components, including material characterization and element formulations, are provided in the Draft Project Report.

The baseline finite element model of the NETC 4-bar bridge rail was used to simulate full-scale crash NETC-3. The test corresponded to R350 Test 4-12 on the sidewalk-mounted bridge rail system. The results of the analysis were compared to the full-scale tests to validate the fidelity of the model. The validation included qualitative assessments included: (1) comparing sequential snapshots of the test and simulation to verify vehicle kinematic response, as well as, the sequence and timing of key phenomenological events, (2) comparing acceleration and angular-rate time-history data from the FEA and test, and (3) comparison of crash-specific phenomena from the event related to structural adequacy, occupant risk and vehicle trajectory.

There were issues regarding missing information from the test data that were noted. In particular, the physical properties of the test vehicle were not included in the test report but were visibly different than that of the FEA model. Also, quantitative comparison of the time-history data could not be performed since the test data was not available.

In general, the results of the analyses demonstrated that the finite element model replicated the basic phenomenological behavior of the system under Report 350 Test 4-12 impact conditions. There was good agreement between the tests and the simulations with respect to event timing, overall kinematics of the vehicle, barrier damage, and deflections. One exception involved the rear bumper snagging on the bridge rail resulting in higher longitudinal deceleration of the vehicle than occurred in the FEA. The model is, however, considered adequately "valid" and will be used as a baseline model for developing and evaluating MASH impact conditions for the NETC bridge rails.

Task 2b: Development and Validation of NETC AGT to 2-Bar Bridge Rail Model

This task was initiated this quarter. A task report will be included in the next QPR.

A finite element model of the NETC AGT to 2-Bar bridge rail is being developed and validated based on comparison to Test 401181-1 (i.e., R350 Test 3-21). The NETC design contains many of the same components of the MassDOT transition; thus, the development of the FEA model for the NETC design is relying heavily on the model previously developed for MassDOT in a recent study performed by the research team. In particular, the two systems have the following components in common:

- W-beam rail and hardware
- Nested thrie-beam rail and hardware
- 6x8 wood posts and blockouts

- Post-in-Soil model
- Thrie-beam transition rail. Note that the current NETC design uses a symmetrical thrie-beam transition rail; thus, the symmetrical transition rail design will be developed based on the modeling methodology used for the asymmetrical design.

A portion of the 2-Bar bridge rail is also being modeled. This portion of the model will be developed relying on the modeling methodology and existing model components for previous hardware models when applicable (e.g., 4-Bar model developed in Task 2(a), bridge rail models developed for NYSTA, as well as for MassDOT).

The results of the analysis will be qualitatively and quantitatively compared to the full-scale test results using the verification and validation procedures of NCHRP Web-Document 179 to ensure that the model provides realistic and valid results. The level and detail of the validation will depend upon procuring sufficient test data, including electronic accelerometer and rate gyro time-history data, as well as test videos.

Task 3. MASH TL4 Evaluation of NETC 3-Bar Bridge Rail

The finite element models developed in Task 2 will be used as a baseline for developing the NETC 3-Bar bridge rail which will include any design revisions proposed in Task 1 and approved by the project TAC. The model will be used to assess crash performance of the system under MASH testing conditions and criteria.

This task has not yet been initiated.

Task 4. MASH TL3 Evaluation of NHDOT AGT to 3-Bar Bridge Rail

The finite element models developed in Task 2 will be used as a baseline for developing the transition system for the NETC 3-Bar bridge rail and will include any design revisions proposed in Task 1 and approved by the project TAC. The model will be used to assess crash performance of the system under MASH testing conditions and criteria.

This task has not yet been initiated.

Task 5. MASH TL4 Evaluation of NETC 4-Bar Bridge Rail

The finite element model of the NETC 4-Bar bridge rail developed in Task 2, including any design revisions proposed in Task 1 and approved by the project TAC, will be used to assess crash performance of the system under MASH testing conditions and criteria.

This task has not yet been initiated.

Task 6. MASH TL4 Evaluation of MaineDOT AGT to 4-Bar Bridge Rail

The finite element models developed in Task 2 and Task 4 will be used as a baseline for developing the transition system for the NETC 4-Bar bridge rail and will include any design revisions proposed in Task 1 and approved by the project TAC. The model will be used to assess crash performance of the system under MASH testing conditions and criteria.

This task has not yet been initiated.

Task 7. MASH TL3 Evaluation of NETC 2-Bar Bridge Rail

The finite element model of the NETC 3-Bar and 4-Bar bridge rails developed in Tasks 2,3 and 5 will be used as a baseline for developing the NETC 2-Bar bridge rail which will include any design revisions proposed in Task 1 and approved by the project TAC. The model will be used to assess crash performance of the system under MASH testing conditions and criteria.

This task has not yet been initiated.

Task 8. MASH TL3 Evaluation of NHDOT AGT to 2-Bar Bridge Rail

The finite element models developed in Task 2, 4 and 6 will be used as a baseline for developing the transition system for the NETC 2-Bar bridge rail and will include any design revisions proposed in Task 1 and approved by the project TAC. The model will be used to assess crash performance of the system under MASH testing conditions and criteria.

This task has not yet been initiated.

Interim Technical Report and Meeting

The research team will submit a technical brief of the literature review conducted in Task 1 in the form of a white paper within 2 months of the start date for the project. A teleconference will then be scheduled with the MaineDOT project panel to discuss the recommended design(s) for further evaluation in Task 3

This task was completed this quarter. Refer to Task 1 and to the *Contacts and Meetings* section below for more details.

Final Deliverables

Prepare the final deliverables that documents the research effort, provides conclusions and recommendations for implementation based on system performance. In the event one or more designs are found to not meet MASH, the final report will then include analysis of design problems and recommendation on how to overcome these issues.

This task has not yet been initiated.

Contacts and Meetings

- **Kickoff Meeting –** A teleconference kick-off meeting was held between the research team, MEDOT and the project technical advisory committee (TAC) on October 29, 2018, 1-3pm EST. Jeff Folsom provided a review of the objectives and expectations of the project. Dr. Plaxico provided an overview of the project tasks, key milestones and deliverables. The meeting minutes and meeting slides are included as Attachment C.
- **Monthly Progress Meetings** – One monthly progress meeting was held this quarter on December 18, 2018. The focus of this meeting was on the results of the literature review.

Roadsafe presented the results from the literature review, comparison of designs and strength calculations for the NETC style bridge rails. The presentation complimented the draft interim report submitted on 12/13/2018. The meeting minutes and meeting slides are included as Attachment D.

Contractual

The contract was signed on 9-October 2018 with an end date of 31-December 2019. Work on the project began on October 15, 2018. A summary of the progress and fiscal status of the project is shown in Attachment A. The project was on schedule this quarter; however, due to staff vacations and the TRB winter meeting for which the staff were highly involved, the schedule for Task 2 was projected to be behind in the upcoming quarter. A revised schedule was sent to MEDOT on 12/14/2018, and the schedule extensions are noted in Appendix A. These delays are not expected to affect the overall completion schedule for the project.

Sincerely,

Chuck Plaxico

Chuck A. Plaxico, Ph.D.

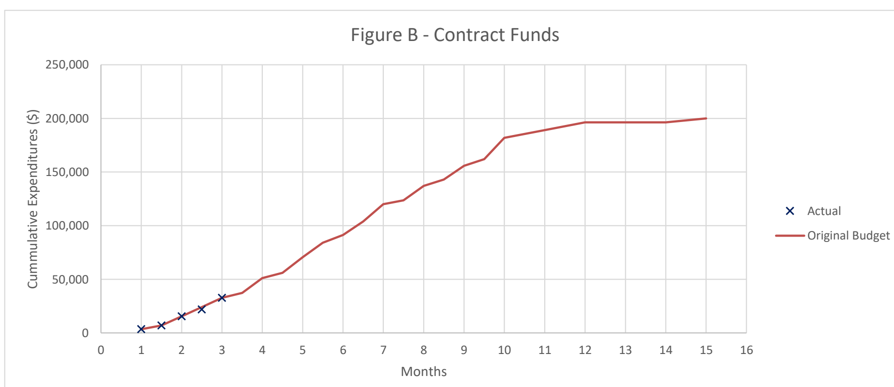
Attachment A:	Fiscal and Schedule Summary
Attachment B:	Response to Panel Comments
Attachment C:	Kick-Off Meeting Minutes and Slides
Attachment D:	Monthly Meeting Minutes and Slides
Attachment E:	Draft Project Report

ATTACHMENT A

NETC 18-1 Progress Schedule
QPR 01 - 3rd Quarter 2018
31-Dec-18

Task		Task Description	QTR	QTR 1			QTR 2			QTR 3			QTR 4			QTR 5			%
NO.	Code		Month	Oct	2	3	Jan	5	6	Apr	8	9	July	11	12	Oct	14	15	Complete
1	Literature Review	Literature Review and Preliminary Assessment of Current Designs		25	50 75	85 100													100
2(a)	BR Model Validation	Development and Validation of NETC 4-Bar Bridge Rail Model			25	50 80													80
2(b)	AGT Model Validaiton	Finite Element Model Development and Validation of 2-Bar AGT				10													10
3	3-Bar BR (TL4)	TL4 Simulations of the NETC 3-Bar Bridge Rail Design																	0
4	3-Bar AGT (TL4)	TL4 Simulations for AGT to 3-Bar Bridge Rail																	0
5	4-Bar BR (TL4)	TL4 Simulations for the NETC 4-Bar Bridge Rail Design																	0
6	4-Bar AGT (TL4)	TL4 Simulations for AGT to Concrete Abutment																	0
7	2-Bar BR (TL3)	TL3 Simulations of the NETC 2-Bar Bridge Rail Design																	0
8	2-Bar AGT (TL3)	TL3 Simulations for AGT to 2-bar Bridge Rail																	0
9	Interim Meetings	Interim Reports / Meetings				13													12.5
10	QPR	Quarterly Progress Reports																	0
11	Final Report	Final Report																	0

Original Schedule
Projected Schedule



Funds Expended:		16.36%	Time Expended:	20%
Contract Amount:	$	199,972	Start Date:	10/9/2018
Expended this Quarter	$	32,720.95	Completion Date:	12/31/2019
Total Expended to Date:	$	32,720.95		
Balance:	$	167,251.05		

ATTACHMENT B

MEDOT Project NETC 18-1
Development of MASH Computer Simulated Steel Bridge Rail and Transition Details

Review of the Task 1 Report
Comments

Panel member comments on the Task 1 report are shown below in a regular font. The research team's responses are shown in an italic font.

Reviewer No. 1

My only comment is I am surprised that 2" of curb reveal makes such a difference that under 9" reveal the system passes, but under the 7" reveal it does not from a moment capacity standpoint. We can also increase our curb concrete strength to 5,000 psi pretty easily.

The research team is not exactly clear on the comment. It is assumed that the reviewer is referring to the curb-mounted 3-Bar bridge railing. From Table 11 in the interim report (and Attachment E with this QPR) both the 7" and 9" curb results in adequate strength. Table 5 and Figure 8 of that report indicates that the 7" curb results in insufficient contact width on the face of the railing with respect to the height of the bridge rail (i.e., Contact/Height < 0.6). This is also reflected in Table 14 (i.e., Summary of MASH equivalency assessment for the NETC bridge rail designs).

The FEA analysis results in Task 3 will provide additional information regarding the performance of the 3-Bar system on the 7" curb with 4,000 psi concrete, since that was the design selected for further review by the TAC (refer to Table 50 in Attachment E).

I would recommend the 4-bar sidewalk mounted rail be the standard for all 4 bar efforts as the curb mounted 4-bar should meet the requirements if the sidewalk mounted rail does. (We typically use 3-bar curb mounted rail opposite a sidewalk.)

The reviewer is correct. This is also reflected in the RFP and proposal. Analysis of the curb-mounted 4-Bar system is not part of the scope of work in this project.

We would also be good with using M270 Gr 50 for our post material type.

Although consistency for material specifications is a goal of the project, the strength properties of M270 Gr 50, ASTM A709 Gr 50 and ASTM A572 Gr 50 are equivalent (see Table 9 of Attachment E).