Semi-Annual Progress Report

Date of Report: February 27, 2009 **Project Number:** 9-4973 **RMC:** 5

Period Covered: [X] September 1, 2008 – February 28,2009 [ ] March 1 – August 31

Project Title: Guidelines for Designing Bridge Piers and Abutments for Vehicle Collisions

Research Supervisor (name & agency): C. Eugene Buth, TTI

Please see note about contract modification at the end of this report.

1. Progress to Date, by Task

Task # 1a.	**Task Name / Description** Literature Review
% Complete 100	**If task is complete, state when Technical Memorandum was submitted to RTI** *Technical Memorandum was submitted to RTI*
Work Accomplished this Period (Brief description of work done and any major problems encountered.)	
Work Planned for next Reporting Period (Brief description of work planned.) Researchers will continue to monitor literature.	

Task # 1b.	**Task Name / Description** Computer simulations of vehicle/bridge column and abutment collisions
% Complete 75%	**If task is complete, state when Technical Memorandum was submitted to RTI**

Work Accomplished this Period (Brief description of work done and any major problems encountered.)

The last two simulation matrices were conducted using the tractor-trailer vehicle model. TTI researcher measured the dimensions of an existing trailer as well as collected information from online web sites of manufactures of such trailers. Then the TTI research team constructed the trailer model along with needed mechanism for the rear tandem axels and king pin to fifth wheel interactions. Material properties of the trailer bed and other components were assigned to reflect the proper physical behavior of such components. Contacts were defined to capture the physical impact phenomena among the components of the tractor and the trailer bodies.

Once the tractor trailer model was complete, several simulations were conducted to measure the impact force exerted on a 36" rigid column using both rigid and soft ballast for a total vehicle weight of 80 k lbs. Velocities of 40, 50, and 60 MPH were evaluated. Results for peak forces dues to engine block impact and ballast impact are listed in the table below.

Tractor Trailer Simulation Matrix Results Summary

	Pier Diameter	Vehicle (Weight)	Cargo/Ballast	Impact Speed	Force (Kips) Engine Block	Force (Kips) Ballast
Matrix IV	36"	Tractor-Trailer (80 k-lb)	Deformable	40	520	800
	36"	Tractor-Trailer (80 k-lb)	Deformable	50	580	
	36"	Tractor-Trailer (80 k-lb)	Deformable	60	600	1020
Matrix V	36"	Tractor-Trailer (80 k-lb)	Rigid	40	500	> 500
	36"	Tractor-Trailer (80 k-lb)	Rigid	50	550	> 2000
	36"	Tractor-Trailer (80 k-lb)	Rigid	60	600	> 2000

Work Planned for next Reporting Period (Brief description of work planned.)

Simulations section of the final report is being drafted and will be updated with the up to date simulation results. Special simulation cases may be conducted upon consultation and approval with the PD.
These potential simulation cases are:
1/ Simulation an actual impact (to be selected from the accident data collected in Task 1.c) for validation of a typical pier-bent-foundation system model.

2/ using the validated model with proper changes in simulating a proposed crash test of such a system.

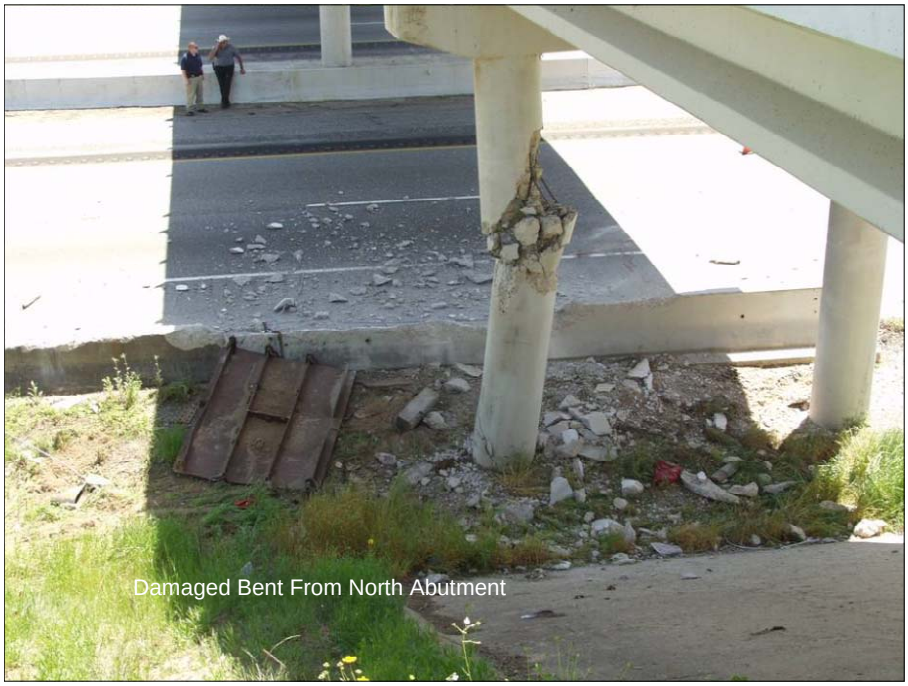
The results of these simulations will help the project in determining the parameter defining the final crash test.

Task #	Task Name / Description
1c.	Accident survey and analysis study
% Complete	**If task is complete, state when Technical Memorandum was submitted to RTI**
90%	

Data have been obtained for 12 highway collisions involving trucks and bridge piers as listed below:

Accident #1 – FM 2207 Bridge Over IH-20, Tyler, Texas

Several years ago, a truck-tractor trailer loaded with structural steel crashed into a bridge pier on IH-20 near Tyler, Texas. This bridge is located on FM 2207 and carries traffic over IH-20. This vehicle impacted the eastern-most 30-inch diameter pier of the 2-pier bent located on the shoulder of the west bound lanes of IH-20. The collision with the pier caused failure in the 30-inch diameter pier. The bridge did not collapse as a result of impact. Reinforcement in the pier consisted of eight number nine size longitudinal bars equally spaced. Transverse reinforcement in the column consisted of number two spiral stirrup reinforcement with a 6 inch pitch. Photos of the accident are shown in Figure 1.



Damaged Bent From North Abutment

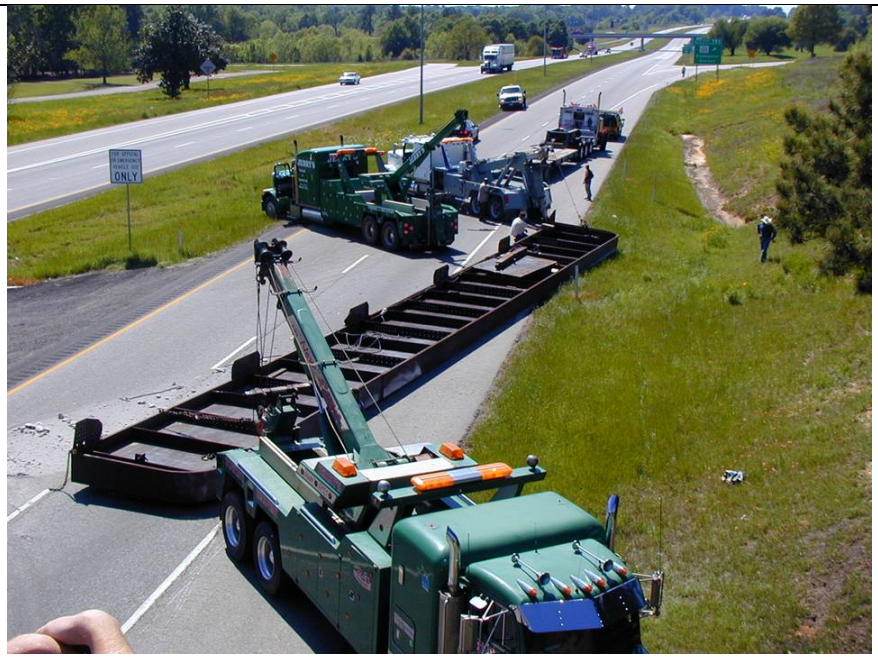


Figure 1 - Truck Accident - FM 2207 Bridge Over IH-10, Tyler, Texas

Accident #2 – Bridge Over IH-45, Dallas County, Texas

In May, 1965, a tractor-trailer with an unknown load crashed into a bridge pier on IH-45 in Dallas County, Texas. This vehicle impacted a 30-inch diameter pier of the 2-pier bent located in the median of IH-45. The collision with the pier caused failure in the 30-inch diameter pier. The bridge collapsed as a result of the impact. Reinforcement in the pier is unknown. This accident was one of the first collisions to cause catastrophic failure/collapse of a bridge in Texas from a vehicular impact.

Accident #3 – Bridge 26 ½ Over IH-70, Grand Junction, CO.

On August 15, 2007, a truck-tractor trailer loaded with 55-gallon barrels of sodium hypochlorite (flammable liquid) crashed into a bridge pier located on the shoulder of the west bound lanes of IH-70 in Grand Junction, Colorado. This bridge is located on 26 1/2 Road over IH-70. A phone interview was conducted with Colorado State Trooper John Ferguson. The vehicle impacted the bridge pier at a high rate of speed. Structural details for the bridge were not obtained. A photo of the accident is shown as Figure 2.

Figure 2 - Truck Accident – Bridge 26 ½ Over IH-70, Grand Junction, CO

Accident #4 – IH-20 Over Rabbit Creek, Longview, Texas

On September 6, 2007, a truck-tractor trailer loaded with an unknown load crashed into a bridge pier on IH-20 near Longview, TX. This bridge is supported by numerous 2 and 3-column bents. This vehicle impacted an exterior 24-inch diameter pier of and interior 3-pier bent located over Rabbit Creek of the east bound lanes of IH-20. The collision with the pier caused failure in the 24-inch diameter pier. A phone interview was conducted with Officer Chris Brock with the Texas Department of Public Safety. Officer Brock indicated that the vehicle weight was estimated to be near 80,000 lbs. The speed of the truck as it left the roadway was estimated to be between 70-75 mph. The bridge did not collapse as a result of the impact. The pier that was impacted was a 24-inch diameter pier with eight number seven size rebars in the longitudinal direction of the pier. Transverse reinforcement in the pier consisted of number two spiral stirrup reinforcement with a 6 inch pitch. A photo of the accident is shown as Figure 3.

Figure 3 - Truck Accident - IH-20 Bridge Over Rabbit Creek, Longview, Texas

Accident #5 – IH-240 Bridge over IH-40, Shelby County, Tennessee

On September 28, 2007, a truck-tractor trailer loaded with produce struck an exterior pier of a bridge carrying IH-240 over IH-40, Memphis, Tenn. The vehicle speed and weight are unknown. The 30-inch diameter pier suffered minimal damage. Structural details for the bridge pier are not known at the time of this writing.

Accident #6 – IH-275 North Ramp Bridge at IH-40 East, Knoxville, Tennessee

On December 5, 2003, a truck tractor trailer overturned on IH-275 North ramp at IH-40 East in Knoxville, Tenn. The vehicle overturned and fell to the roadway below and impacted a large bent supporting the elevated ramp. The large bent was slightly damaged. A police report was obtained. Structural details have not been obtained on the bridge pier impacted by the vehicle.

Accident #7 – Autumn Avenue Over IH-40 Ramp & IH-240, Shelby County, Tennessee

In December 1988, a propane tanker impacted near a bridge pier on the IH-40 ramp near the Autumn Avenue Bridge. The curving ramp had a posted speed limit of 25 mph. The truck caused minimal damage to the 3-ft. diameter bridge pier. The speed and weight of the vehicle at not known. The propane tanker exploded during the accident and caused severe damage to the bridge.

Accident #8 – IH-580/IH-880 Collapse By Tanker Truck Fire.

On April 29, 2007, a tanker truck fire on the IH-580 overpass in Oakland, California caused severe damage to a bridge which resulted in collapse of the bridge due to the intense heat from the fire.

Accident #9 – Exit 111 Bridge Over IH-24, Manchester, Tennessee

On March 17, 2008, a truck-tractor trailer loaded with pies impacted a large bridge pier on the Exit 111 Bridge over IH-24 in Manchester, Tennessee. Damage to the pier was minor. The speed and the weight of the truck are not known.

Accident #10 – Murphy Hollow Road Over IH-24, Marion County, Tennessee

In 1989 a westbound truck with a box type trailer impacted a 2-pier bent in the median of IH-24. The weight of the truck and trailer along with the impact speed are not known. The collision with the pier caused failure in the 24-inch square pier. Longitudinal reinforcement in the pier consisted of eight number 10 bars equally spaced. Transverse reinforcement consisted of number 4 closed stirrups spaced at 12 inches on centers. The bridge did not collapse as a result of the impact.

Accident #11 – IH-90 Bridge, #53812, Minnesota.

On June 3, 2003, a large single unit truck impacted a bridge pier located along IH-90 in near Worthington, Minnesota. The collision with the pier caused failure in the 32-inch diameter pier. The bridge did not collapse as a result of impact. Reinforcement in the pier consisted of nine number nine size longitudinal bars equally spaced. Transverse reinforcement in the column consisted of number 4 spiral stirrup reinforcement with a 6 inch pitch. A photo of the accident is shown as Figure 4.

Figure 4 - Truck Accident - IH-90 Bridge, #53812, Minnesota

Accident #12 – FM-1401 Bridge Over IH-30, Mount Pleasant, Texas

On May 29, 2008, a truck-tractor trailer loaded with car parts crashed into a bridge pier on IH-30 near Mount Pleasant, Texas. This bridge is located on FM 1401 and carries traffic over IH-30. This vehicle impacted the western-most 30-inch diameter pier of the 3-pier bent located on the shoulder of the east bound lanes of IH-30. The collision with the pier caused failure in the 30-inch diameter pier. The bridge did not collapsed as a result of impact. The collision killed the driver. State Trooper Daniel Crooks with the Texas Department of Public Safety was interviewed. Officer Crooks was present on scene immediately after the accident. Officer Crooks indicated that the vehicle was traveling at a high rate of speed. The approximate weight of the vehicle was near 80,000 lbs. when it struck the pier. The column that was impacted was a 30-inch diameter pier with eight number nine size rebars in the longitudinal direction of the pier. Transverse reinforcement in the pier consisted of number 3 spiral stirrup reinforcement with a 6 inch pitch. A photo of the accident is shown as Figure 5.

Figure 5 - Truck Accident - FM-1401 Bridge Over IH-30, Mount Pleasant, Texas.

Summary of Shear Capacities of Circular Piers from Accident Investigations

Bridge piers impacted by large trucks are typically subjected to large shear and bending forces. These forces can cause catastrophic structural failure in the piers. As part of this project, several large truck accidents involving large trucks were investigated. In most of the cases investigated, structural failure in the bridge column occurred as a result of the impact. From the piers investigated for this project, a typical failure

mechanism from a large truck collision is shown in Figure 6.

Figure 6 – Typical Failure Mechanism in Bridge Pier From Large Truck Collision.

Typically, the truck collision force is relatively close to the ground surface as shown in Figure 1. Although a large bending force is applied to the pier, the high shear force from the truck collision exceeds the shear capacity of the pier, thus resulting in a shear failure mechanism in the pier. For this project, shear capacity analyses were performed on the piers investigated for this project to determine the shear resistance of the piers.

Structural analyses were performed on several piers impacted from the accident investigations. Structural details for each specific pier were obtained from the state bridge engineer from the associated state from which the accident occurred. The nominal shear strength of each pier was calculated in accordance with American Concrete Institute (ACI) 318-05 Specifications. These capacities are based on 2 failure planes resisting the strength force with resistance also provided from the transverse stirrup reinforcement (spirals). These 2 shear failure planes radiate at approximately 45 degrees from the applied impact force as shown in Figure 7.

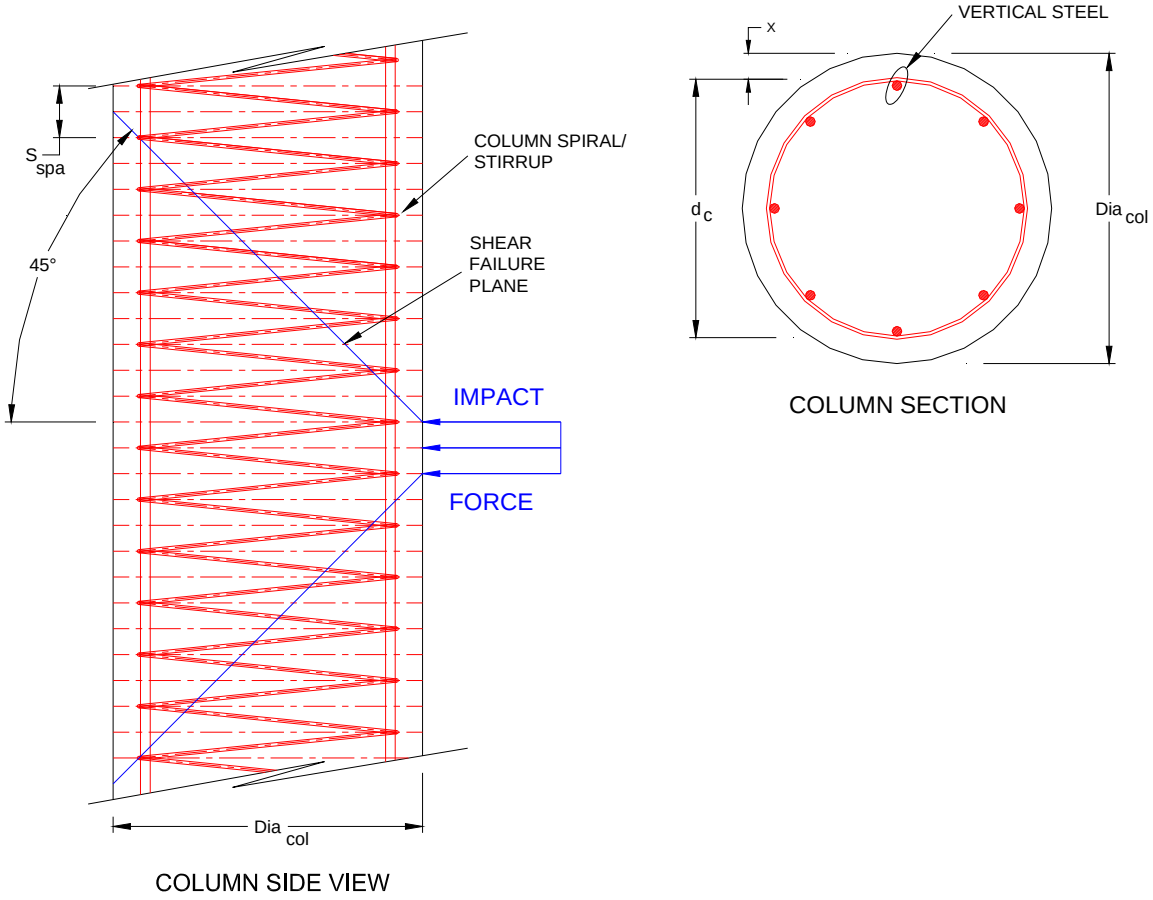


Figure 7 – Observed Failure Mechanism From Impact Force on Bridge Pier

To date, data has been obtained for a total of 19 accidents involving large truck collisions. Each accident was numbered from 1 to 19 for the purpose of reporting. Shear capacity calculations were generated for each accident with sufficient information to determine the shear capacity. The failure mechanism shown in Figure 7 was observed in many accidents investigated for this project which were impacted by large trucks. In all cases, the design compressive strength of the concrete as provided by the structural drawings was used. In addition, the nominal shear strength of each pier was calculated using a higher estimated strength which could exist due to years of concrete age. Please refer to Table 1 for a summary of the calculated shear capacities for the piers investigated for this project.

Table 1 - Shear Capacities of Circular Piers From Accident Investigations

Accident No.	Pier Dia. (in.)	Design (Estimated) Con. Comp. Str. (psi)	Shear Reinfor. Size	Vertical Reinforc.	Calc.Shear Cap. (kips)*
1	30	3050 (4000)	#2 - 6" Pitch	8 - #9's Eq. Spa.	230.6 (255.6)
2	30	3050 (4000)	#2 - 6" Pitch	8 - #9's Eq. Spa.	230.6 (255.6)
3	30	3050 (4000)	#2 - 6" Pitch	8 - #9's Eq. Spa.	230.6 (255.6)
4	30	3050 (4000)	#2 - 6" Pitch	8 - #9's Eq. Spa.	230.6 (255.6)
5	30	3050 (4000)	#2 - 6" Pitch	8 - #9's Eq. Spa.	230.6 (255.6)
7	30	3050 (4000)	#2 - 6" Pitch	8 - #9's Eq. Spa.	230.6 (255.6)
8	30	3050 (4000)	#3 - 6" Pitch	8 - #9's Eq. Spa.	304.3 (329.2)
10	24	3050 (4000)	#2 - 6" Pitch	8 - #7's Eq. Spa.	161.6 (178.2)
17	32	4300 (5500)	#4 - 6" Pitch	9 - #9's Eq. Spa.	481.2 (511.3)
18	30	4300 (5500)	#3 - 6" Pitch	8 - #9's Eq. Spa.	304.3 (329.2)
19	30	4300 (5500)	#2 - 6" Pitch	8 - #9's Eq. Spa.	230.6 (255.6)

*** - Design (Estimated) Concrete Compressive Strength**

The calculated strength capacities listed in Table 1 are the nominal (ultimate) shear strengths of the piers considering the compressive strengths of the concrete, transverse (spiral) reinforcement and two shear planes radiating at 45-degree angles from the direction of impact.

Work Planned for next Reporting Period (Brief description of work planned.)

Perform analytical pier shear capacity calculations for pier sizes ranging from 30 to 60 inches to investigate the impact strength of the larger piers.

Task #	**Task Name / Description**
1d.	Development of a risk analysis methodology for vehicle/bridge column and abutment collusions (analogous to AASHTO LRFD vessel impact requirements)
% Complete	**If task is complete, state when Technical Memorandum was submitted to RTI**
75%	

Work Accomplished this Period (Brief description of work done and any major problems encountered.)

The purpose of this task is to develop a methodology for estimating the risk of a collision between a heavy vehicle and bridge columns. Over the last fifteen months, the research team collected crash data involving heavy vehicles (all body styles) running-off-the-road and heavy vehicles hitting a bridge pier located on principle arterial highways in Texas and Minnesota, both controlled and non-controlled access facilities. The data collection also included information about the location of bridges on these highway segments that was provided by the Transportation Planning and Programming Division and Minnesota Department of Transportation (MnDOT). Four years of data were collected (1998-2001) for Texas and five years of data were collected (2002-2006) for Minnesota. The sources of Texas data were provided by DPS (Accident, Roadway Inventory, and Vehicle files) and TxDOT (TRM). The sources of Minnesota data were provided by the FHWA's Highway Safety Information System (HSIS) managed by Highway Safety Research Center at the University of North Carolina.

Using the Texas data, two series of analyses were conducted initially. The first one consisted in developing a risk analysis methodology based on conditional probabilities, which involves the risk for a heavy vehicle to leave the traveled-way, and once it leaves the traveled-way, the probability for the vehicle to hit a bridge pier. The second methodology aimed at developing predictive models to estimate the risk for a heavy vehicle to hit a bridge pier as a function of the number of bridges crossing on top of the segments under study as well as other roadway characteristics. The analysis was conducted on all undivided and divided segments. The analyses also included crash risk estimation straight (tangent) sections and horizontal curves existing on undivided and divided highways.

Work Planned for next Reporting Period (Brief description of work planned.)

Given the results with Texas data, the similar analyses for estimating the risk for a heavy vehicle to leave the traveled-way, and once it leaves the traveled-way, the probability for the vehicle to hit a bridge pier will be carried out with the Minnesota data. These results will then be used to compare the risk between the two states.

Task #	**Task Name / Description**
1e.	Detailed justification and work plan for research (if any) to be conducted under Phase 2 of the project
% Complete	**If task is complete, state when Technical Memorandum was submitted to RTI**
5%	

Work Accomplished this Period (Brief description of work done and any major problems encountered.)

Concepts for a crash test matrix have been stated for consideration in phase 2.

Work Planned for next Reporting Period

Work plan and supporting justification for research for phase 2 will be completed and submitted to TxDOT

Task #	**Task Name / Description**
1f.	Provide facilities and host a meeting to present Phase 1 results to project sponsors, including pooled fund project contributors from other state DOT's
% Complete	**If task is complete, state when Technical Memorandum was submitted to RTI**
5%	

Work Accomplished this Period (Brief description of work done and any major problems encountered.)

Arrangements for this meeting have been made and the meeting has been scheduled.

Work Planned for next Reporting Period
The meeting will be held April 14, 2009.

Task # 2a.	**Task Name / Description** Crash testing with a single unit truck to verify loading from Phase 1 literature survey and computer simulations.
% Complete 0%	**If task is complete, state when Technical Memorandum was submitted to RTI**
Work Accomplished this Period (Brief description of work done and any major problems encountered.) Task scheduled to begin after meeting on April 14, 2009.	
Work Planned for next Reporting Period (Brief description of work planned.) Work will be completed during next reporting period.	

Task # 2b.	**Task Name / Description** Crash testing of a 5-axle tractor trailer rig to verify loading from phase 1 literature survey and computer simulations
% Complete 0%	**If task is complete, state when Technical Memorandum was submitted to RTI**
Work Accomplished this Period (Brief description of work done and any major problems encountered.) Task scheduled to begin after meeting on April 14, 2009.	
Work Planned for next Reporting Period (Brief description of work planned.) Work will be completed during next reporting period.	

2. Progress to Date, by Deliverable

Deliverable #	Deliverable Description	Progress to Date &/or Date Submitted to RTI
P1	Guidelines supplementing current AASHTO LRFD Specifications for collision loads on piers and abutments, including example utilizing proposed methodology	Due 8-31-09 None
P2	Presentation materials in suitable format for use in introducing concepts and new methodology to bridge design engineers.	Due 8-31-09 None
R1	Research report comprehensively documenting all phase 1 work performed, including recommendations for Phase 2 work (if any).	Due 10-31-09 90% completed
R2	Research report comprehensively documenting all Phase 2 work performed (if Phase 2 is conducted).	Due 10-31-09 None
PSR	Summary of work performed, findings, and conclusions.	Due 10-31-09 None

3. Equipment Purchases

Description of Equipment	Date Purchased	Task and / or Deliverable Directly Related to Equipment Purchase
No Equipment Requested		

4. Meetings / Conferences (List any project meetings or conferences that were conducted during this reporting period and / or are planned for the next reporting period.)

Date & Time	Location	Purpose of Meeting / Conference
Feb 10, 2009	Texas Transportation Institute offices	Review results of phase 1 with representatives from TxDOT and FHWA, and plan the upcoming meeting with representatives of participating states.
April 14, 2009	Texas Transportation Institute offices	Review of phase 1 and planning of phase 2 with representatives from participating states.